IMPLEMENTING "DESIGN FOR SUPPLY CHAIN" TO ENHANCE NEW PRODUCT DEVELOPMENT

A Design Science Approach

FILIPE DANIEL GONCALVES SARMENTO

Doctor of Philosophy

ASTON UNIVERSITY

February 2024

© Filipe Daniel Goncalves Sarmento, 2024.

Filipe Daniel Goncalves Sarmento asserts his moral right to be identified as the author of this thesis.

This copy of the thesis has been supplied on condition that anyone who consults it is understood to recognise that its copyright belongs to its author and that no quotation from the thesis and no information derived from it may be published without appropriate permission or acknowledgement.

Aston University

Implementing "Design for Supply Chain" to enhance New Product Development: A Design Science approach

Filipe D G Sarmento

Doctor of Philosophy, 2024

Thesis Summary

In today's manufacturing environment, characterised by continuous innovation and disruptions, the success of new product development (NPD) projects depends on the ability to adapt and scale swiftly. In an era where technology and mobility trends like electrification and digitalisation are propelling the need for frequent product iterations and a rapid time-to-market, supply chain design (SCD) becomes a vital part of NPD projects.

Anchored in Design Science Research (DSR) philosophy, this research builds on the existing concept of Three-Dimensional Concurrent Engineering (3-DCE), evolving towards a proposed definition of Design for Supply Chain (DfSC). The study operationalises DSR with the following methods: first, a research synthesis to identify underlying mechanisms for the adoption of DfSC; second, a scenario-based experiment to identify and assess perception asymmetries; and third, the gamification of the scenario that constitutes an artefact solution to the research problem. The methodology also encompasses workshops conducted in leading automotive and aerospace organisations and expert validation interviews, whose insights allow for the development of a roadmap for DfSC implementation. The findings suggest that 3-DCE is not rooted in managerial decision-making, highlighting the need to incorporate the behavioural dimension in the study of DfSC adoption. Accordingly, this research constructed a boundary object to facilitate the transformation of existing behaviours towards DfSC behaviours, offering a fresh perspective on existing knowledge. The research identifies a learning culture and effective leadership commitment as essential to closing functional perception asymmetries. This thesis contributes to the broader discourse by offering a richer empirical understanding of functional perception asymmetries in the context of SCD in NPD projects while formulating key findings to facilitate the adoption of DfSC behaviours in NPD teams. Through these insights, it empowers decision-makers and organisations with a refined roadmap for DfSC implementation to navigate the complexities of modern manufacturing product development.

Keywords: Supply Chain Management, New Product Development, Manufacturing, Cross-Functional Integration, Three-Dimensional Concurrent Engineering, Design Science Research, Behavioural Implications, Gamification

ACKOWLEDGMENTS

As with life itself, a PhD research project is a journey that cannot be completed alone. This journey and the people I encountered along the way had a profound and lasting impact on my life, for which I am immensely grateful. None more important than my wife, Melissa Venegas — whom I would never have met if not for this PhD, who now shares my life, and whose presence has been the greatest achievement of this journey.

I would like to express my deepest gratitude to my supervisor and academic mentor, Professor Aristides Matopoulos, for making all of this possible. His invaluable guidance and unwavering support shaped every stage of this research project and profoundly influenced my academic thinking. I would also like to thank my supervisor, Dr Brian Price, whose vast knowledge I have long admired and whose valuable advice I have sought since my Master's dissertation. I am equally thankful to Dr Evanthia Thanou and Dr Dimitra Kalaitzi for their constant encouragement and for supporting my work.

My gratitude extends to Aston University, the ESRC, my VIVA examiners, and all the participants in my research whose invaluable insights have made the completion of this thesis possible.

Finally, I would like to thank my friends — they know who they are — for their encouragement and emotional support. Last but by no means least, I dedicate my PhD thesis to my parents, whose love and example inspire my every action.

TABLE OF CONTENTS

List of Abbreviations

3-DCE	Three-Dimensional Concurrent Engineering
ABS	Abstract
AVE	Average Variance Extracted
CAD	Computer-Aided Design
CE	Concurrent Engineering
CFA	Confirmatory Factor Analysis
CIMO	Context, Intervention, Mechanisms, Outcomes
DfM	Design for Manufacturing
DfMA	Design for Manufacturing and Assembly
DfSC	Design for Supply Chain
DoD	Department of Defence
DSR	Design Science Research
EE	Extended Enterprise
EoL	End-of-Life
ESI	Early Supplier Involvement
EU	European Union
GBOM	Generic Bills of Materials
GE	Geothermal Energy
HBR	Harvard Business Review
ICT	Information and Communication Technology
IE	Ease of Component Interface
ITPs	Integrated Project Teams
LCA	Product Lifecycle Analysis
MANOVA	Multivariate Analysis of Variance
MDE	Mechanics, Dynamics, and Emotions
MP&L	Materials Planning and Logistics
MPc	Manufacturing Process changes
MRT	Middle-Range Theory
NPD	New Product Development
NPDPerf	NPD Performance
O&SCM	Operations & Supply Chain Management
OEM	Original Equipment Manufacturer
PLC	Product Lifecycle
PM	Product Modularity

PrOH	Process Oriented Holonic
QCD	Quality, Cost, and Delivery
QCDISME	Quality, cost, delivery, improvement, safety, man, and environment
QFD	Quality Function Deployment
SC	Supply Chain
SCD	Supply Chain Design
SCM	Supply Chain Management
SCV	Supply Chain Visibility
SLR	Systematic Literature Review
SMEs	Small and Medium Enterprises
SP	Supplier Participation
SSM	Soft-Systems Methodology
TPB	Theory of Planned Behaviour
TRA	Theory of Reasoned Action
TRL	Technology Readiness Level
UK	United Kingdom
USP	Unique Selling Point

List of Figures

List of Tables

1 INTRODUCTION

1.1 Overview

This chapter introduces the context of the research, highlights the relevant literature, and recognises the practical problems and research gaps. Furthermore, it presents the research aim and the central questions, as well as the research methodology and the empirical context of the study, including the structure for the remainder of this thesis.

1.2 Research background, problem, and scope

New Product Development (NPD) success is central to sustaining the competitive advantage of any manufacturing organisation. A NPD project entails a number of steps with the goal of introducing a new product to the market that can do so effectively and efficiently. The 2018 'Global Innovation 1000' study, conducted by PwC, shows that the gross profit of the 88 companies considered high-leverage innovators grew 2.1 times faster than the remaining companies on the list from 2012 to 2017, having vastly outperformed them following the 2008 Great Recession by growing 6.6 times higher in the 2007–2012 period. These high-leverage innovators are companies that efficiently launch successful new products, showing that innovation is not a measure of how much a company spends in R&D. According to the same study, the 10 most innovative companies outperformed the top 10 biggest spenders on a range of financial metrics (Jaruzelski, Barry et al., 2018). Thus, underscoring the critically of getting NPD right for the success and prosperity of organisations.

Not surprisingly, there is a well-established stream of literature that looks into the improving NPD. This research focuses primarily on three main areas: the "product side", the "process side", and the "people side" of NPD projects (Ulrich et al., 2020; Kahn et al., 2012; Cooper, 2008; Cooper et al., 2004c, 2004b, 2004a; Brown and Eisenhardt, 1995). Each of the three research areas provides a distinct contribution to the complexity of problems that arise from NPD projects. For example, on the "product side", Ulrich (1995) raised awareness of the trade-offs associated with the choice of a product architecture in a manufacturing organisation. While on the "people side", Cooper (2008) focused on the role of the stage-and-gate process as a robust idea-to-launch system to achieve higher payoffs in NPD projects. Also on the "people side", Cooper et al. (2004a) emphasise the influence of project team structure on project outcomes, claiming that cross-functionality and team accountability go a long way towards ensuring project success. Combining these ideas set up the trend for concurrent engineering (CE) approaches in product development, allowing participants to ensure adequate information exchange between people, the product, and the process (Terwiesch et al., 2002; Smith, 1997; Winner et al., 1988).

However, a necessary body of literature identified another contributing area to successful outcomes in NPD projects: the organisation or "supply chain" side (Fine, 1998; Fisher, 1997). Fine (1998, 2000) defends the strategic importance of considering not only product and process designs but also supply chain design in NPD projects. He regards the alignment of these functions, particularly in activities where they overlap, as a vital element in the organisation's ability to secure competitive advantages (Fine, 2000, p. 218). The scope of this thesis reflects this integrative approach between the identified areas of NPD, aiming to expand the ideas within Charles H. Fine's conceptual framework of Three-Dimensional Concurrent Engineering (3-DCE) into a "Design for Supply Chain" (DfSC) principles.

In this context, DfSC represents the underlying principles that need to be embedded in organisational and individual behaviours to fully realise the benefits of 3-DCE. Whereas supply chain design focuses on the interactions and configurations required to manage the flow of materials, products and information accessing the supply chain. It is the aim of this thesis that DfSC not only underpins the actions taken in supply chain design decisions, but also enhances the effectiveness of their integration within the 3-DCE framework by providing a design approach that guides organisations towards ensuring mutually beneficial outcomes throughout the product lifecycle. This dynamic is illustrated in Figure 1.1, which presents DfSC as the fundamental tenet that sustains the incorporation of 3-DCE into decision-making processes in NPD projects.

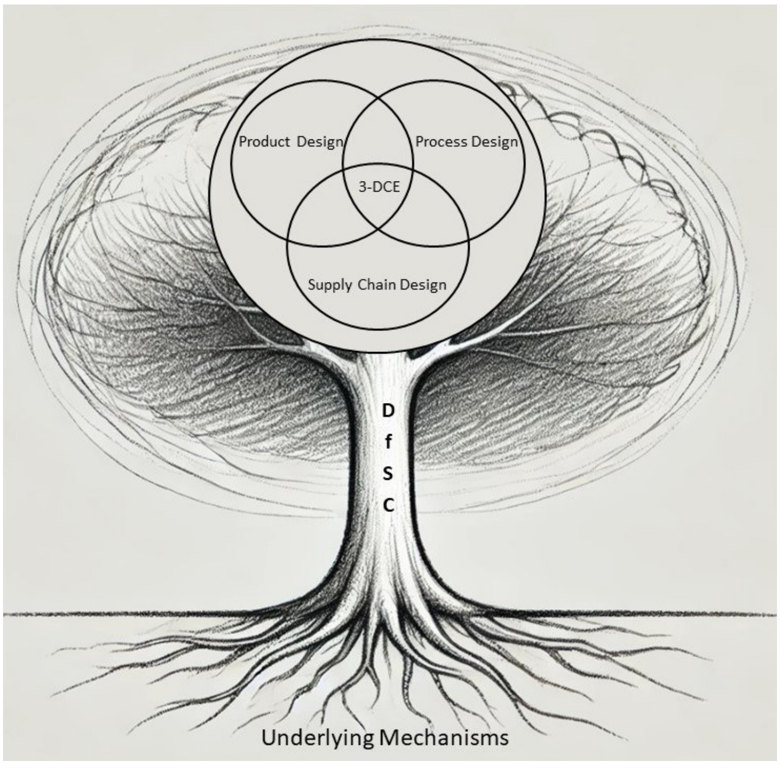


Figure 1.1 - Illustration of the dynamics between DfSC and 3-DCE

There is a rich collection of literature on the tangible benefits of implementing concurrency principles in NPD projects. These benefits include shortened lead times, elevated design quality, enhanced cost efficiencies, increased customer acceptance, and greater environmental responsibility (Reitsma et al., 2023; Khan et al., 2012; Valle and Vázquez-Bustelo, 2009; Ellram et al., 2008; Van Hoek and Chapman, 2007; Fine et al., 2005; Fixson, 2005; Winner et al., 1988). In practice, 3-DCE enables designers, customers, manufacturing engineers, and supply chain specialists to engage collaboratively in multiple design interactions at the appropriate time (Khan, 2018). For one, this approach helps to mitigate the need for late-stage product changes or compromises after firms have already committed to substantial capital investments (Fixson, 2005). Moreover, it enables NPD teams to undertake additional "what if" scenarios, facilitating, for instance, the production or selection of components that are not only superior in quality but can be lighter, stronger, and more cost-effective (Khan, 2018). Ultimately, the 3-DCE approach significantly improves the visualisation of the functional impact of these complex decisions throughout the product's lifecycle.

Yet, despite the reported positive contributions, many organisations struggle to successfully adopt 3-DCE ideas into their NPD decision-making. As evidenced by Tesla's decision to select less available batteries, which resulted in supply chain disruptions that led to avoidable delays in the production of the Model 3 (Gan et al., 2021). Similarly, the development of the A380 "superjumbo" suffered major delays and cost overruns because of Airbus's inability to revisit their organisational structures (Sosa et al., 2007). Also, Tang et al. (2009) report on the challenges of using unproven technologies and synchronising just-in-time deliveries in the Boeing 787 Dreamliner projects, leading to technical problems and delays. This mismatch between objective benefits and practical adoption poses pressing questions: first, the motives for this misalignment to persist; second, how to assist organisations and their professionals in bridging the gap.

The apparent disconnect between academic theory and practical implementation is perhaps due to the conceptual nature of 3-DCE research, lacking a coherent overview of the interrelations between the activities or focusing on a particular side of these complex dimensions (Reitsma et al., 2023; Pashaei and Olhager, 2015; Ellram et al., 2007). Moreover, managerial behaviour towards the adoption of 3-DCE has not been studied. These managerial perceptions are critical because they shape decision-making processes, impacting the successful implementation of 3-DCE practices regardless of their objective benefits (McCabe and Dutton, 1993). Therefore, it is pivotal to delve into these perceptions, yielding a new lens through which to facilitate the implementation of 3-DCE in NPD projects.

Ultimately, this study presents a novel understanding of the challenges faced by practitioners in integrating supply chain considerations into their decision-making processes. A roadmap is proposed, focusing on organisational and individual behaviours, to serve as the foundation for the adoption of DfSC principles. That is, the principles of considering multifaceted functional and supply chain decisions concurrently, with the objective of ensuring mutually beneficial outcomes throughout the product lifecycle. This roadmap emerges from a synthesis of research, in combination with a scenario experiment and an artefact solution which acts as a boundary object design to promote behavioural changes towards the embedment of DfSC behaviours.

1.3 Thesis objective and Research questions

The objective of this research is to advance the adoption of an integrative approach in which the decision-making process embeds every complex aspect of NPD, including elements related to "product", "process", and "supply chain" design. Particularly, the promotion of DfSC behaviours in discrete manufacturing industries.

Kreipl and Pinedo (2004) assert that discrete manufacturing industries, characterised by the production of distinct, countable products through assembly and production processes, typically exhibit higher clockspeed, a term used by Fine (2000) to describe the rate at which products, processes, and organisational structures evolve. This research focus on two distinct types of discrete manufacturing industries to capture a broad perspective. The automotive industry, characterised by product differentiation and shorter lifecycles due to frequent model updates and intense competition (Viles et al., 2021) The aerospace industry, where clockspeed is comparatively slower due to longer product life cycles, substantial capital investments, less product differentiation and increased system complexity (Chaudhuri et al., 2013; Bozdogan, 2010). These industries underscore the importance of agile and responsive decision-making, thereby emphasising the role of supply chain design in NPD projects.

The development of a new product in these industries is a complex endeavour, marked by numerous consequential trade-off decisions and implications. The central argument of this thesis is that by embracing DfSC beliefs, both individuals and organisations involved in NPD projects within discrete manufacturing industries can be better positioned to anticipate those implications; thereby, this mindset equips them with the ability to make more informed decisions.

Indeed, advocacy for similar principles is not uncommon among researchers. Recent research studied organisations that implemented collaborative product development strategies (DeCampos et al., 2022; Cai and Wang, 2021; Hald and Nordio, 2021). Others have directed their focus towards devising the necessary processes for internal and external integration

(Kumar et al., 2020; Morita et al., 2018). Still others have chosen to concentrate on product architecture and platform management as a way to reduce product complexity (Gan et al., 2021; Sun and Lau, 2020; Yin et al., 2014). These studies indicate that academics are interested in the consequences of product, process, and supply chain designs in NPD, particularly within the context of discrete manufacturing industries.

Herein lies the challenge: despite the availability and implementation of these ideas and frameworks, why are there still numerous instances of NPD project failures, particularly resulting from a lack of attention to the supply chain implications of product development? Even mature organisations like Tesla or Airbus, which understand the strategic importance of aligning their supply chain within their NPD projects, have not been immune to these avoidable failures. This prompts a fresh perspective to understand the mechanisms involved in the adoption of these principles, a perspective that the present research aims to provide.

The motivation behind this research is structured by two overarching research questions. These questions have been formulated based on a CIMO-logic approach, meaning that they are driven by a desire to comprehend and contribute solutions to the field problem at hand (Saunders et al., 2023). The CIMO-logic states that interventions are useful within the problem in-context, as the desired outcomes will or will not be achieved through the activation of underlying mechanisms (Denyer et al., 2008). Therefore, to achieve the research aim, this study needs to fully grasp the underlying mechanisms behind DfSC implementation. In addition, an investigative question was devised to complement the response to the first overarching research question.

RQ1 – How do key underlying mechanisms influence the successful implementation of "Design for Supply Chain" in NPD projects within discrete manufacturing industries?

RQ1.1 – How do decision-makers perceive changes in product, process, and supply chain design in NPD projects?

RQ2 – How can teams and organisations incorporate "Design for Supply Chain" behaviours in NPD projects within discrete manufacturing industries?

1.4 Research design

The problem of failure to adopt 3-DCE principles in managerial practices requires a pragmatic perspective. Pragmatism is oriented towards practical problem-solving and supports research that drives the reflexive process intended to inform future practice (Elkjaer and Simpson, 2011). That is, bringing together the theoretical object of 3-DCE principles with the practical challenges and managerial perception of the benefits. Concretely, this research follows a design science approach to the problem.

Design Science Research (DSR) is a philosophy and approach to academic research that focuses on refining management theories, or models, to be used in the practical world of business organisations. According to Van Aken (2004), a key aspect of this approach is the development of grounded technological rules validated by rigorous testing in the field that provide practitioners with reliable knowledge that can be effectively applied. Likewise, Holmström et al. (2009) view DSR as a means of closing the gap between theory and practice, particularly when it comes to solving unstructured or wicked problems such as the one in this thesis.

This study's design science approach consists of four stages, presented in Table 1-A, and later detailed in Chapter 5. A research synthesis was conducted by analysing published empirical studies of relevant ideas on 3-DCE and similar interventions. The study, then, examines the research problem through the lens of organisational behavioural theory. Initially, conducting a vignette-based experiment that places decision-makers of NPD in a real-world setting and studies their perceptions regarding the 3-DCE concept. Later, by gamifying the scenario, a detailed revision of the previously identified underlying mechanisms can be understood in the ways they are trigged and affect behavioural change. The game is designed as a boundary object to facilitate the integration of the different viewpoints and include a lifecycle view of the project (Carlile, 2002, 2004). Concurrently, two workshops were conducted in the aerospace and automotive industries, respectively, allowing for the field testing of the grounded rules and validation of the findings. Ultimately, this thesis proposes a roadmap for "Design for Supply Chain" implementation based on the research findings. This stage was developed following the abductive process and conceptual development.

Table 1-A: Design Science Research Strategy stages

DSR stage	**Method**	**Description**	**Presented in**
Abductive Reasoning	Research Synthesis	Seeks to "unpack the mechanism" of how complex programmes work (or why they fail) in particular contexts and settings.	*Chapter 3*
Systems & Behaviours	Vignette-based Experiment	Experiment in which varying versions of a descriptive vignette are deployed to convey scripted information about factors of interest suited to understanding decisions in complex issues.	*Chapter 6*
Artefact Design	Boundary Object development / Gamification	Pragmatic boundary process in which the implemented elements linearly proceed to affect psychological states and experiences, and eventually user behaviour.	*Chapter 7*

Grounded Technological Rules	General discussion of research findings	A roadmap for implementation and discussion of *Design for Supply Chain* oriented behaviours	*Chapter 8*

1.5 Outline of the Thesis

This thesis is organised into nine chapters to address the research problem introduced in this chapter. Broadly speaking, each chapter contributes to the understanding and solving of the main research problem. The main structure of the ensuing chapters is depicted in Figure 1.2.

Chapter Two introduces the fundamental concepts of 3-DCE. This begins with an understanding that the aim of the NPD project is to launch a successful product. To achieve this goal, there is a need to explain the processes which require cross-functional integration. Moreover, this chapter argues that the inclusion of supply chain design is critical for that success, particularly when considering a product lifecycle perspective. The research gaps are examined in detail, exposing the challenges of 3-DCE implementation in *"real-world"* projects and how the ensuing research will address them.

Chapter Three reviews case studies published in peer-reviewed journals where similar practices to 3-DCE were implemented. Furthermore, this chapter introduces the concept of DfSC, an extended version of the original 3-DCE idea. The review follows a research synthesis structure, which unpacks the underlying mechanisms that affect the adoption of these practices. Thus, allowing for the development of a proposed roadmap for DfSC implementation which constitutes an initial conceptual framework for the Thesis.

Chapter Four supports that a reflection from the vantage point of organisational behaviour theory is needed for addressing the underlying mechanisms of DfSC adoption, as outlined in Chapter Three. A review of various behavioural theories is carried out to determine the most suitable contribution to the existing research problem. In the end, considering the pragmatic perspective and research strategy presented in the previous chapter, constructing boundary objects emerges as an especially fitting theoretical approach, offering novel solutions to the identified challenges.

Chapter Five describes the research methodology, linking the philosophical position of the thesis to solve the research problem at hand. In that regard, the value of following a Design Science Research (DSR) strategy will be discussed in great detail. Based on this discussion, the methods best suited to operationalise DSR and solve the field problem will be presented. This chapter can be read beforehand to gain clarity on the thesis' research position and methodological selections.

Chapters Six and *Seven* encompass the empirical field-testing segment of this thesis. Both chapters introduce the designed boundary objects, mentioned previously. Chapter Six introduces the Powertrain scenario, a vignette-based experimental design used to explore managerial perceptions regarding the three dimensions of product development and their implications for the decision-making process. Chapter Seven develops the initial scenario into a game-like exercise. Thus, it allows for the visualisation of design consequences, affecting psychological states and eventually decision-making behaviour. Workshop activities were conducted in both chapters, generating a discussion about the implications and adoption of 3-DCE into NPD projects.

Chapter Eight brings together the knowledge generated in the preceding chapters, framed from the theoretical perspective of Chapter 4. In essence, this chapter discusses the overall findings of this thesis, presenting a revised roadmap for DfSC implementation and giving insight on how to promote DfSC behaviours. Consequently, answering the proposed overarching research questions.

Chapter Nine concludes this research by presenting the limitations of the work as well as future research avenues that could enhance extended organisational capabilities to solve the inherent challenges of developing new products in manufacturing settings.

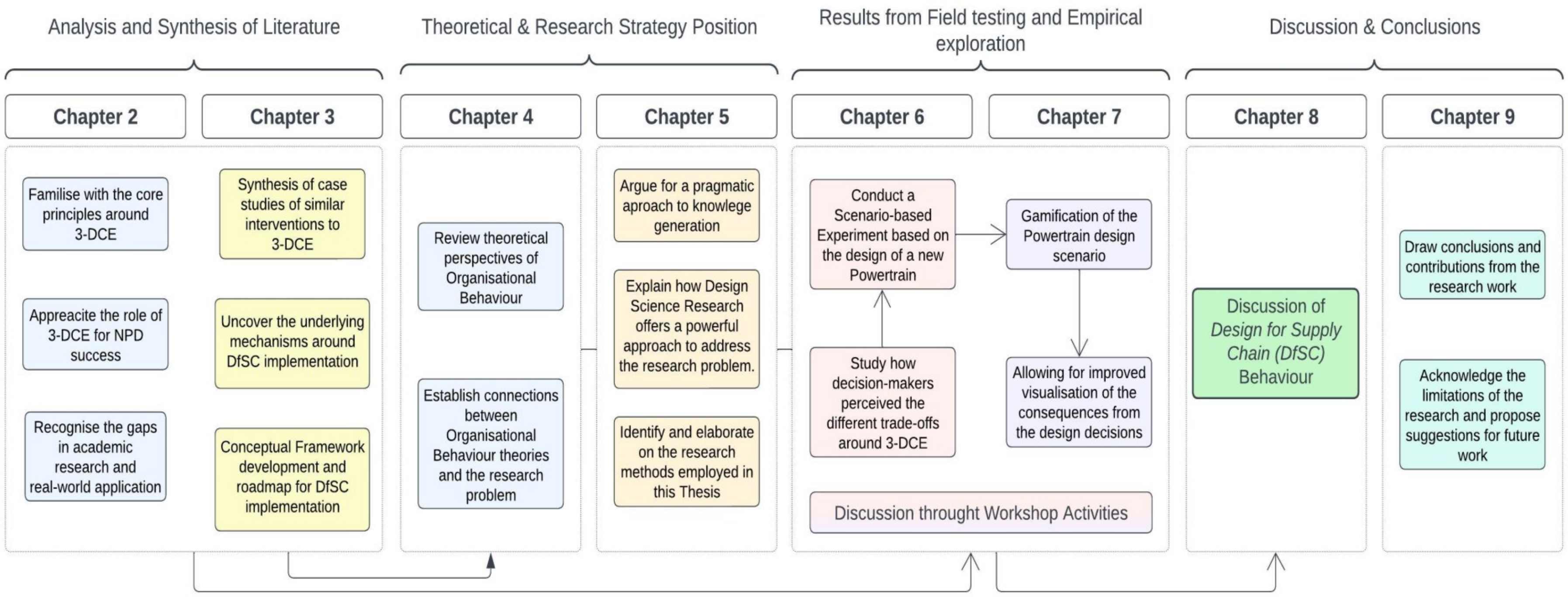


Figure 1.2 – Storyboard of the Thesis

2 LITERATURE REVIEW: EXPLORING 3-DCE IN NPD PROJECTS

2.1 Overview

This chapter provides a clear introduction to the basic concepts drawn from the principles of Three-dimension Concurrent Engineering (3-DCE). Ultimately, this chapter has two main objectives. Foremost, it endeavours to lay out a compelling argument for the manifest benefits accrued by incorporating these principles into New Product Development (NPD) projects. Subsequently, the chapter seeks to clarify the inherent limitations of existing academic research on 3-DCE, along with pragmatic examples that demonstrate the challenges related to its managerial adoption.

The motivation behind implementing 3-DCE in NPD is primarily to improve the performance of NPD projects (Ellram et al., 2008). NPD projects are perhaps the most relevant set of activities that organisations undertake to sustain competitive advantages (Koufteros et al., 2010). Thus, *Section 2.2* journeys into the streams of literature as organised by Brown and Eisenhardt (1995) to grasp the success factors of NPD. Additionally, this section emphasises the critical role of product design decisions and their interplay with manufacturing process decisions.

In the path to understanding concurrent engineering (CE), Section 2.3 introduces two important dimensions: the "people" side and the role of "time" in NPD projects. The former focuses on the role of cross-functional integration in product development success. While the latter reflects on the implications of including a lifecycle perspective in product development decisions. Ultimately, the consideration of these two factors contributed to the widespread adoption of CE in a number of industrial sectors (Abdalla, 1999).

The final section of this chapter brings together the previous dimensions of NPD projects to explain the 3-DCE concept. Placing strategic supply chain design as a vital element to successful NPD outcomes. Furthermore, this section frames the research problem, asserting that, despite the tangible benefits of 3-DCE, organisations still struggle with its adoption, establishing the Thesis's relevance.

2.2 New Product Development

2.2.1 The Success Factors

New Product Development (NPD) represents a pivotal field of academic study that has generated considerable attention throughout the years in various and distinct fields. These span from an economical oriented tradition, such as research on innovation, to an organisational oriented tradition, such as research on project management. This thesis situations itself on the latter tradition, specifically on how organisations can generate sustained value through their engagement in NPD initiatives.

Performance metrics commonly employed to measure NPD success are product quality, associated with the ability to satisfy customer needs; product cost, the manufacturing costs of producing each unit of the product; development cost, investment on the development of the product; development time, which determines the ability to receive economic returns from the team's efforts, among others (Ulrich et al., 2020). The vast body of literature on NPD success seeks to identify and explain the numerous factors that may influence performance.

This section goes back to the seminal work from Brown and Eisenhardt (1995). They organised NPD literature into three streams of research: one perspective targets financial success measured in product revenue or costs; another perspective concerns with the perceptual success of the project, for instance the team and management rated performance for quality or innovation, while the other focuses on operational success measured in terms of speed and flexibility of development. Yet, they found that in their essence all streams investigate how product decisions, people, processes, and structures affect performance. Thus, complementing each other in the success factors of product development.

For one, Krishnan and Ulrich (2001, p. 1) first defined product development as *"the transformation of market opportunity and a set of assumptions about product technology into a product available for sale"*. This definition suggests a rational and systematic approach to product development. This perspective places the success factor of NPD development into the organisation's ability to target marketplace advantages, while executing through excellent internal organisation. This broad approach leads to an effort to have a comprehensive understanding of product features as well as the product development process.

The product development process is a sequence of steps required to conceive, design, and commercialise the product. Still, Ulrich et al. (2020, p. 13) offered an alternative view to think about this process. They also view it as an information processing system, where "the process concludes when all the information required to support production and sales has been created and communicated". This links with the second stream of literature proposed by Brown and Eisenhardt (1995). Here, the premise is that communication leads to more successful development processes. Ancona and Caldwell (1992), an established example of this stream, focus on the structure of NPD teams, particularly the effects of cross functional boundaries to improve performance. While acknowledging this research direction, Brown and Eisenhardt (1995) pivoted their attention to the remain two streams for their NPD performance model. Koufteros et al. (2010) confirm the same tendency by the academic community, perhaps since this stream limits its study to a single dependent variable: communication. Regardless, this thesis considers important to retain the perspective of measuring the perceptual success of the project to study these phenomena.

The third stream of research evolved from the Japanese product development practices, and regards successful product development as “a balancing act” between multiple trade-offs (Brown and Eisenhardt, 1995, p. 359). This requires effective planning and a consistent and articulate strategy that team members can understand (Rauniar and Rawski, 2012; Eisenhardt and Tabrizi, 1995). This body of literature often acknowledges the role of senior management support and concurrent development activities to face uncertainly and complexity in product development (Song and Montoya-Weiss, 2001). For instance, Koufteros et al. (2010) discovered that integration couple with the presence of heavyweight managers are instrumental to avoid deviations from requirements that affect product development time. According to Koufteros et al. (2010), these *heavyweight* product development managers are integration agent that perform a similar role to the “Gatekeepers” introduced by Brown and Eisenhardt (1995): performing individuals who bring information into the organisation and dispersed it to their fellow members. They are responsible to facilitate cross-functionality, provide leadership, spread communication and to bring about senior management support to the NPD project.

In summary, cross-functionality, leadership, and communication combined with senior management commitment to the project appear to be characteristics consistent with the ability of different organisation to quickly respond to market needs and succeed in NPD projects (Thomas, 1995). Ernst (2002) organised success factors in NPD projects into five broad requirements: 1) a market orientated NPD process, with continuous commercial assessments during all product development phases and excellent planning before entering into the development phase; 2) an organisation with intensive internal communication from several areas of expertise, cross-functional autonomy and a project leader with necessary skills and holds sufficient power; 3) create a culture that incentivises new product ideas, where a “promoter” contributes to overcame barriers that are blocking new products, 4) senior management commitment by allocating resources into NPD projects; 5) a NPD strategy with clear definition and communication of goals. More recently, a review from Hilletofth and Erikson (2011, p. 266) indicate that “NPD success may result from numerous reasons arising from market, product, strategy and process characteristics”.

The aim of this section is not to present an extensive literature review on NPD success factors but to appreciate that given the uncertainty and complexity intricate to these projects, the decision-making process requires a great deal of expertise, communication, strategic thinking, and integration. The concept of 3-DCE evolves from the understanding that decisions in one dimension invariably influence the others and impact the outcomes of the projects. Therefore, it is essential to comprehend how these dimensions are intertwined. The ensuing subsections delve into relevant literature on product design decisions, product development processes, and cross-functional integration decisions.

2.2.2 Product Design Decisions

From an engineering perspective, product design refers to the process of transforming "a complex assembly of interacting components" into a physical product (Krishnan and Ulrich, 2001, p. 3). In this perspective, design decisions generally involve geometric models of assemblies and components, a bill of materials and control documentation for production. Often, the goal is to optimise the design parameters related to product size, shape, configuration, and function. That is, product design involves making decisions about the functionally and partitioning of components within product architecture.

Ulrich (1995) defines product architecture as the scheme by which the function of a product is allocated to physical components. This concept is explained further by Fixson (2005), who states that product architecture is fundamentally dictated by the function-component interfaces. In fact, one of the critical decisions in defining product architecture involves determining the degree to which the product exhibits a more modular or integral interface between its components. Products with a modular architecture are characterized by one or very few components that execute a well-defined function, underpinned by clearly delineated interactions between those components. Conversely, integral-complex products comprise a multitude of components that collectively fulfil a diverse range of functions, thereby resulting in more intricate interactions between the components (Fixson, 2005; Ulrich, 1995). For a visual representation of this product architecture typology see Figure 2.1, sourced from Fixson (2005, p. 352), which used an example of two trailers with different architectures from Ulrich (1995, pp. 421–422).

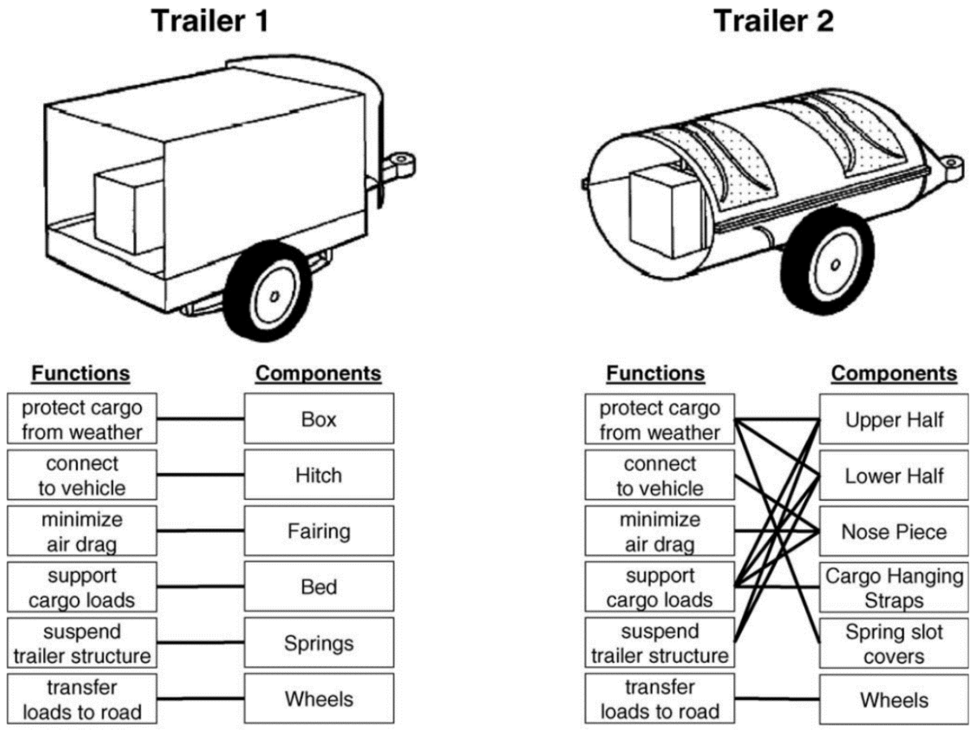


Figure 2.1 – A modular trailer architecture vs an integral trailer architecture, with function-component mapping sourced from Fixson (2005, p. 352)

Cutherell (1996) posited that the selection of an integral architecture is often motivated by the aim to enhance product performance or minimise system cost, whereas modular architectures are driven by the team's flexibility to change the product and facilitate reversibility. Increased modularity would enable the implementation of postponement strategies, increase product variety, and improve delivery or service requirements. However, the benefits associated with both modularity and integrity are not always unequivocal, and may result from different factors such as technological availability (Hölttä-Otto and De Weck, 2007). Despite these complexities, there is a consensus within the prevailing body of literature regarding the critical role of correctly defining product architecture on NPD performance (Yin et al., 2014).

On a similar note, the distinction between modular and integral architectures bears significant practical implications that can influence the configuration of the physical supply chain and the type of process used to assemble the product. For instance, Sosa et al. (2003, 2004) studied product architectures to identify the design interfaces between components and analysed its alignment with team interactions, both within and across organisational boundaries. They found a significant proportion of misalignment across boundaries. That is, teams often are unaware of component interfaces across system boundaries, perceived them as noncritical and, therefore, do not match the required level of team interactions for a successful NPD project. This underscores the vital importance of visualising the effects of product architecture decisions, particularly as they transcend organisational boundaries.

Gokpinar et al. (2010) also studied the misalignment between product architecture and communication patterns. Specifically, examining the effects of coordination deficits on product quality within complex NPD projects. Their findings indicate an inverted-U relationship among the number of interfaces a product sub-system shares with other sub-systems, high centrality, and the occurrence quality problems. In other words, quality issues increase with sub-system centrality up to a certain point. Sub-systems with high centrality could be part of both modular and integral products. Nevertheless, in more integral product the sub-subsystems are usually more interdependent, which could potentially lead to higher centrality. Their results suggest that organisational coordination could be improved by identifying the pairs of sub-systems that warrant more interfaces between them, and match those with the appropriate communication patterns.

In another example, Yassine and Wissmann (2007) explored the way product architecture influence the processes deployed to the development that new product. They recognise that product variety can add significant manufacturing costs to producing a product (Child et al., 1991). Product variety and product portfolio are strongly related to product architecture, particularly when it comes to modularity decisions (Krishnan and Ulrich, 2001). Overall, Yassine and Wissmann (2007) argue that the design of a manufacturing process is often determined by the product architecture, as it significantly influences the flexible of assembly processes in response to product or interface alterations.

It is now evident that while meeting customer needs is at the centre of product development initiatives, product architecture holds a crucial role in product design decisions. Decisions of architecture are typically made in the early phases of the NPD process due to their potential sweeping implications. These impacts the include the flexibility to change the product, the range of product models the organisation can produce, the component standardisation options, the performance of the product, its manufacturability, and the organisational structure by allocating design functions to the team (Ulrich et al., 2020). Figure 2.2, adapted from Krishnan & Ulrich (2001, p. 14), illustrates this pivotal role of product architecture and its overarching implications to other NPD dimensions.

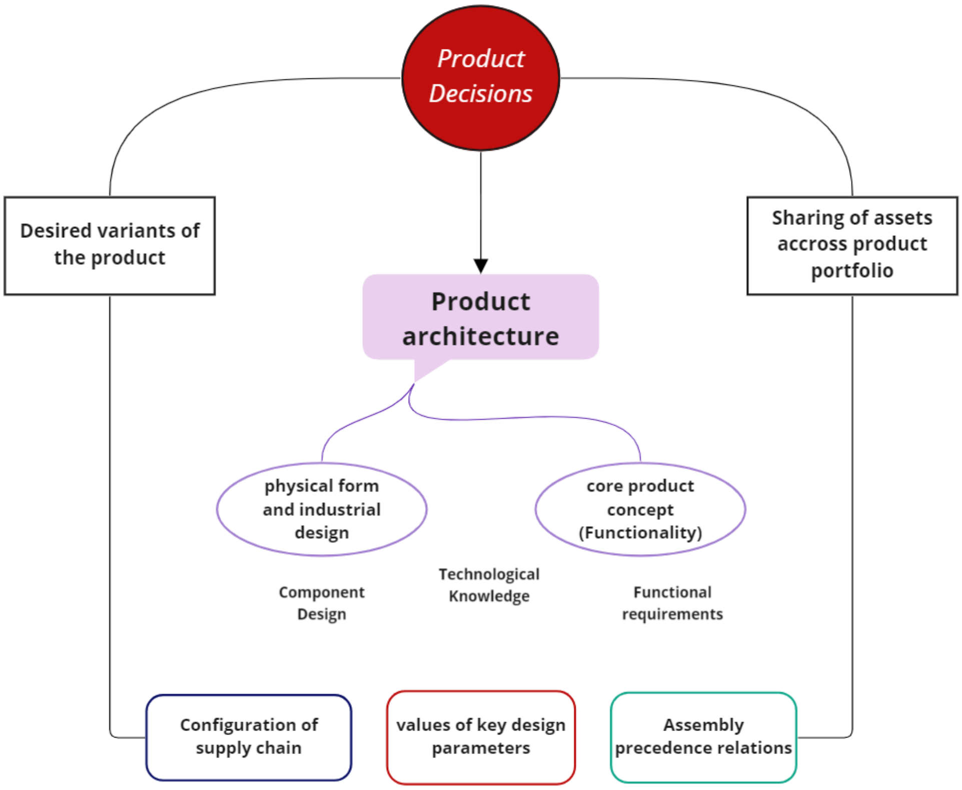


Figure 2.2 – Interdependencies in Product Decision Domain

The selection of product architecture is dictated by bringing together component design and their interfaces, meeting functional requirements with the available technological knowledge. Depicted in Figure 2.2 are the consequences of these choices. The product architecture design should consider the significant trade-offs between the advantages of the product platform, the component commonality between the new product and the organisation's portfolio, the number of product variants, and the differentiation of the new product (Crippa et al., 2010).

Component design has particularly relevant Supply Chain implications. For instance, Huang et al. (2005) developed a model using Generic Bills of Materials (GBOM) to represent components that supports product design while minimising the total cost of the supply chain. Their results suggest that product platform commonality has major implications on performance by reducing overall inventory costs and supply chain configuration. This results in reduced fixed costs for each product, from component sharing at the product level. Ramdas et al. (2003) present optimisation models that determine the desired component sharing for a product portfolio, concluding that consumers' perceptions of product differentiation, and component cannibalisation influences the gains of coordinated projects over project-by-project approaches. Similarly, Yadav et al. (2011) used a GBOM representation to devise an optimisation model to address the conflicting criteria of selecting the appropriate product portfolio. They argue that the issues that arise when designing a supply chain are often due to sub-optimal product family selection.

On the other hand, Fixson (2005) developed a framework that uses product architecture as a mechanism to coordinate product development decisions based on functional requirements. That is, the mapping between components and their functions. This framework allows for the definition of component and function hierarchies and set up a product platform strategy, by measuring the scale of interaction between components, their reversibility and interface standardisation. Such frameworks are particularly relevant in the development of product portfolios since product functionality is a requirement for customer satisfaction (Jiao et al., 2007). However, Jiao et al. (2007) warn that the technical feasibility of design parameters is key to achieving that functionality.

For Ulrich et al. (2020) product architecture is contingent on technology knowledge. Technological advances dictate if the product is fully defined during concept development or system-level design. Technical capability must be translated into product features to meet customer requirements, but according to Markham and Kingon (2004) many companies overlook their technological advantages. Therefore, the gap between technology and product design is not easy to fill.

Technology-to-product-to-market becomes a core capability for an organisation involved in NPD initiatives. Particularly in complex engineering projects, technological maturity introduces significant uncertainties in product development. Hence, the common employment of different Technology Readiness Level (TRL) tools in their NPD projects (Khire et al., 2010).

In conclusion, product design decisions emerge as a critical element of NPD projects. As explored in this subsection, product design considerably influences various aspects of such projects and the organisations involved. However, it will soon become evident that the activities related to the production of the product hold equal significance in the NPD process. This happens due to the interconnected nature of design and manufacturing. With that in mind, the subsequent subsection will engage in an examination of the decisions involved in the manufacturing process.

2.2.3 Manufacturing Process Decisions

Prior to this discussion, it is important to distinguish between product development process and manufacturing process decisions. According to Ulrich et al. (2020), the generic product development process consists of six different phases and set of activities that enable to conceive, design, and commercialise the new product. While, manufacturing processes are the activities responsible to produce those tangible, physical products. Before focusing completely on the manufacturing processes, the phases of product development process are introduced.

Product development processes are project management methods to achieve the desired outcome. The phases presented by Ulrich et al. (2020), similar to Cooper's (2008) stage gate model, include planning, concept development, system-level design, detail design, testing and refinement and production ramp-up. The first specifies objectives and assessment of technology, key assumptions, and constraints. The second provides a description of the form, function, and features of a product. The third usually includes the functional specification of each of the sub-systems, and a preliminary process flow diagram for the final assembly process. The fourth finalises the process plan and tooling for each part to be fabricated within the production system. The fifth involves the construction and evaluation of multiple preproduction versions of the product to identify necessary engineering changes for the final product. The purpose of the sixth and final phase is to train the workforce and to work out the remaining problems in the production processes for a successful product launch. Figure 2.3 illustrates Ulrich et al.'s (2020) six phases of the sequential process.

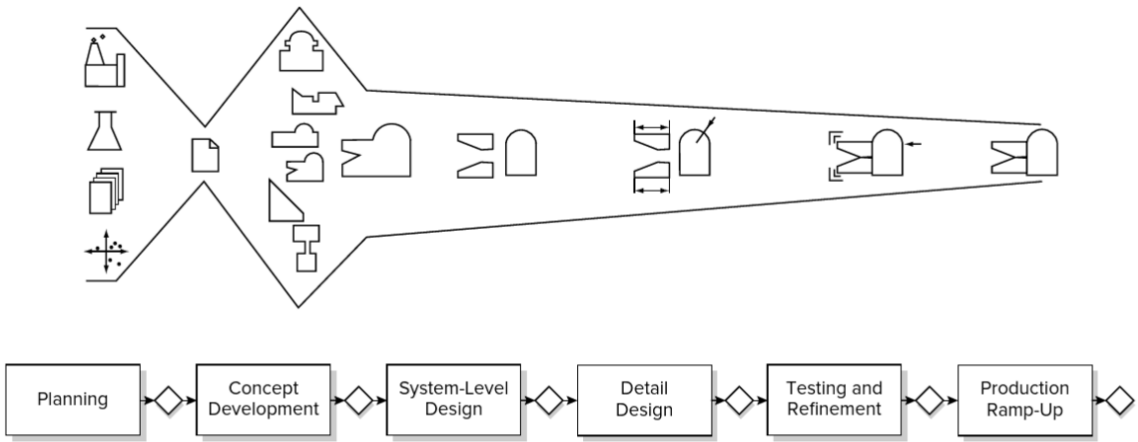


Figure 2.3 – The generic product development process sourced from Ulrich et al. (2020)

Hayes and Wheelwright's seminal HBR articles (1979b, 1979a) set the foundation for manufacturing process decisions. Their work proposes the idea of process lifecycle just as the product passes through different lifecycle stages. They introduced a product-process matrix, later validated by Spencer and Cox (1995), which positions the manufacturing function in relation to the product structure. This matrix aims to facilitate manufacturing decision-making.

The manufacturing process decisions include determining the appropriate mix of manufacturing facilities, identifying the key manufacturing objectives for each plant, and monitoring progress on those objectives at the corporate level. They also involve reviewing investment decisions for plant and equipment in terms of their consistency with product and process plans, determining the direction and timing of major changes in a company's production processes, evaluating product and market opportunities in light of the company's manufacturing capabilities, and selecting an appropriate process and product structure for entry into a new market.

Marsillac and Roh (2014) gives the example of sugar as a commodity and functional product with high volume and high standardisation product requirements, which then fits well with a continuous flow of production. Alternately, they use innovative products that with low volumes and low standardisation product requirements, should consider a jumbled flow of production or job shop (Marsillac and Roh, 2014). Figure 2.4 outlines the strategies firms should follow considering the interrelationships between product and process structures. That is, firms should compete in the diagonal of the matrix, where the process should become more automated when the product evolves to a more highly-volume, highly standardise item.

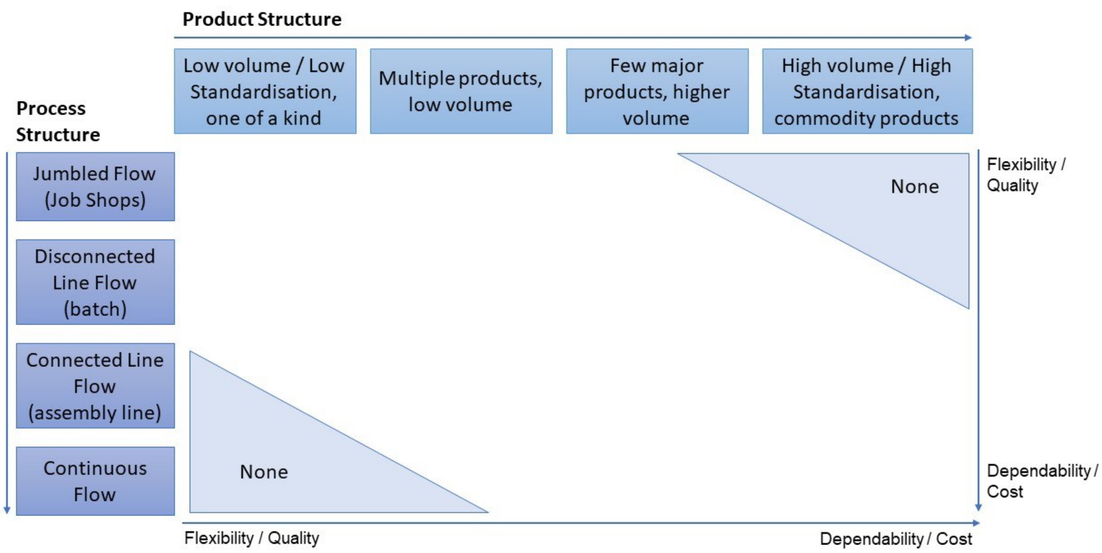


Figure 2.4 – 'Product-Process matrix'
sourced from Hayes and Wheelwright (1979a)

The matrix shows that operations managers need to strategically define manufacturing processes concerning flexibility and dependability (Gerwin, 1993; Slack, 1983). Manufacturing flexibility aims to help organisations cope with uncertainties such as market acceptance of the products, length of product lifecycles, machine downtime, characteristics, and sourcing of materials, among others. Anderson (2003, p. 158) states that flexibility has cost parallels with quality, in the sense that most of the gains from flexibility operations can pay for the efforts of flexibility. However, Gerwin (1993) argued that more flexibility is not always the solution, and managers should analyse the discrepancies between required, potential and actual flexibility and shouldn't overlook the opportunity to identify and eliminate flexibility.

Some of the main decisions in the domain of manufacturing process domain are manufacturing methods, equipment, layout, capacity, scheduling, team organisation (Ellram et al., 2007; Fixson, 2005). Olhager and Rudberg (2002) argue that these are strategic decisions whose impact is present only at lower planning levels. They adapted Hayes and Wheelwright's (1979a) original matrix to link market requirements, product, and process characteristics to manufacturing planning control system. Their understanding is that consistency between these three dimensions leads to better performance. Recently, Kumar et al. (2020) proposed three strategies for distributed manufacturing, a paradigm where the production process is geographically dispersed. The choice of strategy depends on the product-process matrix and company characteristics. Their findings highlight not only the importance of digitalisation but, most important for this research, the implications that aligning product and process designs have for product customisation, reduced lead time for delivery, and supply chain transparency.

The realisation of the intricate interdependencies between process and product structured decisions transformed the nature of manufacturing process decisions. Initially, product development projects were viewed as a relay race. The design, once selected, was passed on to manufacturing for production, after which the new product would subsequently pass to marketing for selling to customers (McDermott and Handfield, 2000). This sequential approach was refined with the advent of ideas such as *Design for Manufacturing (DfM)* (Anderson, 2003; Huang and Eastman, 1996) or *Systems Approach* (Clegg and Boardman, 1996), paving the way for the emergence of Concurrent Engineering (CE) processes (Boothroyd et al., 2002). A detailed exposition of CE will follow in the subsequent section.

2.3 Cross-Functional Integration

2.3.1 The Structure of NPD Teams

All three research streams introduced by Brown and Eisenhardt (1995) stress that having well-coordinated cross-functional teams is fundamental for successful product development results. Cross-functionality allows teams to play on existing synergies, enhancing internal organisation. Cooper et al. (2004a) study of practices employed in NPD projects and the resulting performance found that the way teams are organised strongly influence project outcomes. In fact, they found that cross-functional teams are largely embraced among NPD project teams and that is not enough to discriminate between best performers.

Dougherty (1992) reports on interpretive barriers to effective communication that result from functional bias. For instance, product designers define the market based on what the product does and may neglect certain business considerations such as how many customers are willing to for it". They think: "*…in a few months we could fix the problems, so let's take a risk… That helped push the technology…*" (Dougherty, 1992, p. 189). While, manufacturing people are concerned about the plant or operations, and feel that other function might not understand their inflexibilities. They complain: "*Sales and marketing live in the future and my needs are today.*" (Dougherty, 1992, p. 190).

Nevertheless, this paper also presents a clear description of functional conflicts: "… *there are six or eight decision makers. No one says yes but anyone can say no… The production guy wants to know if his yield will be better… The quality control guy says, 'will I have to change my tests?'. The sales manager says, 'will my customers like the finished product as well?'. The purchasing guy says, 'what will you do for me?'...You need to work with all these guys and their bosses.*" (Dougherty, 1992, p. 190). This exchange clearly demonstrate the need for those *heavyweight* product development managers, as indicated by Koufteros et al. (2010).

McDonough (2000) suggests that the effective use of cross-functional teams consists of three internal elements. First, a stage-setting element, that should be completed early in the project. Second, an enabling element, that facilitate the efforts of the team. Third, a behavioural element, that facilitates trust and cooperation in the team. Later, Daspit et al. (2013) tested this framework and concluded that the first element only indirectly influences cross-functional team effectiveness, by impacting the other two elements. This framework offers a process-orientated conceptualisation, as illustrated in Figure 2.5.

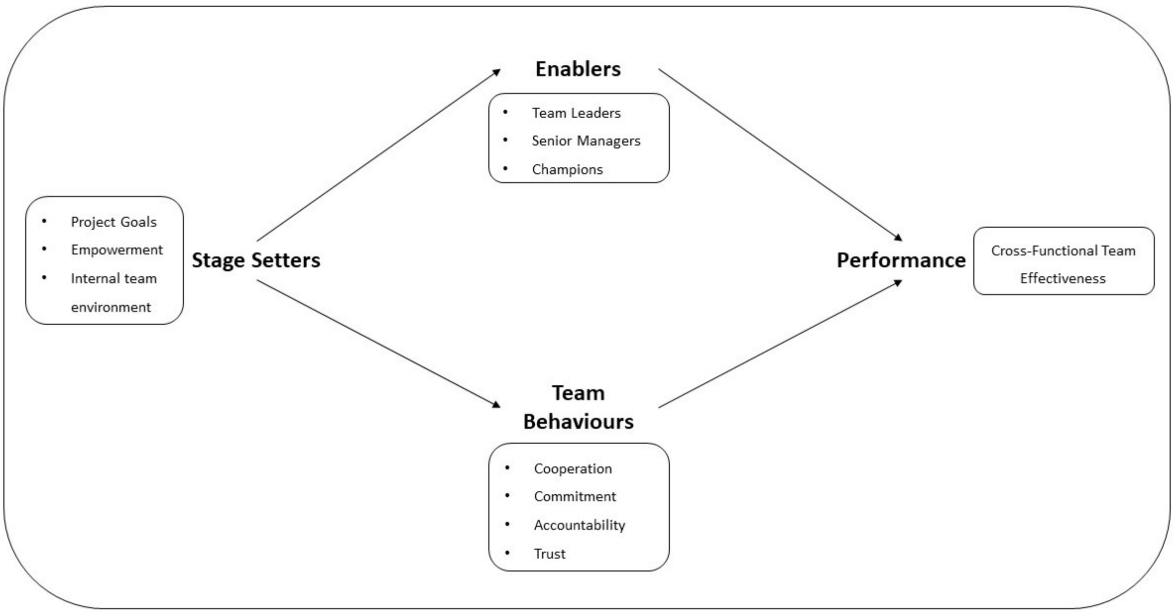


Figure 2.5 – Conceptual model for cross-functional team effectiveness adapted from McDonough (2000) and Daspit et al. (2013)

In continuation of improving cross-functional integration, Haque et al. (2003) proposes a methodology to develop social mechanisms that foster a collaborative environment. This approach follows the call from Dougherty (1992) to design an innovative social order that enhances integration. In their approach, they combined organisational theory with business process re-engineering approaches. By studying organisational issues that occur in cross-functional project teams, they found that project leadership, commitment, and strategic positioning of geographically situated facilities are decisive to the integration success. Of significant note for this Thesis is their fresh approach of considering human behaviour factors, acknowledging that managers drive adoption of theoretical concepts. Such insights align with the broader scope of this research.

The expansion of Volvo's car assembly plant in Ghent, Belgium exemplifies the implications of manufacturing processes design in teamwork structures. Van Hootegem et al. (2004) studied the challenges posed by this expansion and takeover by Ford. The expansion and takeover, will see the Ghent plant assemble at an annual outcome of 270,000 units, thus turning into a high-volume assembly plant. Therefore, Ford would have the opportunity to introduce a teamwork structure more in line with their own production system.

The Ford Production System is a version of lean production, characterised by standardisation of the product and segmentation of work into specialised tasks. The system relies on the transfer of "off-the-shelf" best practices from central task team to manage all its facilities. On the other hand, Volvo's model lies on the idea of "self-managing teams", where the additional transfer of indirect tasks and responsibilities is rotated between team members. The content of these activities is derived from general targets of quality, cost, delivery, improvement, safety, man and environment (QCDISME) unit level. Ultimately, manufacturing process design decisions should consider the pressures between manufacturing efficiency and worker motivation, stressing the importance of the social element to NPD projects (Angelis et al., 2011; Pil and Fujimoto, 2007).

Cross-functional integration is fundamental to concurrent engineering practices. The premise is that effective cross-functional teams improves communication flows which leads to more successful development processes (Ancona and Caldwell, 1992). In contrast, sequential product development often leads to inadequate communication which may result, for example, in loss of abstract information, affecting the consistency of the product concept or manufacturability (Forza and Salvador, 2001). The realisation that the need for communication does not end at the firm's boundaries accentuates the need for customer and supplier integration (Stock, 2014; Salvador and Villena, 2013; Petersen et al., 2005). Further discussion on integration beyond organisational boundaries is presented in the subsequent section, which focus on the 3-DCE concept.

2.3.2 Product Lifecycle Perspective

The incorporation of process lifecycle into Hayes and Wheelwright (1979a) model underscores the importance of positioning product development on a lifecycle perspective. Lifecycle theory is adapted from biological sciences that postulates the inevitable role of change in human beings, organisations and products (Roscoe et al., 2020; Lester et al., 2003). The initial adoption of the product lifecycle (PLC) concept in business research was established by Marketing scholars following the American economy success in the aftermath of the Second World War (Cao and Folan, 2012).

From a Marketing perspective, products progression through distinct life stages: development, growth, maturity, and decline (Cao and Folan, 2012; Levitt, 1965). Product portfolio management strategies were developed based on this perspective on PLC, notably the BCG matrix (Hambrick et al., 1982). However, Cao and Folan's (2012) review indicates a paradigm shift in marketing research, where PLC is perceived as a useful metaphor than a hard-line theory. This change in perspective can be attributed, in part, to critical observations such as of Dhalla and Yuspeh (1976).

From an Engineering perspective, the PLC concept examines the complete life of a product, instead of solely the market life. The product circles from conception, through definition or design, to realisation or production, then service or customer use, and recovering or recycling (Johnson, 2010, p. 2). Moreover, efforts were made to integrate product lifecycle analysis (LCA) into the process and product development, mainly motivated by increased globalisation, resource efficiency and environmental concerns.

This extended responsibility of organisations involved in NPD projects, lead to an increase of thinking in terms of life cycles (Westkämper et al., 2001). Lee (2002) studied how the product lifecycle is connected to demand and supply uncertainties that should be aligned with the correct supply chain strategy. Khan et al. (2004) proposed an indexed system comprised of different attributes to facilitate LCA application in decision-making. Kobayashi (2005) developed a tool to assess appropriate lifecycle options for different components. Similarly, Bevilacqua et al. (2007) used data from LCA both during NPD and in re-designing processes to reduce the overall environmental impact of products. Noticeably in all these models is the role collaboration and product-process integration as key elements of PLC management (Johnson, 2010).

In more recent research, PLC continues to be employed to study organisational complexities. Specifically, focusing on devising efficient processes for increased collaboration, and resource efficiency and supply chain agility. First, Nagashima et al. (2015) examines the impact of collaboration on demand forecast accuracy in different product categories throughout the PLC. Their findings suggest that higher investments in collaboration during introduction and growth stages of a PLC are crucial for enhancing demand forecast accuracy. Also, Matopoulos et al. (2015) emphasise that creating resource-efficient supply chains is deeply intertwine with PLC. changes that occur over the lifecycle. Their review shows that LCA is clearly and its variations are clearly the selected method to assess resource used and its impact. Furthermore, a parallel study conducted a LCA to measure the environmental impact in an agri-food supply chain (McCarthy et al., 2015). Finally, Roscoe et al. (2020) studied the effects of internal and external process connectivity at German manufacturing firms. They acknowledge the need to apply PLC theory as process-related enablers of supply chain agility.

Kriwet *et al.* (1995) introduced an integrated PLC design, between the product, its related processes and its logistics support. Their aim is to integrate aspects of End-of-Life (EoL) into the product design. They suggest that the planning of these three elements should be done concurrently for an appropriate view of all the relevant parameters. Figure 2.6 depicts their PLC system underscoring the importance of Concurrent Engineering.

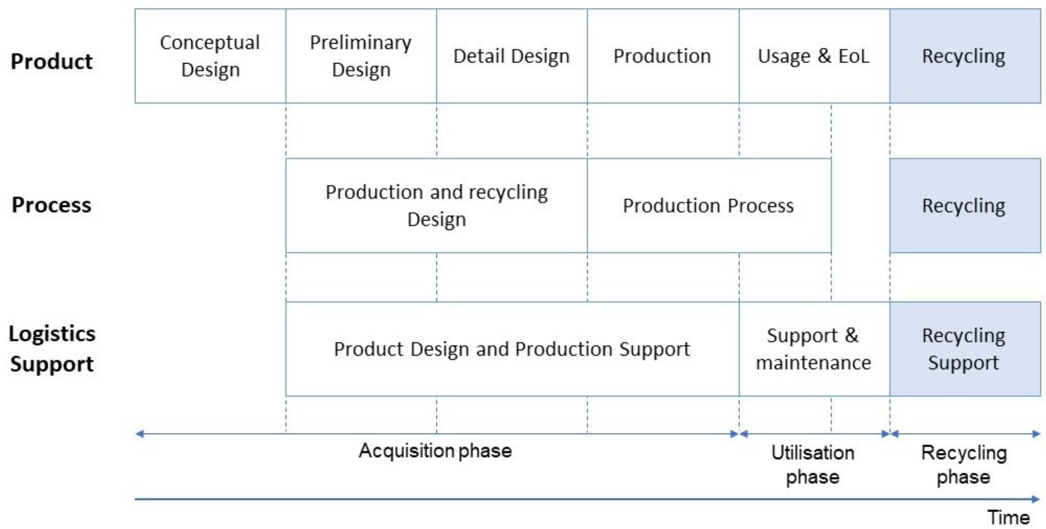


Figure 2.6 – Concurrent Product, process, and support lifecycles, sourced from Kriwet et al. (1995)

The product lifecycle perspective is fundamental to the concurrent engineering concept. After the integration of the "people" side, researchers understand the need to integrate time into their NPD endeavours. In fact, Fine and Li (1987) worked to extend the Product-Process Matrix precisely for their understanding of the importance of evaluation of PLC. They observe that process design is flexible, depending on the available technologies, and that products have asynchronous lifecycles. Furthermore, they note that original the model is not open to external elements, such as market competition. Unsurprisingly, Charles H. Fine would later develop the idea of 3-DCE, by adding Supply Chain design to CE and therefore to the PLC phenomenon.

2.3.3 Concurrent Engineering

In the context of concurrent engineering (CE), Winner et al. (1988, p. v), in a report commissioned by the US Department of Defence (DoD), provide a seminal definition of this approach. They articulate CE as "*systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product lifecycle from conception through to disposal, including quality, cost, schedule and user requirements."* It is worth noting that this report was not the originator of this concept (Khan, 2018, p. 100; Smith, 1997). Still, it provides an exact description of the CE concept. The system lifecycle model delineated by Kriwet et al. (1995) clearly illustrates Winner et al. (1988)'s definition, as depicted in Figure 2.6.

From this definition and other paper on CE, Valle and Vázquez-Bustelo (2009) came up with an inspired view of the concept. They present CE as a method for dealing early with the problems that arise in NPD endeavours, where all functions needed for this process are considered simultaneously, so that "downstream" factors are incorporated into the "upstream" phase of the project (Hatch and Badinelli, 1999; Lee, 1992; Shenas and Derakhshan, 1992; Wheelwright and Clark, 1992). This approach would prevent continuous setbacks that arise in different stages of product development, increasing flexibility improved time-to-marked and internal communication.

Tangible benefits of CE practices were documented by Hoffman (1998) from a survey report on US companies this concept. These benefits can be grouped into improvements in lead time, quality, and process design. Similar advantages have been corroborated in other publications (Khan, 2018; Valle and Vázquez-Bustelo, 2009; Boothroyd et al., 2002; Koufteros et al., 2002; Kott et al., 1990). The tangible benefits presented by Hoffman (1998, p. 2) are as follows:

- Development and production lead time:
    - Product-development time shortened as much as 60%
    - Production time shortened 10%
    - Total process time shortened as much as 46%
- Measurable quality improvements:

    - Manufacturing defects reduced as much as 87%
    - Yield improvements as much as 400%
    - Field failure rates lowered as much as 83%
- Engineering process improvements:
    - Engineering changes reduced as much as 93%
    - Early production engineering changes reduced 50%
    - Inventory items stocked reduced as much as 60%
    - Engineering prototype builds reduced as much as 66%
    - Scrap and rework reduced as much as 87%

The adoption of CE in NPD projects become a major breakthrough for manufacturing organisations. The emergence of important manufacturing methodologies, including the "House of Quality" (Hauser and Clausing, 1988), as well as various Design for "X" approaches (Huang and Eastman, 1996), such as *Design for Manufacturing and Assembly* (DfMA) (Boothroyd et al., 2002), contributed for its widespread adoption. According to Boothroyd et al. (2002), DfMA is a driver for quality and cost improvements and is used as "the basis for concurrent engineering studies to provide guidance to the design team in simplifying the product structure, to reduce manufacturing and assembly costs, and to quantify the improvements". This notion aligns with Rungtusanatham and Forza (2005) view that these manufacturing techniques fit under the broader umbrella of a concurrent approach to product development.

The implementation of CE principles lies fundamentally in the early involvement of cross-functional teams in a concurrent work-flow (Koufteros et al., 2001). In a book on DfMA, Anderson (2003) elucidates the advantages of incorporating a complete cross-functional team during the architecture phase. The case in point is Lexmark, a laser printer manufacturer, which reported 40% reduction in real time-to-market. This substantial saving was attributed to architectural optimisation that effectively minimise the necessity for revisions and redundant interactions. These advantages are illustrated in Figure 2.7.

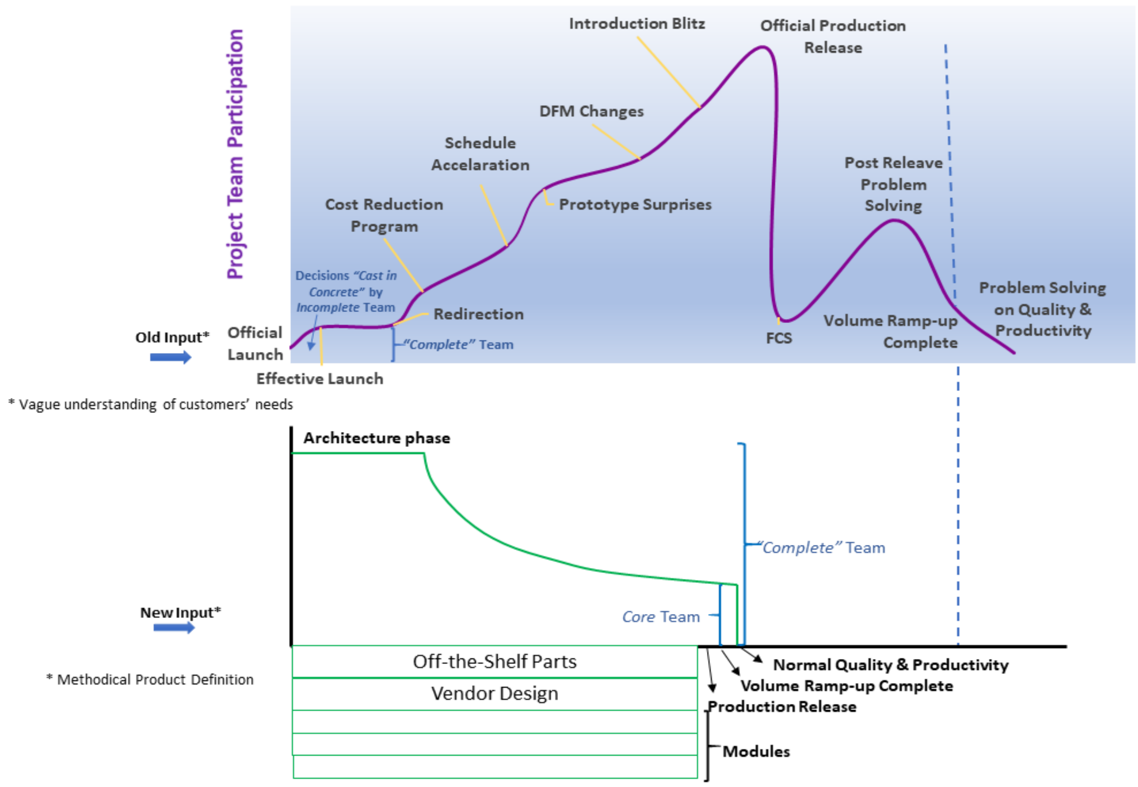


Figure 2.7 – Team participation: traditional vs concurrent model, sourced from Anderson (2003)

As observed, CE practices appear to yield positive benefits. Particularly, they appear to be connected to improved project management capabilities, such as the early identification of design flaws. However, notably, McDermott and Handfield (2000) and Koufteros et al. (2002) found that, in certain instances, this practice does not exhibit significant effects on product innovation. For instance, McDermott and Handfield (2000) note that in cases of more radical innovations, where technology is still unproven, the concurrent approach is not always the most suitable. Nevertheless, computer-aided design (CAD) systems can play a vital role in enabling cross-functional teams to attain higher levels of performance in these uncertain environments (Koufteros et al., 2002).

Ultimately, concurrent approaches have a positive influence on NPD performance. The emphasis on proactive issue resolution suggests a relationship between CE and *risk management*, while the early involvement of cross-functional teams aligns CE to a *people* dimension. These themes are recurrent throughout this Thesis. Staring by exploring, in Chapter 6, the managerial behaviour towards the implications of concurrency practices. Subsequently, in Chapter 7, by designing an artefact-solution in the form of a gamified scenario that focus on improving visualisation of the risk due to lack of such behaviours in product development projects.

The scope of the last two sections was to capture the holistic perspective that NPD projects require to succeed. In this section, a conscious effort was made to describe the critical role of cross-functional integration for this success. However, the integration described thus far concerns exclusively to the internal dimensions of product and process development, over which the focal organisations maintain direct control. The next section underscores the importance of incorporating the supply chain dimension of concurrent engineering, recognising that in a globalised world, new products are not developed in isolation.

2.4 Three-Dimensional Concurrent Engineering

2.4.1 Incorporating Supply Chain Design

The idea behind 3-DCE can be summarise by this sentence from Fine's book Clockspeed: Winning Industry Control in the Age of Temporary Advantage: "*…When firms do not explicitly acknowledge and manage supply chain design and engineering as a concurrent activity to product and process design and engineering, they often encounter problems late in product development, or with manufacturing launch, logistical support, quality control, and production costs…"* (Fine, 1998, p. 133).

This section discusses Three-Dimensional Concurrent Engineering (3-DCE) practices, by elucidating the dimension of the Supply Chain design. Fine (1998, p. 76) states that Supply Chain design ought to be thought of as an assembling chains of capabilities rather than merely collaboration between organisations. Echoing this sentiment, Petersen et al. (2005) contend that beyond capabilities, the cultural attributes of a supplier exert significant influence on the effectiveness of collaboration. In essence, 3-DCE advocates that a firm's ultimate capability hinges on its the ability to design for supply chain. This is because the double helix of concurrent engineering, which primarily emphasises on aligning product design with internal processes, is insufficient and only provides temporary advantages. As presented before, when studying products with asynchronous PLC (Fine and Li, 1987), Fine understood that not all industries have the same speed, so he deem vital to design *Clockspeed*-strategies.

Clockspeed relates to change during the product lifecycle, and the ability to maintain competitive advantages. Fine (2000) refers to these strategies as the incorporation of the strategic nature of supply chain design within product and process development based on the necessity to adapt to the dynamics of fast-evolving industries. The change is organisational, product and process, the first is about the response to changes in the overall business environment, the second is the impact of market-wide changes in product development, and lastly is the impact that changes in process development have on product terms.

Fundamentally, the concept of 3-DCE is the integration of product, process, and supply chain designs. Table 2-A is adapted from Ellram et al. (2007) and Marsillac and Roh (2014, p. 320) for the concept definitions and a common understanding of these base concepts.

Table 2-A: Concept definitions of the core dimensions of 3-DCE

Core 3-DCE Concepts	**Definition**	**Contributing authors**
Product Design	Multitude of decisions regarding product specifications intended to develop a tangible, physical product.	(Hong and Roh, 2009; Koufteros et al., 2002; Krishnan and Ulrich, 2001; Brown and Eisenhardt, 1995)
Manufacturing Process Design	Methods and activities responsible to manufacture the product, including facilities, equipment, output	(Yang, 2011; Hayes and Wheelwright, 1979a, 1979b)
Supply Chain Design	Complex interactions with other members of the supply chain with the purpose of conveying materials, products, information, and capital from source to consumer and back	(Koufteros et al., 2010; Choi and Hong, 2002; Lee, 2002; Fisher, 1997)

Navigating the interdependencies between these core concepts is fundamental to the essence of 3-DCE. First, the original 'Concurrent Engineering' term, discussed in detail in the previous section, considers the trade-offs that arise from the influence of product on and the processes required to produce them. Then, the interplay between product design decisions and supply chain structure has important considerations for make or buy decisions and in building an effective supply network (Fine, 1998). Ellram et al. (2007) incorporates this into three additional literature streams: early supplier involvement (Koufteros et al., 2005), voice of customer (Christopher and Towill, 2001) and channel structure (Williamson, 2008). Also, the process-supply chain interchange underscores the importance of extending information exchange beyond organisational boundaries. Overall, the 3-DCE model highlights the need for proper integration among manufacturing, logistics, inventory, and information processes from end-to-end in the supply chain. Figure 2.8, sourced from Ellram et al. (2007) perfectly illustrates these interdependencies, providing the means to better envisage the 3-DCE concept.

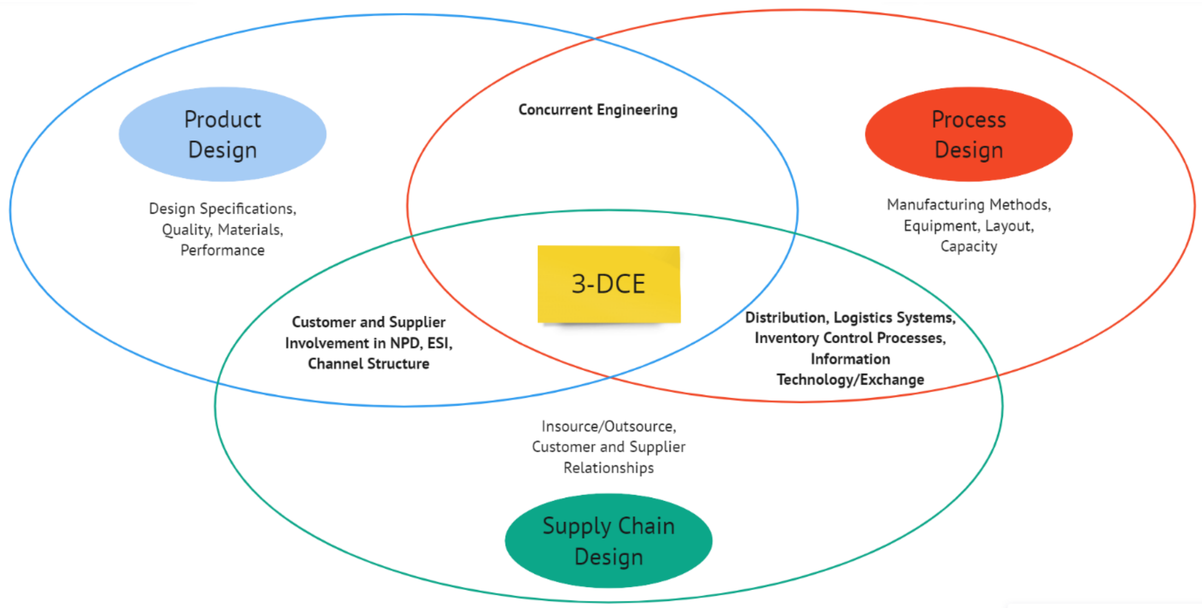


Figure 2.8 – Interdependencies within 3-DCE sourced from Ellram et al. (2007)

The cases of Intel and Chrysler were used by Fine (2000) to illustrate the ideas behind 3-DCE. Intel's rapid growth over less than a decade, resulted from its ability to execute new product and process development with new suppliers at breakneck speed. While Intel integrated product and process to dramatically reduce technical complexity, it was the link between process and supply chain design that was integral for their success. Particularly regarding supplier development, where Intel nurtured start-up companies to focus on developing advanced technologies for their next-generation processes. Similarly, in the 1990s, Chrysler managed to compete with much larger rivals by defining an outsourcing strategy that allow them a much faster concept to car rating on the most desirable designs and features. These lessons allowed Fine, other academics and practitioners to recognise the strategic role of supply chain design.

With increased global competitive pressures, shorter product lifecycles, and radical innovations, NPD decisions were deemed increasingly important for building sustainable competitive advantage (Koufteros et al., 2002). The general scope of those design decisions would initially concentrate on *Design for Assembly*, which coordinates engineering processes with manufacturing processes, or *Design for Manufacturing*, adding the product component to the mix. Ken Keys (1990) used the terminology of Design for Lifecycle, opening the scope of DfX to other functions of design, planning and development such as customer support or marketing. The argument is that for a product to successfully retain competitive advantage throughout its lifecycle, the NPD decisions should open their scope to other functions. In the case of 3-CDE, these decisions include the supply chain dimension as the ultimate capability of simultaneously designing the product, process, and supply chain, portrayed by the conceptual framework in Figure 2.8.

Cross-functionality was perceived as an effective solution to implement CE practices in NPD projects. While this remains true for 3-DCE, other articles place the emphasis on the increasing collaborative processes external to the organisations. For instance, early supplier involvement (ESI) is expected to improve the alignment between the product, process, and supply chain dimensions (Binder and Clegg, 2008; Petersen et al., 2005). The rationale remains the same as in cross-functional teams: an effort to solve problems in the earlier stages of the product development process. Extensive literature shows that a successful implementation of this collaborative process leads to product quality improvement, as well as the reduction of development lead times and costs (Binder and Clegg, 2008; Petersen et al., 2005; Caputo and Zirpoli, 2001). However, Suurmond et al. (2020, p. 39) conducted a meta-analysis which found that ESI "is not always better". They identify that the degree and appropriate timing of supplier involvement is more positively related to higher levels of NPD efficiency and effectiveness. Therefore, suggesting that supply chain decisions should be taken in holistic way in relation to the product and process they serve.

The successful implementation of 3-DCE reinforces the long-term benefits of integrating the diverse functional and organisational voices. These benefits can be understood in conventional Quality, Cost, and Delivery (QCD) measures of NPD success (Fujimoto, 1999). Table 2-B summarises the main benefits of 3-DCE, placing them into these three overarching goals of product development. Further implications of thinking 3-DCE in NPD projects are explored in the following subsections.

Table 2-B: Benefits of 3-DCE for Quality, Cost and Delivery performance, adapted from Mombeshora (2016)

Balancing Goals	**Benefits of 3-DCE**
Quality	▪ Improved product innovation ▪ Increased number of design iterations ▪ Reduced post-launch engineering changes ▪ Reduced product development risks
Cost	▪ Reduced development costs ▪ Improved inventory management ▪ Less expensive products and components ▪ Lifecycle cost reduction
Delivery	▪ Time-to-market (lead time) reduction ▪ Improved channels of distribution

	▪ Higher accuracy of information ▪ Improved market adaptability ▪ Reduced relationship risks

2.4.2 The implications of 3-DCE

The message throughout this chapter has been to explore the wide-ranging implications of including supply chain design to the product-process double helix. This subsection delves on the implications on product characteristics, and the organisational structures of NPD teams. These are particularly relevant implications for the study of managerial perception gaps, conducted through a scenario-based experiment on Chapter 6. Still, similar concepts to 3-DCE have overreaching implications to globalisation and environmental impact, resilience and risk awareness, and innovation complexity to name a few.

On Product Characteristics

Pashaei and Olhager's (2015) review on 3-DCE shows that the majority of the research focuses on dyadic relationships. Some articles study primarily the alignment between product design and supply chain, with an emphasis on product modularity and supply chain modularity (Khan et al., 2008; Fine et al., 2005; Doran, 2003). Voordijk et al. (2006) propose an intriguing approach to modularity by pairing manufacturing process design into time and space. That is, a highly modular process is one very dispersed in both time and space. Similarly, highly modular supply chains are geographically, culturally, or organisational dispersed measured by the autonomy granted to suppliers. This approach to modularity is illustrated in Figure 2.9. Voordijk et al. (2006) argue that three dimensions tend to reinforce each other, supporting the causations in changes between product architecture and organisational structure.

The alignment between product and supply chain modularity is, arguably, a critical technical implication of adopting a 3-DCE thinking. The concept of modularity adopts a systems perspective to product design (Baldwin and Clark, 2003). The inclusion of a lifecycle perspective, as suggested by Sako (2003) and Fixson (2007), highlight the temporal dimension that supply chain design considerations bring to the product-component interface strategy. In this sense, designing a product with process and supply chain implications in mind can be seen as a risk management strategy of the product lifecycle with clear impact to the product architecture.

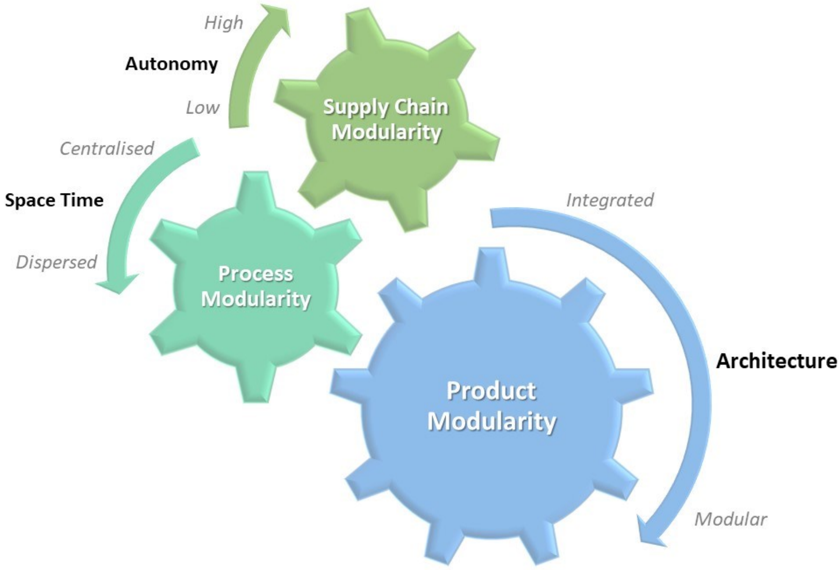


Figure 2.9 – Modularity in supply chain adapted from Voordijk (2006)

The case for the impact of 3-DCE on product characteristics moves around modularity decisions. Fine et al. (2005) developed a model that clearly identifies the advantages of aligning modular products with modular supply chains. Likewise, Khan et al. (2012) studied a fashion company that by aligning product and supply design improved supply chain resilience and responsiveness and enable it to become a leading global retailer. Notwithstanding, Doran et al. (2007) found that the benefits often associated with modularisation dissolve when it moves to second and third-tier suppliers. Also, Fixson and Park (2008) indicate that, in their case study, their tool called for a decrease in that firm's product modularity based on its industry structure and as a response to the new technological shocks. Later, Chiu et al. (2014) show that modularity brings different gains to supply chain execution: a more modular product improves the time-based performance of the supply chain network, whereas a less modular product yields superiority in terms of cost performance.

The driving force behind adopting product modularity in various industries is due to its potential benefits, such as flexibility, customisation, and cost reduction. The relationship between supply chain design and product modularity often go hand in hand, particularly regarding make or buy decisions. In the automotive industry, for instance, OEMs move towards modularisation by relying on independent suppliers that pre-assembled and pre-tested modules such as doors or cockpits (Campagnolo and Camuffo, 2010, p. 264). Thus, underlining the dependency of supply chain coordination or organisational structure on product design choices.

On Organisational Structures

Campagnolo and Camufffo (2010) reported on the tendency in many industries for more modularity in product design. As seen, there is an unequivocal relationship between product design and supply chain design. However, Sako (2003) suggests different paths to the way product design influences supply chain decisions, in particular outsourcing strategy, as depicted in Figure 2.10. Some authors state that the trend for more product modularity, forces suppliers to shift their outsourcing strategies by seeking a position of more flexibility in the organisational structure to capture more value (Fine et al., 2005; Doran, 2003). Whereas some report that pressures for more outsourcing decisions and the adoption of postponement strategies drive product modularity decisions (Christopher, 2016).

The path a-c-d, where the focal firm defines its product modularity prior to outsourcing decisions, involves generally lower risks than a path a-b-d, where the firm first outsources product components, then accepting the modularity architecture selected by the supplier (Campagnolo and Camuffo, 2010). However, in mature industries is to be expected that firms are already committed to outsourcing decisions, meaning that firms in these industries are often conditioned to follow the second path towards modularity (a-b-d). The rational beyond Fine's 3-DCE concept is that product and supply chain decision go hand-in-hand and a lifecycle perspective to product development is needed before committing to irreversible decisions.

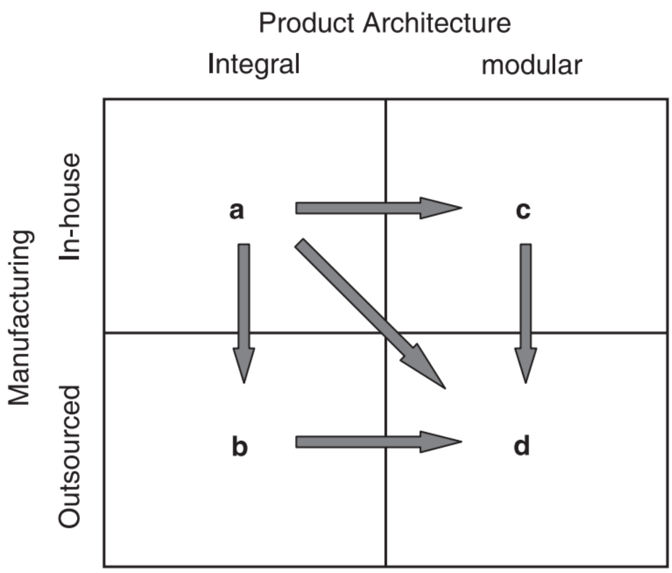


Figure 2.10 – Paths towards module outsourcing
sourced from Campagnolo and Camufffo (2010), adapted from Sako (2003)

Frandsen (2017) confirms a change of perception in academic research regarding modularity. He states that researchers stopped focusing exclusively on the product design, but rather studying the impacts of modularity in other domains, particularly on organisational structures.

To illustrate, Howard and Squire (2007) examined the impact of product modularisation on supplier relationship management. Their results indicate that modularisation can lead to greater levels of buyer-supplier collaborations, particularly when this relationship is mediated by asset specificity and information sharing. This is because the development of modular product often requires joint efforts, either in new technologies or process innovation. Furthermore, they found that information sharing between the firm and the module supplier increases throughout the different stages of product development, from design to delivery. Howard and Squire (2007)'s findings suggest that modularisation lead to closer collaboration to co-develop products and reduce interface constrains, going against a stream of literature thinking which suggests that modulation creates arm's-length relationships, due to increased supplier independence.

The pressure for outsourcing, both from a product architecture point of view but also knowledge transfer requirements transforms supply chains into truly extended enterprises (Jayaram and Pathak, 2013). Davis and Spekman (2004, p. 20) defines Extended Enterprise (EE) as "the entire set of collaborating companies, both upstream and downstream, from raw material to end-use consumption, that work together to bring value to the marketplace". Dyer (2000, chap. 8) provides another interpretation of EE, referring to a set of firms within a value chain or production network that have established collaborative relationships, enabling them to work together as an integrated team to produce a finished product. This concept is very aligned with the 3-DCE, as it elevates supply chain decisions to a higher level of relevancy in NPD projects. However, adopting a 3-DCE mindset does not always require the emergency of extended enterprises.

These structures arise from the dynamic environment described in Fine's book. They seek cross-firm linkages to gain competitive advantages, they are non-hierarchical structures concerned with managing the supply chain, that promote a win-win philosophy which has a gain and risk-sharing system. The advantage of the EE derives from a firm's ability to quickly utilize the entire network of suppliers, vendors, buyers, and customers.

The traditional way of managing buyer and supplier relationships changes in EE. Traditionally, the power in all aspects of decision-making rested solely with the prime contractor. There are natural tensions between contractual relations and working relationships that are governed by contractual manuals.

These new relationship structures require trust to function. Whipple and Frankel (2000) identified two main sources of trust creation, one based on a character and the other based on competence. The former refers to the partner's level of honesty and principles, the identification of the partner strategic intentions, the consistency and predictability of their actions, the wiliness to be open about problems, and the ability to be maintain confidentiality regarding common strategic plans. While the latter refers to specific operational knowledge and skills, the ability to effectively perform their responsibilities and work well with others, the competence in a broad sense beyond a specific area of expertise, and judgment or the decision-making ability.

Despite understanding that trust is the “glue” beyond successful extended enterprises, the development of strategies to build trust is still a challenge. Conversely, successful example are Supplier Development programmes that improve the performance of a key supplier, focusing on not only improving the technical capabilities and management skills but also training the supplier to converge to their own quality, cost and delivery targets (Davis and Spekman, 2004, pp. 173–174). Such programmes build trust given the emphasis on communication and commitment to the proactive alignment of their overall business goals. In the ensuing chapter 3, a research synthesis is conducted to explore case studies where similar interventions were implemented. The aim of this synthesis is to understand the underlying mechanism, such as trust building, beyond 3-DCE adoption.

The fundamental principle of 3-DCE finds parallels in various other concepts studied within the field of O&SCM. Notably, the commitment to bringing together different functional and organisational voices bears resemblance to the tenets addressed in Extended Enterprises. As Spekman and Davis (2016) observed, these structures function as learning bodies, making collaboration a cornerstone of their operational framework. So much so, they noted that the term “collaborative supply chains” appears to have gradually replaced the term “Extended Enterprises” in the span of the 12 years since their first work. The following section explores some other concepts that are committed to paradigms such as the alignment and design trade-offs inherent in NPD projects, ultimately culminated in the complete notion of “Design for Supply Chain” to be formulated by the end of this Thesis.

2.4.3 3-DCE relationship to other concepts

Fine’s 3-DCE is a powerful yet simple concept, therefore is only natural that cannot cover all the complex aspects mentioned in the organisational management of NPD projects. Voordijk et al. (2006) pointed out some of the shortcomings of the concept such as the lack of consequences on different levels of product architecture, unclear systems boundaries, and unspecified governance structures. In fact, the understanding from the present review is that 3-DCE was developed as a concept to place Supply Chain on equal footing with the other design domains in NPD projects. The complexity of NPD projects and the implications that 3-DCE intended, urge a reflection on other topics that have been covered so far and constitute the base of a future “DfSC” definition, namely, how to align supply chain activities in NPD, a "systems thinking" rationale, management of functional trade-offs, with a lifecycle perspective, among others. In fairness the idea of extending the 3-DCE framework is not new, Pal and Torstensson (2011) highlight the necessity of incorporating intangible value propositions into the concept.

Supply Chain and NPD alignment

The idea of committing to the alignment of the supply chains involved in NPD projects has been a subject of attention since Fisher's (1997) landmark article. Van Hoek and Chapman (2006, 2007) explored how organisations can achieve greater market impact and revenue growth by leveraging their supply chain capabilities. They come up with three steps to move from a "get the product out there" into a more collaborative approach. First, improving basic alignment between functions, individuals, management goals and NPD teams on an internal level. In other to make progressive improvements in communication, training and planning are needed. Second, improving supply chain readiness to reduce execution issues and put the organisation in a position to be less affected by "last-minute" crises. The third step is leveraging supply chain capabilities, this relates to Supplier Development programmes as mentioned in EE. The goal is to create partnership arrangements to make sure that supply chain considerations, NPD performance targets, and organisational goals are aligned. Figure 2.11 sourced from Van Hoek and Chapman (2006), highlights the path towards alignment as previously described.

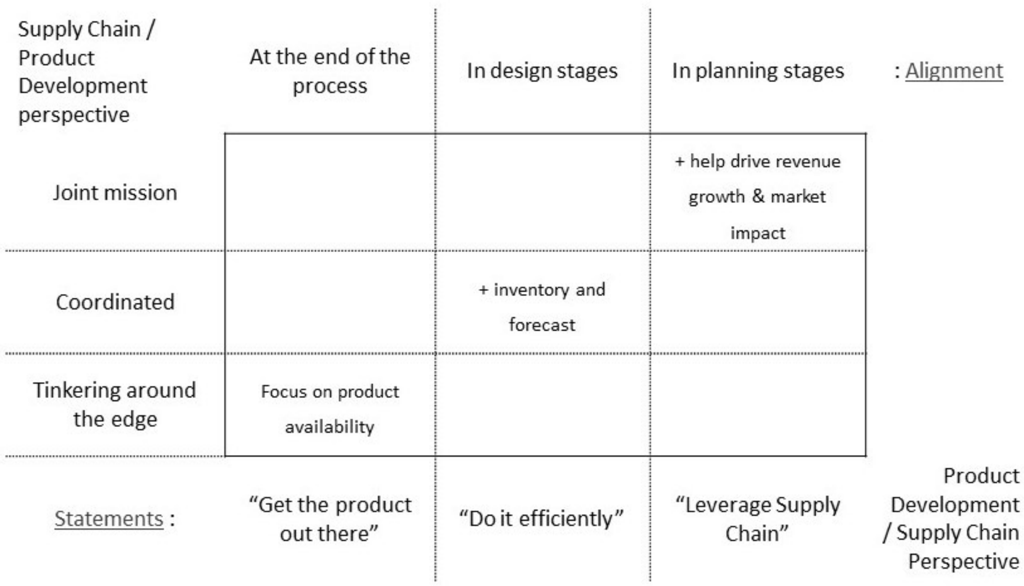


Figure 2.11 – Aligning product development and supply chain sourced from Van Hoek and Chapman (2006)

Innovation Ecosystems

In a concept review, Granstrand and Holgersson (2020) includes both collaboration and competitive relations together with the products and technologies that exist in the system in their definition of innovative ecosystems. For them, an innovation ecosystem is defined as a loosely interconnected network of companies and other entities that coevolve capabilities around a shared set of technologies, knowledge, or skills, and work cooperatively and competitively to develop new products and services. Their definition appears to be a broad interpretation of Davis and Spekman's (2004, p. 20) EE, building of the value creation in network contexts (Autio and Thomas, 2014). Moreover, according to Pagani and Fine (2008, p. 1103), 3-DCE builds on the dynamic complexity of the value network, based on the need to augment traditional product-process engineering with value chain engineering or supply chain design.

Fine (2000, p. 217) calls system complexity a key clock-speed damper, comparing the ability of Dell to come out with new computer models, against new fighter jets from Lockheed-Martin due to the former far more complex system. The complexity of the system will affect the number of products developed in a given period, the types of relationships with suppliers, the organisational structure of the Supply Chain and the functional goals of the project. Nevertheless, delivery time is essential for any product development and such pressure for speed highlights the importance of modularity and outsourcing. According to Fine (2000, p. 221), a well-executed 3-DCE strategy can significantly reduce the complexity at product launch, as stated in the Intel example. However, conceiving the conceptual structure needed to implement 3-DCE is a complex activity in itself. Caridi et al. (2009) study shows that higher innovation levels, both in product and process innovativeness have particular demanding consequences on the supply side with "suppliers asked to supply complete systems and sub-assemblies and no longer just components" (Caridi, Pero and Sianesi, 2009, p. 394).

Boardman and Clegg (2001) have shed light on the intricate nature of dealing with such complexities through the lens of "systems thinking". They advocate the need for supply chain actors engaged in NPD projects to develop "human activity systems" to enhance the processes needed for establishing successful EE. While these processes operate autonomously, they recognise the risks and benefits of participating within the system. To navigate these challenges, Boardman and Clegg (2001) approach focuses on four perspectives. Firstly, the "make versus buy" perspective, focusing on maintaining core competencies while delegating peripheral ones. Secondly, the "meta-system" perspective that perceives the EE or "collaborative supply chain" as a singular organisation. Thirdly, the "strategy" perspective concerned with the evolving dynamics within the EE. Finally, the "modelling" perspective that examines the structural architecture of the EE, subsequently proposing visions for progressive improvements based on evolving environmental factors.

Translating this multi-dimensional approach towards 3-DCE implementation, highlights the need for a comprehensive roadmap for entities aiming to adopt such complex supply chain scenarios.

Cross-Functional Trade-off Management

Navigating functional trade-offs within structures such as innovation ecosystems requires a nuanced balance of cooperation and competition, as well as a clear understanding of the shared objectives and individual goals of the participants in the project. Liu et al. (2022) present a compelling case from the Ventilator Challenge UK. This unique initiative witnessed the convergence firms across diverse section to establish a new network for the purpose of creating ventilators in the fight against COVID-19. Interestingly, the tensions that normally arise from participating in such ecosystems were mitigated based on the rapidly network formation, and realisation of complementary benefits. At the heart of this accelerated innovation, Liu et al. (2022, p. 88) identified four fundamental preconditions. Predominantly pertinent to trade-off management in the context of 3-DCE is establishing a shared sense of purpose. More tangibly, in the capability to share design and technical details among partners and accessing manufacturing and operational flexibility, for instance, by sharing physical resources, such as production line, or repurposing existing production processes.

Fine et al. (2005) offered a quantitative methodology or "modelling" perspective to manage 3-DCE trade-offs, by exhibiting the potential conflicts among multiple objectives: sourcing of components, capacity utilisation, batching strategy, and product quality. Their analysis focuses on the strategic and tactical levels of decision-making, trying to provide a tool to support those decisions. However, as the authors indicate the modelling tool deals with matters of subjectivity and complexity that cannot be taken "off the shelf". Unfortunately, most papers appear to approach those trade-offs with mathematical models focusing on the optimisation of those decisions (Shekarian et al., 2020; Pullan et al., 2013; Nepal et al., 2011; Yadav et al., 2011).

The benefits of 3-DCE can only be fully grasped if studied in the overall system (Matopoulos, Tate, et al., 2015). With that in mind, Fixson (2005, p. 351) agrees that the alignment of the three design domains "must capture all relevant dimensions of the product architecture simultaneously, but show them separately", allowing detection of the "cause-consequence relationships". However, Campagnolo and Camuffo (2010) discovered that "functional perspective" studies are chronologically antecedent from those which consider a "lifecycle perspective", meaning that most of those studies pursue optimisation of the functional trade-offs for a single phase of the product lifecycle. Thus, the development of a true DfSC behaviour must capture functional trade-offs throughout the production lifecycle.

Lifecycle Product Management

Throughout this chapter, the evolving landscape of NPD projects underscores a pressing reality: projects demand complex adaptive systems that hinge on the intricate interactions among a vast network of suppliers (Choi et al., 2001). As explained, the successful management of these networks requires the balancing of inherent trade-offs. Yet, the imperative notion that seems to escape in the 3-DCE concept is that these systems are not static, they traverse a temporal dimension. Product development is characterised by a lifecycle in which suppliers and service providers can change over time. Consequently, the relationships established at a certain phase of the NPD project will not only influence the actors and key functions involved in subsequent phases, but also could impact future NPD projects.

For instance, Johnsen et al. (2019) identified lifecycle as a significant dimension of NPD, drawing from a case study in the offshore wind power industry where supply networks frequently change from one project to the next. Nonetheless, this lifecycle dimension is not confined to this specific case, it emerges across multiple industries albeit with different levels of complexity. Yet, the holistic incorporation of the lifecycle dimension is somewhat sparse, highlighting the need for a deeper exploration, particularly as a risk management strategy to enhance visualisation of benefits and costs of decision-making throughout the different stages of NPD projects. This gap offers an opportunity for academic research to place more emphasis in the lifecycle perspective when assimilating DfSC behaviours. Indeed, an important contribution of this research is the endeavour to amplify the range of the 3-DCE framework by bringing this and other topics of interest to the forefront of the discussion.

The following section addresses the gaps uncovered within 3-DCE research and delineates how this thesis seeks to address them.

2.5 Research gaps and how to address them

The concept arises from 3-DCE, which postulates that product, process, and supply chain should be considered in NPD design decisions. The first part of the chapter introduced topics related to product and process design, such as product architecture and concurrent engineering. Those topics have extended research and were successfully incorporated by practice. Then, the focus turns on integrating supply chain design into the mix by aligning supply chain considerations into the NPD activities and transforming them into truly "collaborative supply chains".

Yao and Askin (2019) details the research landscape around the topics of 3-DCE principles. The topics around the integration of supply chain management in NPD projects evolve from supplier selection, supply chain configuration and supply chain design. They provide a visual representation of the efforts by the research community in this topic. The upper layer represents product architecture via GBOM, while the lower layer adopts other product design schemes. Figure 2.12 highlights the predominancy of multi-period, stochastic, sustainability supply chain configurations in NPD projects.

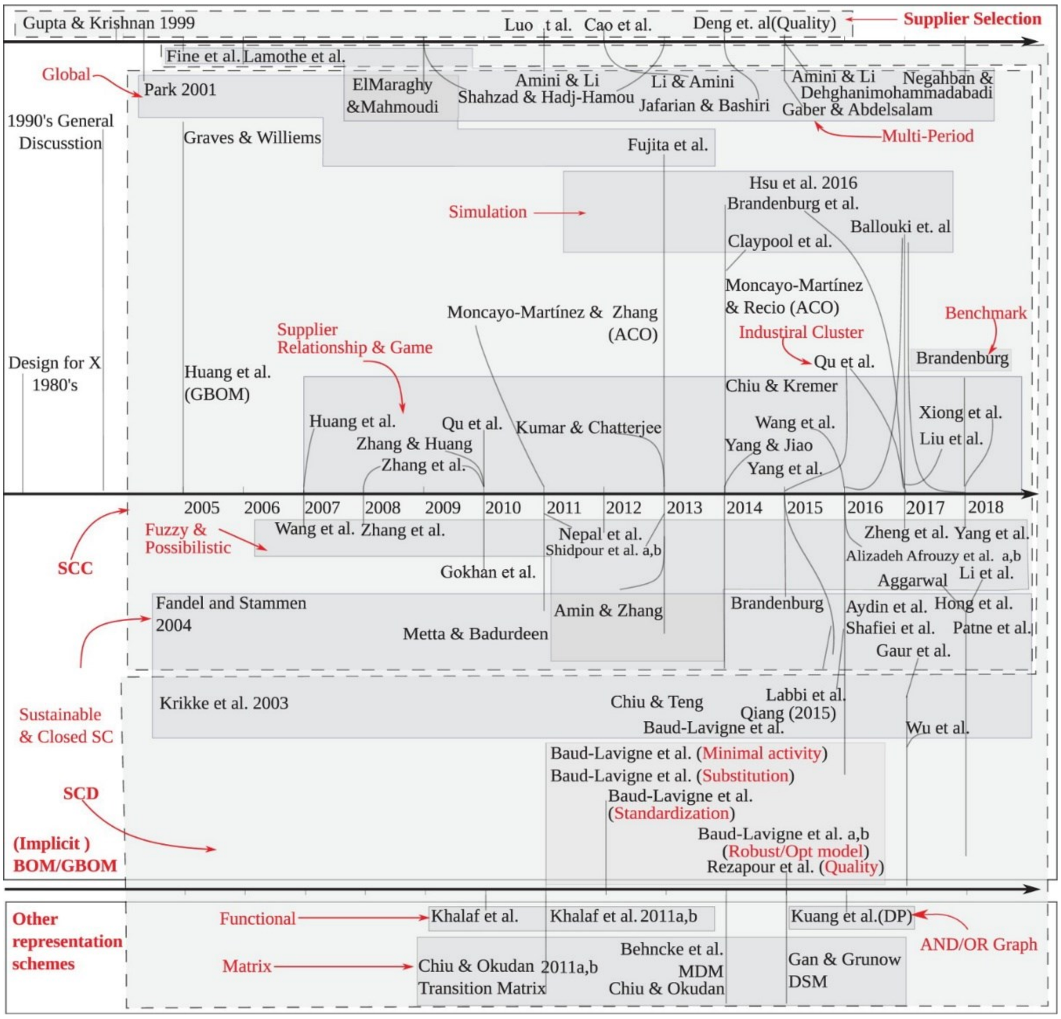


Figure 2.12 – Changes in the joint product-supply chain research landscape sourced from Yao & Askin (2019)

Evidenced by Pashaei and Olhager's (2015) analysis, research of the 3-DCE concept has demonstrated notable patterns. They examined 56 articles, revelling that case study research are infrequently employed to study 3-DCE. Likewise, Ellram et al. (2007, 2008) find 3-DCE research excessively deterministic, with lacking of empirical testing. The emphasis of research seems to lean heavily towards optimising design decisions using mathematical models to navigate the intricate trade-offs.

However, it is alarming to note that, notwithstanding the significant strides in research, a tangible gap persists in the practical realm: the adopting behaviour perspective. Many organisations, including managers, persistently neglect such multifaceted elements influencing the consequences of their design choices, as noted by Hansen and Ahmed-Kristensen (2011). According to their findings there is a clear gap between theory and practice in the context of global product development. They observed a lack of embeddedness of the proposed solutions into the organisation, its structures, processes, and procedures. The persistence of this oversight may result in a practical disregard for the critical role of DfSC behaviour in improving NPD outcomes as well as its role in risk mitigation through the product lifecycle perspective.

In light of these observations, the driving force behind this Thesis is to fully grasp the practical behaviour towards the 3-DCE framework. This begins by capturing the underlying mechanisms that undermine or facilitate the successful incorporation of the concept. Then, by developing a design-solution which supports the fostering of DfSC. Finally, by discussing the novel idea of DfSC behaviour, one that expands on the 3-DCE framework and propels the academic discourse towards new possibilities. As a testament to this, Table 2-C presents the critical research gaps this study endeavours to bridge.

Table 2-C: Summary of the research gaps

Research Gaps	**Addressed in this Thesis**
Lack of consequence of the 3-DCE concept to capture the complexity needed to reach its full potential	This research advances 3-DCE by developing the concept of DfSC behaviour that includes the visualisation of functional perceptions and product lifecycle implications
The research on the 3-DCE concept has been mainly approached from a conceptual or design optimisation position, struggling to grasp the behaviour of participating actors	This research follows a Design Science Research strategy that captures the underlying mechanisms that shape the adoption of this concept, combined with experimental research to measure perception gaps
Lack of a coherent set of strategies that focus on incorporating DfSC behaviour into NPD projects	Design and implement an artefact that supports the embedding of DfSC behaviour within the organisations responsible for designing complex products

The attempt to address the gaps in the literature is expressed by answering the two research questions:

- How do key underlying mechanisms influence the successful implementation of “Design for Supply Chain” in NPD projects within discrete manufacturing industries?
    - How are changes in product, process and supply chain design perceived by decision-makers within NPD projects?

- How to facilitate the embedment of “Design for Supply Chain” behaviours in the teams and organisations involved in NPD projects within discrete manufacturing industries?

2.6 Anticipating the Next Chapter

In summary, this chapter has provided an important exploration of the concepts necessary for the understanding of the 3-DCE concept and its benefits. The chapter addressed two main objects: the first, to provide a compelling argument for the tangible benefits of embracing concurrent design of product, processes, and supply chain in NPD projects. The second, to clarify the position this research work within the broader research on 3-DCE and similar concepts, particularly focusing on the challenges of managerial adoption. This approach enriches the understanding of 3-DCE by bringing a behavioural perspective into the scope of discussion.

Transitioning to the subsequent chapters, the emphasis will be on the uncovering of mechanisms related to 3-DCE documented in academic journal. Specifically, a research synthesis of cases where implementations related to the topic were conducted and studied. The placement of the chapter is a deliberate choice recognising the role of an exhaustive literature review prior to bridging theory with practice. Yet, it is worth noting that this is not merely an exploration of topics in the pursuit of research gaps. Instead, it is a systematic review underpinned by a distinctive objective: to identify the mechanisms by those interventions. The Research Synthesis represents the initial stage of the Design Science Research (DSR) strategy, as detailed in Chapter 5, setting the stage for the subsequent phases, and ensuring the alignment with the overarching goals set forth in this Thesis.

3 A RESEARCH SYNTHESIS AND CONCEPTUAL FRAMEWORK

3.1 Overview

This chapter intends to address the first research question, namely grasp the underlying mechanisms for successfully incorporating DfSC in NPD projects, with the complementary aim of understanding how the 3-DCE concept translates into practice. Rather than a mere exploration of the literature, the approach should be an evidence-based review of the complex interventions that synthesise what does and does not work, and under which circumstances. In fact, Rousseau et al. (2008) advocate for the importance of making effective use of scientific evidence in Management and Organisational science as well as backing the role of research synthesis in that quest.

Deyner et al. (2008) warn that the outcomes of the proposed interventions do not happen in a vacuum, meaning that they need to account for context and the mechanism that are triggered by such interventions. First, the reviewer needs to identify the underlying mechanisms, namely the basic theory of the intervention. The intervention will succeed or not, depending on the context. Then, the task is to "sift through the mixed fortunes" of the intervention and "discover those contexts (C+) that have produced solid and successful outcomes (O+) from those contexts (C-) that induce failure (O-)" (Pawson, 2002, p. 345). However, Pawson (2013) claims that this logic has not always been fully understood, warning that social designs "do not come in pre-ordained chunks called contexts, mechanisms and outcomes". This synthesis seeks to follow that same logic to fully grasp the critical mechanisms for the embedment of the principles within the 3-DCE framework. Such mechanisms underpin the foundation for the proposed conceptual framework of the Thesis.

The research synthesis follows a five-step process, as endorsed in academic guidelines and textbooks (Denyer and Tranfield, 2009; Rousseau et al., 2008; Tranfield et al., 2003) and applied in analogous reviews (Sawyerr and Harrison, 2019; Ali et al., 2017; Matopoulos, Barros, et al., 2015; Thomas et al., 2014; Colicchia and Strozzi, 2012; Pilbeam et al., 2012). To elaborate, the first step commences with defining the scope of the synthesis. This is succeeded by a systematic search for relevant interventions within the literature. Subsequently, there is a thorough screening and appraisal of the evidence, followed by a critical extraction of the data that facilitates the synthesis of the findings. The final stage involves the reporting of these findings which, in this case, constitutes the proposed conceptual framework. The ensuing sections of this chapter provide a detailed explanation of each step, considering its specific aim within the synthesis.

3.2 The scope of the Synthesis

The first step in research synthesis is to use the main research question as a guide. The imperative is to ensure that the reviewer clearly defines the parameters of the research so that directly comparations are possible (Pawson et al., 2006). At this stage, acknowledging the uncertainty and iterative nature of the review process is paramount to this type of review. As advocated by Pawson et al. (2006) and employed by Ali et al. (2017) and Pilbeam et al. (2012), defining a range of sub-questions facilitates the affirmation of the purpose of the review. Therefore, this Research Synthesis deconstructed the initial research question into sub-questions formulated using the CIMO logic framework proposed by Denyer and Tranfield (2009, p. 683).

Explicitly defining the terms under review is a critical part of the specification of the scope of the synthesis. As stated, this review seeks to unpack and comprehend the underlying mechanisms that shape the adoption of '*Design for Supply Chain*' in NPD projects. The concept of DfSC used in this chapter builds upon the 3-DCE framework discussed previously. Consequently, DfSC, for the purposes of this chapter, is delineated as:

"The design principle of concurrently account for the multifaceted functional (design, engineering, manufacturing, logistics, procurement) and supply chain decisions in NPD projects. These decisions, taken by multiple teams and organisations, should aim to ensure mutual beneficial outcomes throughout the product lifecycle". Here, "mutual beneficial outcomes" are those where product and manufacturing performance gains from the design decisions outweigh the end-to-end costs for the different stakeholders across the products' supply chain.

The scope of the research synthesis focuses on a series of CIMO objectives to analyse interventions linked to DfSC using NPD projects as the unit of analysis (C). At first, it aims to identify the issues that are directly tackled by carrying out these interventions (I), examining on both the successes and constraints faced within the wider context. The synthesis then reviews the specific conditions necessary for the activation of DfSC's underlying theoretical mechanisms (M), highlighting factors that facilitate or hinder their adoption. Additionally, it aims to understand the outcomes (O) valued by individuals involved in NPD projects. Together, these objectives strive to offer an overview of how such interventions address Supply Chain implications in NPD settings.

Pawson et al. (2006) promote a methodological review where programme theories are prioritised. Specifically, their approach treads an explanatory path that compares official theoretical expectations with the actual outcomes of the intervention, seeking to discern underlying patterns that go behind the explanatory claims. Yet, Rousseau et al. (2008) introduced alternative paths for research synthesis. One such approach, named "synthesis by interpretation", involves the re-evaluation and reinterpretation of existing studies, aiming to discern fresh insights that can be useful to comprehend new or similar phenomena. This approach, deemed appropriate for the current synthesis, aspires to repurpose the reviewed case studies of interventions akin to DfSC, and re-categorise them into the underlying mechanisms that are fundamental for a successful implementation. In essence, the path pursued in this synthesis adopts an interpretative lens, although with some guidelines Pawson's explanatory synthesis.

3.3 Locating studies: selection and evaluation

Tranfield et al. (2003) outline a structured approach for conducting systematic reviews. Their approach emphasis the need for a comprehensive and unbiased review, which they break down into three distinct stages, encompassing nine phases. The phases pertinent to the actual review process stage are labelled as identification, selection, and quality assessment of the research studies. For the identification of research, it is crucial to provide explicit details of the search strategy to ensure replicability. During the selection of the studies, a well-defined protocol expressing the inclusion and exclusion criteria is vital to obtain the best available evidence. Regarding the quality assessment, decisions are taken to support the fit and “good” quality of the selected studies. These decisions, however, come with further challenges that should be mitigated by a detailed explanation of the reviewer’s actions to minimise biases or errors. These initial stages lay the ground for a robust research synthesis.

The structured search is conducted using predetermined keywords and search strings. This ensures the capture of relevant articles that have implemented the theoretical object of the review (DfSC). Using a combination of keywords, as illustrated in Figure 3.1, search strings were formed employing Boolean connectors. Several esteemed databases including EBSCO, Scopus, Emerald, Web of Science and Wiley Online Library were primarily sourced for research screening, while supplementary searches were conducted on platforms like Science Direct, Google Scholar, and Taylor and Francis.

Theory (DfSC) (ALL)		**Field** (ABS)		**Implementation** (TITLE-ABS)
“Supply Chain Design”	**AND**	Product* **WITH** Development	**AND**	Case* **WITH** Stud*
AND		**OR**		**OR**
Concurr*		Introduction		Research

Note: ALL (search everywhere); ABS (search abstract only); TITLE-ABS (search title & abstract) / *Truncation symbol

Figure 3.1 – Keyword string used in the screening of the articles

Keyword selection was a careful process. First, the term “supply chain design” was coupled with variations of “concurrent”, and further refined by a combination of “product development” in the abstracts, to ensure that the focus of the research article remains on NPD projects. An additional criterion was added to filter for “case studies” since the aim of this review is on the practical application of DfSC interventions. In terms of language and publication type, only studies published in peer-reviewed scientific journals in English were deemed adequate for this review.

Periodic updates to the search were integral to the review’s comprehensiveness. The initial search commenced in September 2022 and revisited in December 2022, a strategy to adopt an abductive approach post the empirical exploration of the subject. The selection criteria did not specify any specific timeline. Yet, unsurprisingly, the results of the screen process wre post-2000, as per the observation that the concept of 3-DCE only truly emerged in academic research towards the end of the 1990s (Fine, 1998; Fisher, 1997).

The selection process described earlier resulted in an initial screening of 141 articles after removing duplicates, primed for abstract review. For a comprehensive coverage of relevant articles for this Synthesis, these articles were uploaded into the Research Rabbit platform (https://researchrabbitapp.com/home). This platform is an AI-powered literature mapping tool that uses citation-based techniques to recommend new papers and establish connections between the selected articles. The tool is starting to be used in academia, in such fields as psychology and information management (Jacob et al., 2022; Sharma et al., 2022). Found et al. (2024) present an early contribution to the supply chain management literature, employing that the tool as a snowballing method for their literature review.

The output from Research Rabbit offered a vivid visualisation of interconnections within the literature. The citation network, depicted in Figure 3.2, colours the initial articles in green and connects them with similar work, marked in blue, based on their citation. Prominent academic contributions by Ulrich (1995), Fisher (1997), Petersen *et al.* (2005), Van Hoek and Chapman (2006), and Ellram *et al.* (2007) form the core of the network. Such linkages insinuate that the articles pulled from the original keyword criteria are aligned with the 3-DCE theme explored in Chapter 2.

Utilising Research Rabbit as a snowballing tool resulted in the addition of 33 articles for further analysis. The articles were selected through their citation links to the initial set, thereby incorporating relevant yet previously neglected studies into the review. This process not only confirmed that the selected keywords matched well with the core literature but also enriched the synthesis.

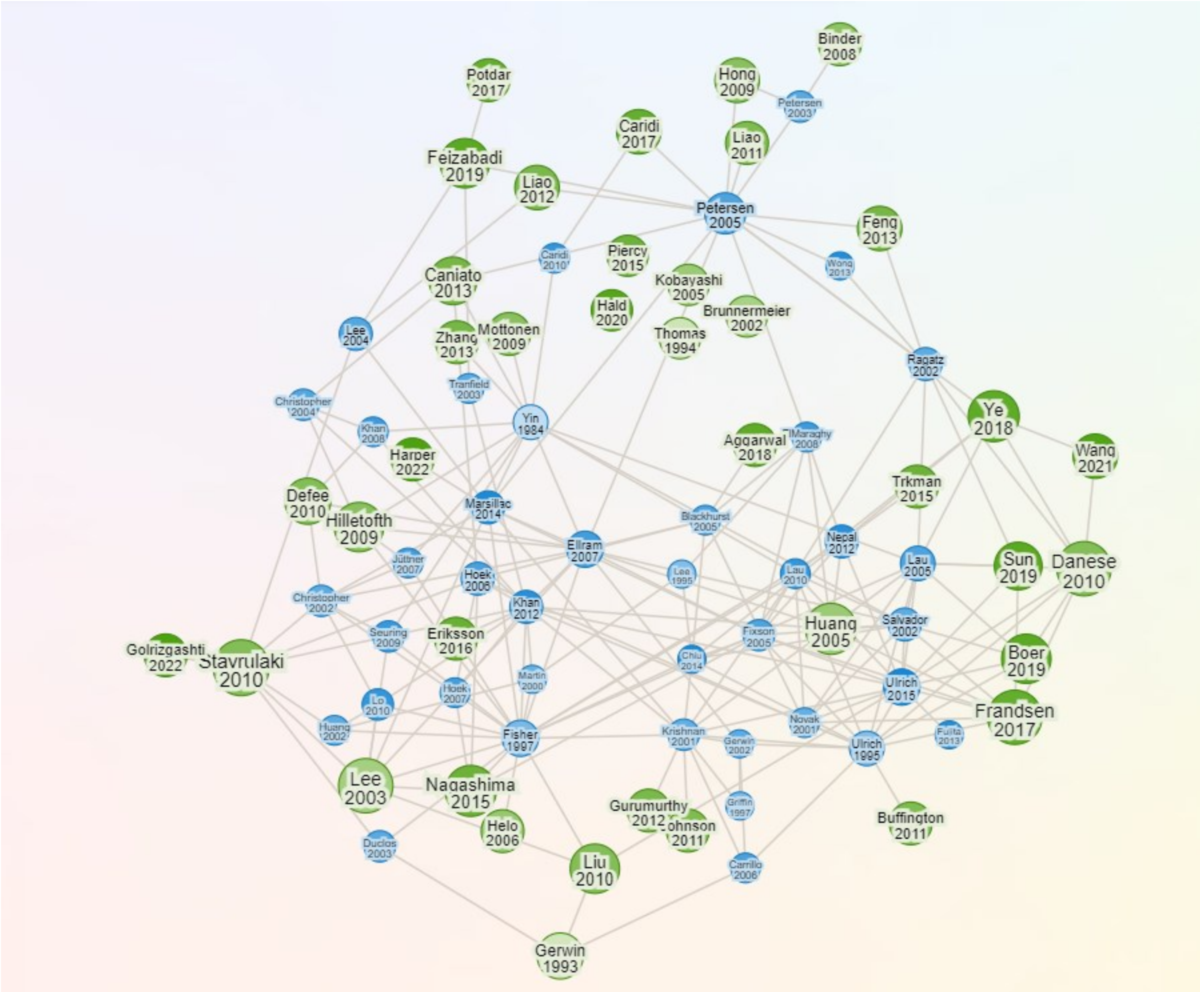


Figure 3.2 – Visualisation of Citation Network from Research Rabbit

The purpose for employing this tool was to capture articles that resonate with the central topic of the research. Based on its recommendations, an additional 33 articles were combined to the initial set for further content analysis. To ensure the retained 174 articles meet the aim of this review, they were subject to further inclusion and exclusion criteria. This approach resonates with the guidelines suggested by Denyer and Tranfield (2009) to maintain transparency, accuracy, and reliability. The protocol with a comprehensive enumeration of these criteria can be found in Table 3-A.

Table 3-A: Inclusion and Exclusion protocol for the Research Synthesis

Inclusion criteria	Exclusion criteria
Type: Published in peer-reviewed journals	**Type:** Conference proceedings, editorial opinions, book chapters and grey literature
Methodology: Case study, empirical research, or another relevant implementation	**Methodology:** Goal programming & simulation approaches, conceptual research with limited empirical validation

Relevance: Supply Chain (e.g. Supplier involvement) & other design domain considerations (e.g. functional trade-offs) in NPD projects, Product Lifecycle management under the DfSC definition	**Relevance:** Not related to NPD or SCM, exclusive focus on topics outside the DfSC definition (e.g. sustainability issues, knowledge transfer, target costing, marketing)

The decision to keep peer-review articles over other forms of literature was that the former typically supersede the latter in terms of quality. By academic consensus, this distinction elevates them above other sources such as conference proceedings, book chapters, or grey literature, where detail could be lacking or not trustworthy (Ali et al., 2017; Pilbeam et al., 2012). The goal of this Synthesis is not merely to gather data but to locate and integrate insights regarding the underlying mechanisms trigged by an intervention around DfSC or 3-DCE (Denyer et al., 2008, p. 408). Therefore, the focus of the review gravitated towards articles that describe relevant implementations. This typically consisted of methodological approaches that employed case studies or other forms of empirical research. Essentially, any highlighter intervention should pivot around the fundamental themes of DfSC, which include collaborative supply chains (SCs) or the integration of product design decisions, among others.

Figure 3.3 illustrates the selection and evaluation process for the studies adopted for the studies that constitute this Synthesis. From the original keywork criteria on the highlighted academic databases, a total of 141 articles emerged after removing duplicates and title relevance screening to the core objective of this review. Furthermore, an additional 33 articles were added from the recommendations by the AI-tool, Research Rabbit. These articles were transitioned to the reference management software, Zotero, for an intricate review.

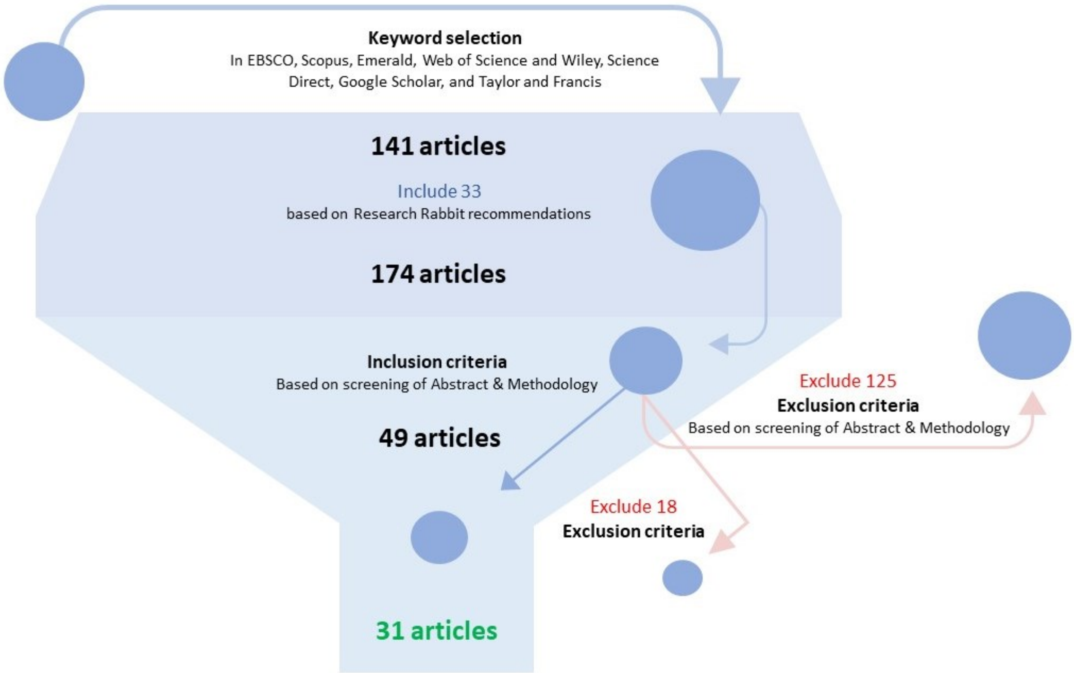


Figure 3.3 – Selection and evaluation process

The cumulative 174 articles were filtered for their publication type. Here, 13 articles were excluded for not being published in pertinent peer-reviewed journals. The remaining articles underwent an evaluation of the abstracts and methodological approach based on the inclusion and exclusion criteria. In this step, a total of 46 articles were rejected since primarily their methodological approach consisted exclusively of online questionnaires, or articles testing models solely in hypothetical case situations, rendering them incompatible with the established protocol. While three additional articles remained unobtainable due to access restrictions, the preliminary assessment of its abstract suggested that their inclusion was not significant. Beyond this, a group of 11 articles was discarded for replicating or echoing very similar cases across different publications.

Following the final screening process, an additional 52 articles were excluded from a quality assessment, based on Miles and Huberman (1994), around their content and relevance to the main objective of this research synthesis. The main motives are delineated as follows:

- Articles that focus exclusively on a single dimension of the 3-DCE concept. Despite only implementing the processes of DfM, the work of Mottonen et al (2009) was included given its grand similarity to DfSC.
- Articles that, while addressing innovation, competitiveness, or SCM performance, do not study these topics in NPD contexts.

- Articles largely related to sustainability research. The work of Dekoninck et al (2016) was included since the intervention on implementation of Eco-design could provide important insights into the implementation of DfSC.
- Articles where the intervention was implemented only in sectors whose product or manufacturing processes are not complex, such as the fashion industry.
- Articles focusing exclusively on Information Systems, Product Design, or other research fields not offering relevant contributions to current topic.

This process returned a total of 49 articles for a comprehensive review of their case study description and discussion chapters. Additional quality criteria resulted in a final sample of 31 articles selected for extraction of the data in the subsequent sections.

Prior to proceeding to the coding classification and data extraction of the reviewed case studies, a descriptive analysis of the articles is provided. This preliminary analysis is critical for placing the findings of this synthesis within its proper context. It has been observed that the 31 articles are fairly distributed across the 22-year period under consideration, as shown in Figure 3.4. Moreover, the articles in question were published by a total of 22 academic journals, with a mere maximum of three articles published by the same journal, as detailed in the overview of academic journals in Table 3-B. Such a distribution lends weight to the previously noted scarcity of empirical research on the topic of 3-DCE, as was attested in Chapter 2.

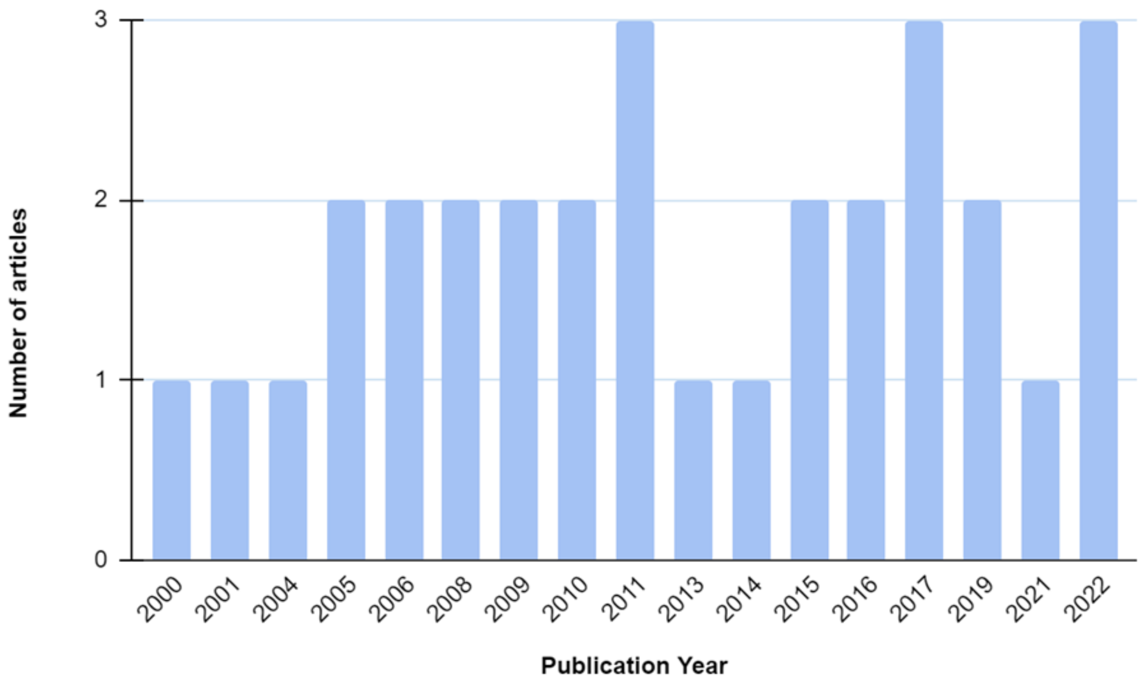


Figure 3.4 – Distribution of the reviewed articles in the Research Synthesis

Table 3-B: Journal outlets of the reviewed articles

Academic Journal	**No. of articles**
Industrial Management & Data Systems, International Journal of Operations & Production Management, Journal of Technology Management, Journal of Purchasing and Supply Management	3
International Journal of Production Research	2
Benchmarking: An International Journal, Business Process Management Journal, Business Strategy and the Environment, CIRP Annals – Manufacturing Technology, *E a M: Ekonomie a Management*, Human Factors and Ergonomics in Manufacturing, International Journal of Physical Distribution & Logistics Management, International Journal of Productions Economics, Journal of Cleaner Production, Journal of Engineering and Technology Management, Journal of Operations Management, Production, Planning & Control, Strategic Management Journal, Supply Chain Management: An International Journal, The Journal of Supply Chain Management, World Academy of Science, Engineering and Technology	1
Total	**31**

The contextualisation of the evidence remains a cornerstone of the realistic review as outlined by the CIMO logic of Rousseau et al. (2008). Hence, characterising the industrial sector pertinent to each case study assumes a particularly relevant component of this descriptive analysis. Given the diversity inherent to the reviewed cases, this categorisation presents a challenging process. For the purpose of the review, the various industry sectors have been grouped into 13 coding classifications, as listed in Table 3-C. The total number of industry sectors found in the reviewed articles stands at 45, with the occurrence of multiple industries studied within a single article. Notably, the Automotive, Motor, Aerospace and Defence Industries represent approximately 30 percent of the total number, a figure that aligns with prior observations regarding the academic interest that characterises these two sectors (Reitsma et al., 2023; Messina et al., 2020). The selected articles, nonetheless, represent a very diverse set of industries, enhancing the potential to draw persuasive evidence towards the objectives of this review.

Table 3-C: Listing of the Industrial Sectors present in the Research Synthesis

Sector ID
Automotive & Motor Manufacturing Industry (8), Aerospace & Defence Industry (5), Industrial & Consumer Manufacturing (4), Furniture & Home Appliances Industry (3), Electronics Industry (3), SMEs Manufacturing Projects (3), Apparel Industry (3), Ship Manufacturing Industry (2), Semiconductor Industry (2) Paper and Printing Industry (2), Plastic Manufacturing Industry (2), Telecommunication Industry (2), Other Manufacturing Industries (6)

NOTE: Other Manufacturing Industries comprises sectors such as Casting, Healthcare, Chemical, Construction, High-Performance Manufacturing, and other Manufacturing Products

3.4 Extraction of the data and Synthesis of the findings

This section endeavours to capture the underlying mechanisms, both positive and negative, inherent in the case studies of each article to discern their effects under various circumstances (Tranfield et al., 2003; Pawson, 2002). Earlier it was noted that this review was conducted by interpretation, a decision driven by the data and goal at hand. Specifically, the option to confine the synthesis to peer-reviewed, published case studies, and not a more diverse range of data. Such decision, however, did not impede the overarching objective: to reinterpret original cases and generate fresh insights that bolster the understanding of DfSC adoption, all whist ensuring the integrity of the initial studies, as advocated by Rousseau et al. (2008). Their paper suggests that the aim of this form of synthesis is to build generalised themes, subsequently classifying these into tentative categories based upon emerging patterns. Labelled as thematic synthesis by Boaz et al. (2006), they warn that this form is intrinsically dependent on "primary studies that provide a deep and rich description of the case". Moreover, they highlight that the coding system is deeply reliant on the research team's skills, rendering reproducibility a considerable challenge. Yet, the review selection is often moulded by the nature and accessibility of primary research (Boaz et al., 2006). Consequently, given the premeditated effort to focus on qualitative empirical studies, synthesis by interpretation emerged as the method of choice.

Integral to this form of synthesis are elements of meta-ethnography, defined by Noblit and Hare (1999) as the synthesis of interpretive research. This implies putting together the ideas of the many case studies in an interpretive rather than aggregative way. Consequently, a systematic extraction process for the selected 31 articles was deployed, wherein a summary of the reviewer's own interpretation of each article was introduced into a spreadsheet. This spreadsheet was organised under three primary headings: descriptive, methodological, and thematic. The descriptive section encapsulated details such as publication year, authorship, title, academic journal, publisher, and the specific industry or sectors highlighted in each case study. Under the methodological header, which played a pivotal role during the screening phase, the primary focus was to detect the unit of analysis of the case studies: single or multiple. Meanwhile, the thematic categories were mapped based on the sub-questions presented earlier in this chapter. The five questions that shaped the forthcoming categories are presented next.

1. What is the proposed intervention in this case study?
2. What was the expected outcome of the proposed intervention?
3. How successful or unsuccessful was the intervention?
4. What would be the required mechanisms for a successful intervention?
5. What were the friction mechanisms or challenges identified in the implementation process?

The coding process was meticulously undertaken by the author of this Thesis, in coordination with the supervisory team, following similar standard practices used by Pilbeam et al. (2012). The coding rationale is delineated in Table 3-D, in which two main categories emerge from the process: methodological and thematic. Regarding the "methodological" category the coding classification encapsulates the unit of analysis of the cases under scrutiny. That is, single analysis which consists of articles that clearly limit their analysis to a single NPD project or industry; and multiple analysis which are those that examine and compare different NPD that may span diverse industries. Whereas the "thematic" category is organised into a coding classification according to elements of the previous five questions: type of intervention, expected outcome, the actual results of the intervention, the requirements for a successful intervention, and the friction mechanisms or challenges in the intervention.

The type of interventions identified in the reviewed cases were divided into five coding categories. The interventions 'process redesign', 'technology support', and 'framework adoption' are intended to primarily impact the focal organisation, while 'extended involvement' places the focus of the intervention on the external dimension of the organisation, and 'strategic alignment' is a coding dimension where the focus intends to impact the balance of both internal and external aspects of the organisation.

The distinction between interventions and expected outcomes is that the former relates to a planned action or artefact in a specified area of the project, and the latter relates to the area that is expected to be improved by the intervention. Nonetheless, there is an anticipation that both categories would be aligned. The outcome of the intervention can be accomplished, not accomplished, and partially accomplished. In articles with multiple units of analysis, partially accomplished outcomes can be those where not all the studied organisations successfully achieved the expected outcomes.

Table 3-D: Methodological and Thematic Classification for the Research Synthesis, based on Pibeam et al.(2012)

Methodological Category	**Coding Classification**	**Rationale**
Unit of analysis	Single analysis	Study of a single organisation, a single network, or a single NPD project
	Multiple analysis	Study of multiple organisations, multiple industries or multiple NPD projects
Thematic Category	**Coding Classification**	**Rationale**
Type of Intervention	Process Redesign	Putting in place new operational processes for the NPD projects
	Technology Support	Developing new tools (such as IT systems) to enhance NPD performance
	Framework Adoption	Adopting new Frameworks in NPD projects (internal to the focal company)
	Extended Involvement	Implementing Collaborative Supply Chain principles in NPD projects (External to the focal company)
	Strategic Alignment	Promoting the alignment of the NPD project goals with the stakeholder's long term strategy (not limited to collaboration)
Expected Outcome	Upstream	Improving NPD performance from the Supplier side
	Downstream	Improving NPD performance from the Customer side
	Focal Company	Improving NPD performance of the focal company
	Holistic	Improving NPD performance of the whole network chain
Outcome of the intervention	Accomplished	The intervention was successful
	Not accomplished	The intervention was not successful
	Partially accomplished	The intervention was partially successful

Table 3-E provides a summary of the underlying mechanisms identified from the research synthesis, offering definitions and presenting evidence from the reviewed studies. Some mechanisms were derived by the author from previous literature, while others were identified during the reviewed process and are presented in the table. A comprehensive understanding of these mechanisms is a critical initial step for addressing the implementation gap, as this research attempts to do.

Table 3-E: Underlying Mechanisms identified in the Research Synthesis

Underlying Mechanisms	Definitions	Evidence from the Reviewed studies
Perception Asymmetries	The differences in perception about concepts and cost-benefit trade-offs (Mena et al., 2020)	Golrizgashti et al., (2022); Mikkelsen and Johnsen (2019); Mello et al. (2017)
Strategic Planning	Devised framework for aligning product development strategy and business-level competitive strategy (Brown and Blackmon, 2005)	Ellram and Stanley (2008); Lee and Kim (2011); Boardman and Clegg (2001)
Organisational Culture	The cultural and structural aspects in relation to an organisation's orientation towards competing values and beliefs (Liu et al., 2010)	May et al. (2000); Mottonen et al. (2009); Vayvay and Cruz-Cunha (2016)
Collaborative Orientation	Ensuring a guiding behaviour towards collaboration at the appropriate time (Eng, 2005)	Eslami and Melander (2019); Golrizgashti et al. (2022); Van Echtelt et al. (2008)
Trust Mechanisms	Ensuring a level of trust among the project stakeholders. (Fawcett et al., 2012)	Ateş et al (2015); Eisto et al.(2010); Caridi et al. (2017); DeCampos (2022)
Incentive Structures	Promoting incentives & risk sharing mechanisms for supplier participation (Fawecett et al., 2012)	Mello et al. (2017); Hald and Nordio (2021)
Power dynamics	The effects of power imbalances between organisations (Cadden et al., 2013)	Khan and Creazza (2009); Vayvay and Cruz-Cunha (2016); Golrizgashti et al. (2022)
Leverage Learning	Disseminating lessons learned (Emerged from Review)	Boardman and Clegg (2001); Sharifi et al. (2013)
Lifecycle Perspective	Having a lifecycle or long-term view of the product design process (Emerged from Review)	Zsidisn and Smith (2005); Mikkelsen and Johnsen (2019)
Visibility of SC implications	The degree of awareness regarding supply chain risks and implications (Emerged from Review)	Sharifi et al. (2006, 2013)
Communication Systems	The data and information-sharing systems present in the project (Emerged from Review)	Mottonen et al. (2009)
Knowledge Pool	The set of technical and organisational knowledge required for the project (Emerged from Review)	Khan and Creazza (2009); Parmigiani et al. (2022)

3.5 Thematic Reporting

This section summarises the thematic findings from the reviewed articles, thus complementing the literature review on 3-DCE undertaken in the previous chapter. It specifically offers a realistic synthesis of the case studies examined, delving into the type of interventions targeted and the expected outcomes. Its purpose is to facilitate a nuanced understanding of the dynamics driving the adoption of DfSC type of interventions. While a detailed examination of the underlying mechanisms that comprise the proposed conceptual framework is reserved for the following section, the insights provided here are important for the appreciation of the contextual factors influencing these interventions. These insights, in turn, also support the development of the "Powertrain Game", which is presented in Chapter 7.

The types of interventions reviewed within this synthesis have been grouped into five distinct categories, each aimed at to improving or enhancing NPD performance outcomes. The first category, “Product Redesign”, focuses on interventions aimed at the reconfiguration of the operational processes. The second category, ‘Technology Support’, involves the development of new technological tools that contribute to the stated aim. The third, ‘Framework Adoption’, regards the application of academic framework as central to the intervention. In the fourth category, ‘Strategic Alignment’, the emphasis is to promote the long-term strategic goals at either a functional or organisational level. The fifth and final category, “Extended Involvement”, primarily seeks to embed collaborative principles into the NPD projects. The distribution of these thematic categories across the reviewed article is available for consultation in the Appendix 11.2.

Process Redesign

The ‘Process Redesign’ category encapsulates primarily the actions of a focal company as the single unit of analysis. A total of eight articles were included in this coding category. Notably, intersections between this and other categories are evident, with two of those articles concomitantly aligning with the ‘Technology Support’ category and another with ‘Framework Adoption’.

These interventions often do not extend beyond the focal company’s point of view. Key among these is the work of Ellram and Stanley (2008), who investigated five companies deploying SCM interventions in conjunction with strategic cost management to bolster supply chain responsiveness, diminish expenses, and ensure competitive advantages. These efforts were essentially customer-driven, with only a small portion of the benefits passed on to the suppliers. Moreover, the authors identified an implicit expectation placed upon these supplies to synergise with upstream entities to amplify the advantages procured from these process redesigns.

Johansson and Johansson (2006) scrutinised the processes of a manufacturer in the automotive sector, particularly tracing material flows from suppliers to assembly lines. This study found strategic dilemmas inherent in redesigning material supply systems to align with new product development processes. Likewise, May et al. (2000), in a study of European automotive supply chains, report on organisational barriers from divergent perspectives of engineers across different supply tiers.

Meanwhile, Ketokivi et al. (2017) embarked on an extensive examination of 35 distinct value chains to discern how product architecture and functional interfaces (coupling), investment specificity, and standardised procedures influence location decisions. Their findings elevate the coupling factor as a pivotal determinant in these decisions, suggesting a stronger influence of the product architecture on NPD decision-making. Similarly, Lau et al. (2005) explore product modularisation at a multinational electronics firm. The study further highlights the interplay between product characteristics and supply chain coordination, particularly for the design of modular and innovative products that introduce additional supplier tiers and require intensive communication.

In evaluating the adoption of DfM processes within an ICT company, Mottonen et al. (2009) identified significant internal communication barriers. These were primarily attributed to a fragmented understanding of the requirements among the various stakeholders as well as cultural differences across the organisation. Also, Mikkelsen and Johnsen (2019) studied the involvement of the purchasing function in technologically uncertain NPD projects. Particularly, they observed that when redesigning their own processes by working closely with the R&D department in new technology sourcing or breakthrough scanning the benefits were clear. However, they emphasise the need for a mature and competent purchasing function within the organisation to ensure a successful implementation. The reported functional dynamics, in both cases, underpins the argument for fostering internal competencies and promoting an openness to collaboration.

In synthesising the articles grouped under this thematic category, certain underlying mechanisms critical to successful interventions have begun to emerge. Notably, there is an indication of the necessity for a strong collaborative orientation alongside the need to bring the gaps in functional perceptions. The collaborative orientation, in particular, is coming through as a significant factor in enhancing performance outcomes, pointing towards the value of cultivating cooperation among stakeholders involved in the NPD process. Equally, addressing perception gaps across different functions emerge as a crucial element, hinting at the need for a more integrated understanding of roles, processes, and goals within NPD. These insights highlight the complex interplay inherent to these projects, and signal how such mechanisms can be consciously cultivated and embedded within NPD practices.

Technology Support

The employment of technological tools into NPD is an important strategy to bolster performance, as evidenced by the ‘Technology Support’ category. This category grouped a total of six reviewed articles, including three previously mentioned works (Mikkelsen and Johnsen, 2019; Lau et al., 2005; May et al., 2000), underscoring the multifaceted role technology plays in product development.

Specifically, Appelqvist et al. (2004) underline the significance of incorporating supply chain modelling early in product development. By examining an aircraft component manufacturer, their research demonstrates the benefits of employing technology to capture the advantages of concurrent engineering. For instance, their simulation model allows for optimally scheduling investments in costly manufacturing equipment. This approach stems from decision-making processes that consider the entire product lifecycle, extending from the initial design concept to full-scale production.

In the same category, DeCampos et al. (2022) studied the dynamics of collaboration and transparency within integrated NPD projects across six case studies. They employed an assessment tool which measure the gaps in collaboration expectation, particularly through the lens of the purchasing entity. The core finding suggests that the strategic timing of supplier involvement is more critical for enhancing NPD performance than the mere act of early inclusion. Moreover, Golrizgashti et al. (2022) introduce a strategic tool aimed at determining product deletions with particular emphasis on environmental factors. This tool is based on a three-phase Quality Function Deployment (QFD) framework, integrating the customer's voice into the data to address the complexities brought about by the focal company's extensive product variety. Both cases highlight the benefits of technological support in enhancing NPD outcomes.

Collectively, the reviewed studies under this thematic category illustrate that the employment of technology into NPD projects is not isolated, but rather it is intrinsically connected with other categories. These tools enable early discernment of product visibility, support appropriate timing for collaboration, and promotes a product lifecycle perspective along with strategic goal planning. Thus, this category reveals similar underlying mechanisms inherent to these types of interventions, further elucidating their embedment in NPD projects.

Framework Adoption

Whitin this thematic category, the imperative of integrating theoretical frameworks into organisational processes is paramount. This review encompasses nine articles, five of which are cross-referenced with other categories. Specifically, Marsillac and Roh (2014), grounded in the 3-DCE framework, investigate process and supply chain redesigns resulting from product design alterations in four firms. Their findings reveal the profound influence of product design alterations in the manufacturing processes and supply chain designed to serve the new product. Additionally, they reveal that these changes are often preceded by external constraints such as competition, consumer trends or technological advances.

Khan and Creazza (2009) advocate for a framework of organisational change, encapsulating co-location, cross-functional teams, a champion for the product range, and cooperation within the extended enterprise, to address downstream supply chain issues and propel the move towards a "design-centric business" approach. Additionally, Mello et al. (2017) apply the CATWOE soft-systems method to a complex shipbuilding collaboration, enhancing clarity in role delineation and system structuring. In parallel, Hald and Nordio (2021) tackle the tension between creativity and efficiency, revealing a framework based on five factors: supplier integration, reward structures, absorptive capacity, alignment strategies, and NPD project organisation. This framework, evidenced through a case study in a healthcare organisation, underscores the need for meticulous risk assessment and the delicate balancing act required for successful interdepartmental collaboration.

Furthermore, Pero et al. (2010) contribute to this category by analysing an electrical appliance multinational's challenge in adapting its supply chain to a new product line. Their proposed NPD-SCM alignment framework correlates NPD variables with SCM intricacies, highlighting that judicious product design can mitigate supply chain complexity and improve performance. Conversely, Sharifi et al. (2006) focus on strategic and operational levels with their own DfSC framework, which they validated against four SMEs producing bespoke products. This analysis revealed a significant reliance on suppliers and highlighted the importance of integrating NPD and SCM processes to navigate dynamic markets effectively.

Finally, Van Echtelt et al. (2008) conduct an in-depth study of Dutch manufacturers, applying an activity-based framework to elucidate strategic and operational supplier involvement in NPD. Their findings accentuate the critical nature of planning activities in risk management and the essential role of product management in leveraging supplier technologies.

Again, the reviewed studied reaffirm the emergence of mechanisms in programmes for enhancing NPD efficiency and fostering robust interorganisational dynamics, with long-term collaboration, risk assessment and continuous alignment being pivotal within this thematic category.

Strategic Alignment

The reviewed cases, under this category, do not confirm their scope to a singular NPD priority but rather a broader spectrum of product development decisions. Consequently, the unit of analysis often encompasses on multiple cases, each bearing holistic implications. Six articles follow under this theme, with three, those by Van Echtelt et al., (2008), Dekoninck et al., (2016), and Hald and Nordio (2021) having been previously addressed.

For instance, Sharifi et al. (2013) outlined a growth strategy implemented across four SMEs manufacturing companies, integrating both short and long-term SCM strategies with market and product strategies. The study underscores the consequences of not proactively considering SCM implications in NPD, indicating considerable missed opportunities and potential for incurring additional project costs. Initially, proactive supplier engagement could have prevented reactive problem-solving and associated development delays. Subsequently, early-stage communication might have spared one firm from relinquishing IP rights to a component design partner. However, the absence of robust absorptive technology and knowledge processes was seen to hinder early supplier involvement in the growth strategy, culminating in missed opportunities.

Similarly, Caridi et al. (2017) investigated, through an analysis of seven NPD projects, the interdependencies between information dissemination to partners during NPD and the subsequent outsourcing decisions. Contextual factors such as the location of partners, the degree of their integration, mutual trust, and ICT support, were identified as critical elements in shaping the visibility of the design chain. All in all, they find that early supplier involvement in product design does not affect node visibility. Instead, it is influenced by the level of trust, mechanisms for sharing risks, and the partners' requirements for information exchange.

Ultimately, the study by Parmigiani et al. (2022) offers a unique angle, concentrating on the effort of the motorhome industry, as a whole, to develop "greener" innovative products. This review examines the interplay between the firms' technical expertise, their relationship management capabilities with their ability to innovate and respond to disruptions. The dynamic synergy between supplier relationships and manufacturing capabilities is posited as a strategic advantage for the development of comprehensive products and component-based innovations alike. However, it is imperative for firms to carefully consider their innovation trajectories when investing in capabilities: superior supplier relationship management is crucial for innovative component development, while robust manufacturing capabilities are indispensable for full product innovation.

Under the umbrella of 'Strategic Alignment', several new underlying mechanisms have emerged. These mechanisms relate notably to the leveraging and investment in stakeholders' capabilities, the development of trust mechanisms, and establishment of incentive structures that encourage risk sharing. Yet, certain mechanisms continue to exert influence over these strategic interventions, among them are the necessity for a collaborative orientation and risk visualisation across the supply chain.

Extended Involvement

The aim of this last thematic category is to implement collaborative principles in NPD projects. Given the nature of the research synthesis, it is not surprising that this category encompasses the majority of the reviewed articles, with thirteen studies falling under this theme. Therefore, the remaining eleven studies are described here.

Commencing with Ateş et al. (2015), the research uncovers the intricate dynamics of design agencies, buying firms, and component suppliers, offering an extensive evaluation of inter-organisational coordination in a triadic setting. Their findings underscore the necessity of understanding partner interactions, influenced by factors such as novelty, design approach, partner involvement, and communication intensity. Similarly, Boardman and Clegg (2001) pioneer the study of the "extended enterprise" concept, applying the EE grid to Rolls-Royce, to enhance the product introduction process and supplier relationships. This strategic advancement underscores the value of cross-boundary collaboration and well-established processes to achieving stronger relationships with suppliers. Also at Rolls-Royce, Zsidisin and Smith (2005), advocate for early supplier involvement as a means to mitigate supply risk and ensuring the alignment of capabilities within the design cycle, emphasizing the need for meticulous planning and management.

In the realm of sustainable innovation, Dekoninck et al. (2016) emphasise the critical need for both internal and external collaboration, urging businesses to change the nature of buyer-supplier relationship for improving the environmental performance of their organisations. Eisto et al. (2010)'s examination of the casting industry reinforces this perspective, highlighting the imperative for clear NPD processes and early supplier engagement to facilitate high-quality information exchange and trust-building. Often customers contacted foundries too late due to a lack of trust between the parts, causing poor quality of information exchange.

Eslami and Melander (2019) scrutinise the collaboration between two leading technology firms, unveiling challenges like product complexity and knowledge transfer. Specifically, the study highlights the buyer's lack of organisational structure for cross-functional teams to operate. Their findings underscore the importance of establishing communication systems between the departments involved in the project. While, Vayvay and Cruz-Cunha (2016) highlight the strategic importance of supplier engagement in NPD within the semiconductor industry, revealing a trend towards joint R&D activities that enhance resource efficiency and cost management.

In a shift towards consumer-focused value, Hilletofth and Eriksson (2011) document a Swedish furniture company's strategic pivot, intertwining SCM with NPD to enhance market responsiveness. In another case, Lee and Kim (2011) study eight green innovation projects within the semiconductor industry, delineating the critical nature of problem definition and supplier capability in achieving successful outcomes. Furthermore, they found that establishing partnerships with supplier with capabilities becomes a critical for competitive advantage.

Moreover, Tuli and Shankar (2015) evaluate product development approaches in the automotive industry. Particularly, they conducted a value stream mapping to compare conventional lean to new collaborative approaches. Their findings demonstrate that the success of the novel approach depends on the stakeholder willingness to collaborate and mitigate inter-organisational barriers. In a similar vein, Váncza et al. (2011) address the need for a socio-technical framework, striving for equilibrium between conflicting perspectives.

In essence, these studies reinforce the premise that successful NPD interventions are intricately linked to underlying mechanisms such as quality and depth of collaboration. Moreover, the synthesis of these articles underlines a distinct spectrum of mechanisms that advance this effort. Central among these are the formulation and execution of strategic plans, the development of knowledge pools that strengthen partners' capabilities through the diffusion of lessons learned. Furthermore, these collective findings suggest that the fortification of relationships is predicated upon the established of mutual trust. The subsequent section will explore the interplay between these fundamental mechanisms, devising a roadmap for the implementation of DfSC principles.

3.6 Conceptual Framework

3.6.1 The underlying mechanisms in DfSC implementation

The previous section outlined the thematic categories that emerged from the type of interventions of the reviewed studies. Such interventions aimed at enhancing NPD performance outcomes either by redesigning processes, devising technological support tools, applying theoretical or conceptual frameworks, aligning operational and strategical dimensions, or extending the scope beyond the focal company. Yet, all reviewed cases displayed a common effort, which highlights the importance of DfSC for successful implementation. The previously identified common factors are the underlying mechanisms that the first research question seeks to uncover.

The compilation of the reviewed cases is a rich source of insights into a variety of interventions and outcomes that are trigged by those mechanisms. As described before, many of these studies revolve around the topics of early supplier involvement and collaboration across various stakeholders in the design and production process, as well as the application of specific strategies to enhance the performance of NPD projects. The task now is to identify the outcome of those interventions. This is not a straightforward task as in many cases the results are not always discussed and reporting on failures is very scattered (Sternberg et al., 2022). However, the work of synthesising the outcomes of the case studies can provide useful cues the allow the reviewer to understand the connections between mechanisms and in what contexts are they prompted.

The overall findings appear support that the message that promoting a **collaborative orientation** within NPD projects often lead to efficiency gains, meaning successful interventions. For instance, Eslami and Melander (2019) found that successful NPD projects were those that only involved technical experts but also included functions such as purchasing and sales. Furthermore, Golrizgashti et al. (2022) emphasised the importance of cross-functional collaboration for aligning business and supply chain strategies. Particularly, Van Echtelt et al. (2008) highlight that the firm's ability to achieve both short-term targets and long-term benefits is contingent on the success of involving suppliers in product development. This reviewed case studies reflects that the predisposition to timely engage with suppliers provides valuable inputs for products design and manufacturing planning that mitigates future risks throughout the product lifecycle.

The concept of “orientation” refers to the guiding behaviour towards a given phenomenon or philosophy, and research has shown an important role in the implementations on the supply chain management domain. For example, going back to the literature review of the previous chapter, Eng (2005) found that a firm’s cross-functional orientation is a critical factor in achieving customer satisfaction and supply chain responsiveness. The synthesis in this chapter suggests a similar narrative: that cultivating collaborative orientation is instrumental for the adoption of DfSC principles.

Yet, fostering a collaborative orientation appears to be subject to another important mechanism: **organisational culture**. According to Liu et al. (2010) organisational culture could be categorised in relation to their orientation towards competing values and beliefs, such as internal or external focus. Some studies confirm that organisational culture has an impact in supply chain integration (Dadzie et al., 2017; Ganbold et al., 2017). Hence, it was considered relevant to acknowledge the role of organisational culture in the orientation towards DfSC principles in the reviewed cases.

Organisational culture encapsulates a range of norms and behaviours, for instance how information is shared, and decisions are made within the teams involved in the NPD projects. Mottonen et al. (2009) illustrate how cultural differences impact the implementation of DfSC, hinting at challenges posed by changes in the organisations. These changes entail a culture of adaptability and learning for successful communication. Equally, May et al. (2000) understood that cultural shits and organisational restructuring towards collaboration would be required before the implementation of their proposed system. To sum up, the case presented in Vayvay and Cruz-Cunha (2016) shows how increasing the joint activities between the different participants in NPD projects shifted the embedded culture towards openness and support. This transformation allowed the case company to rapidly adapt to technological changes that characterise the semiconductor industry.

The cultural transformation of organisations is not, by its own nature, an easy process. As point out by Khan and Creazza (2009), the fear of losing control over their processes particularly in smaller organisations can be a significant impediment to embracing a culture that promotes collaborative orientation. There is a need for a conscious strategy for this transformation to happen, a planning that is based in other mechanisms such as knowledge creation and leverage the created learning. Therefore, **strategy planning** is, yet, another underlying mechanism that impacts successful DfSC interventions.

Strategic planning in the realm of NPD is paramount for guiding the intricate network of activities and decisions that lead to successful product launches. This sentiment is echoed by Ellram and Stanley (2008), which asserted the benefits of integrating strategic cost management with 3-DCE principles for a deeper understanding of cost drivers and a value chain analysis, underscoring the strategic nature of cross-functional teams and supplier development in NPD activities. The challenge, however, as identified by Tuli and Shankar (2015), lies in establishing and maintaining governance mechanisms that foster collaboration. Particularly, they mentioned the need to create collaborative databases for joint benchmarking efforts. The role of strategic planning is thus not only to steer the project but also bridge the gaps between various stakeholders, including suppliers, as demonstrated by Lee and Kim's (2011) on the significance of supplier capabilities and relationships in strategic decision-making.

Likewise, Boardman and Clegg (2001) describes the "us and them" syndrome, which presents a friction mechanism towards DfSC thinking that strategic planning must address. They argue that the incorporation of holistic thinking and constant promulgation of lessons learned can mitigate such challenges, reinforcing the efficacy of strategic reviews and mature internal processes. Sharifi et al. (2013) further elaborate on this mentality and struggles to align diverse functional responsibilities. Particularly, in SMEs that tend to overestimate their own ability to deal with potential supply chain problems, which, if not strategically managed, can derail the NPD process. In conclusion, the research synthesis underscores that strategic planning in NPD projects is not merely about setting objectives but rather anticipating and mitigating challenges.

The *"us and them"* syndrome encapsulates a recurring theme of this synthesis, that is the existence of **perception asymmetries** or mismatches in understanding project objectives. There are many trade-offs to consider in NPD projects: from balancing cost, quality, development speed, innovation, and risk, or focusing on the current market demands versus future opportunities. Furthermore, aligning all stakeholders on how these trade-offs are managed as well as their understanding of the concepts can lead to diverting priorities and potential conflict or inefficiencies. Hence, understanding and closing perception gaps in the development of new products is an essential mechanism for incorporation DfSC principles. For instance, in the Golrizgashti et al. (2022) study, product variety was seen by some departments as a source of differentiation and value, but for other as a source of complexity and cost, underscoring an important gap around what constitutes cost or value in product development decisions.

Another significant mismatch arises from the distinct perception of capabilities. Companies may underestimate or overestimate a supplier's ability to contribute to the project, leading to gaps in expectations and outcomes. Mello et al. (2017) and Mikkelsen and Johnsen (2019) provide clear evidence of the impacts of perception asymmetries. Mello et al. (2017) highlight how reluctance to acknowledge capability limitations or to communicate errors can erode trust over time. On the other hand, Mikkelsen and Johnsen (2019) demonstrate the disparities in partners' perceptions regarding the strategic significance of various investment cycle stages. Additionally, Zsidisn and Smith (2005) offer an interesting contribution to this discussion. They argue that mismatches in the partners' perception of supply chain risk constitute a potential friction point. In sum, distinct interpretations or estimations of threats related to cost, quality, or delivery, as well as different reactions to change and leadership issues can potentially cause serious disruptions to NPD projects.

Building on this synthesis, it becomes evident that in the context of DfSC interventions, addressing perception asymmetries requires strategic planning to change organisational culture and cultivate a collaborative orientation. These four mechanisms identified in this section are essential in guiding the successful adoption of DfSC interventions. However, their implementation is complex, involving persistent efforts to navigate its intricacies and interdependencies. Beyond these four, additional underlying mechanisms, initially introduced in Table 3-D and depicted in Figure 3.5, play a significant role in determining the success of these interventions. As the discussion transitions to the final section of the Research Synthesis, the interdependencies between these mechanisms are explored, employing a Soft-Systems approach. This will lead to the proposal of a roadmap for DfSC implementation, which forms the conceptual framework of this Thesis.

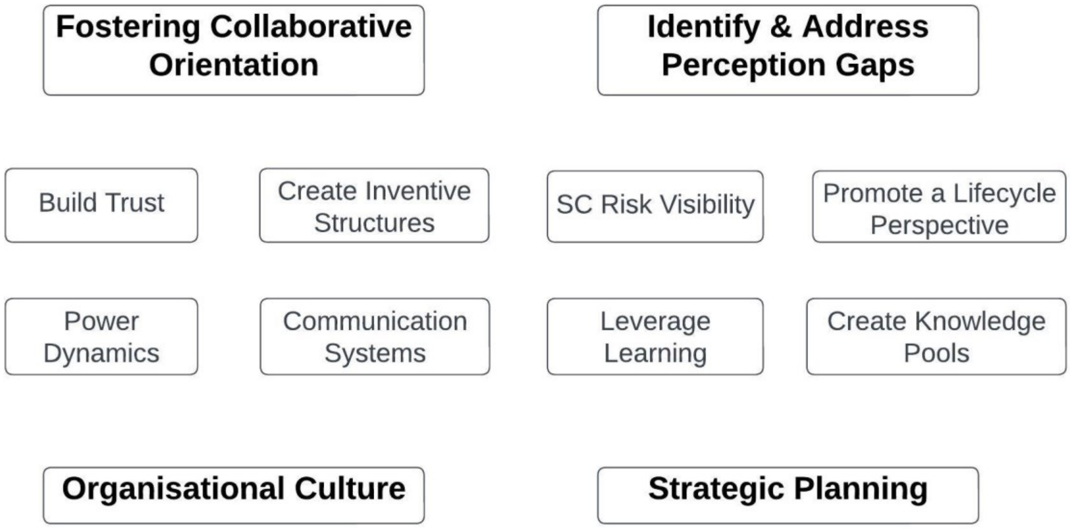


Figure 3.5 – Emerging mechanisms from the Research Synthesis

3.6.2 A Roadmap for DfSC implementation

The fundamental conclusion from the review of selected case studies is that the successful implementation of DfSC is a complex process, where a substantial number of friction mechanisms are activated. The framing of this problem as a system approach can assist organisations in their pursuit for the understanding of the interdependence between these mechanisms. Boardman (1995) captures this sentiment, recognising in a system the concept of hierarchy that is characterised by different levels of complexity within the system, and the concept of boundary, which relates to the limits of the systems under consideration. The process of uncovering the underlying mechanisms in this Research Synthesis is in a way a form of boundary construction in systems thinking.

This resonates with the near-decomposability idea of Simon's (1969) science of the artificial. By using Sarasvathy (2003) paper to explain this idea, it states that a complex system should be constructed as a 'box-within-boxes' form. That is, one should decompose the whole system into hierarchies, semi-independent components corresponding to its many functional parts. In a nearly decomposable system, each component subsystem is approximately intendent to the other components in the short run, this is important because it provides a level of specialisation and for a specific problem a solution can be focus on a single component. In the long run the behaviour of any one of the components depends in only an aggregate way on the behaviour of the other components, meaning that you cannot eliminate any of the components of the system, and a complete description of the system is necessary for theory building. In fact, this need to synthesise and analyse the complexity behind DfSC implementation is at the core of the design-science research strategy of this Thesis, presented in Chapter 6.

Checkland (2000) proposed a Soft-Systems methodology, which is a form of human activity systems thinking that assumes the word as a learning system. The process is characterised by activities such as rich picture building, which involves making drawings to indicate the many elements in the complex system. According to Checkland and Poulter (2020) the purpose of this method is to learn about a situation, create activity models to ask questions and ultimately finding desirable and feasible changes. Two of the reviewed articles from this synthesis employed similar methods to structure their case problem (Mello et al., 2017; Boardman and Clegg, 2001).

Drawing from this methodology, Clegg (2007) developed a technique, labelled process oriented holonic (PrOH) modelling, for real-life application of systems thinking in business process design. The name originates from the term “holon”, or a part of a larger system, described by Clegg and Shaw (2008, p. 449) as a model of a human activity system (e.g. a business process) that contains all the fundamental systems thinking principles. The advantage of using PrOH modelling is that addresses the inherent insufficiencies of soft to explain the relationships between sub-systems, by building holonic descriptions from lower-level systems to higher-level models. Those descriptions allow the researcher to create a storyboard that can be re-interpreted, and re-contextualised by the relevant stakeholders.

In this case, the storyboard structures the identified mechanisms into a roadmap for DfSC implementation that will be validated in the ensuing research activities. The proposed model, which constitutes the conceptual framework of the Thesis, is depicted in Figure 3.6.

Boardman (1995) proposed a soft-systems framework that consists on the following concepts: partness, wholeness, emergence, and hierarchy. The PrOH modelling proposed by Clegg and Shaw (2008) incorporate some of these concepts, such as resource entities and activity descriptions represented within graphical templates. Albeit they build a holarchies rather than hierarchies, meaning that they avoid a top-down, reductionist view of systems and embrace a more interconnected and emergent view. Each element of the proposed framework exists in abstraction to fulfil the purpose of DfSC embeddedness into NPD projects, starting from a place where DfSC was not yet implemented. Thus, the holonic template was employed to organise and illustrate this roadmap.

The individual resources of the system are the underlying mechanisms uncovered in the review synthesis, with the four previously explained mechanisms playing a pivotal role in the system. The emergence refers to the behaviours or feedback loops that emerge from the interactions within the systems, as represented in the connected arrows. While the holarchies are represented by the different layers. For instance, collaborative orientation is observed at a lower level of organisational culture with trust mechanisms completing the sub-system.

Nevertheless, each resource exists in abstract, that is, it exhibits properties that cannot be omitted from the conceptual framework.

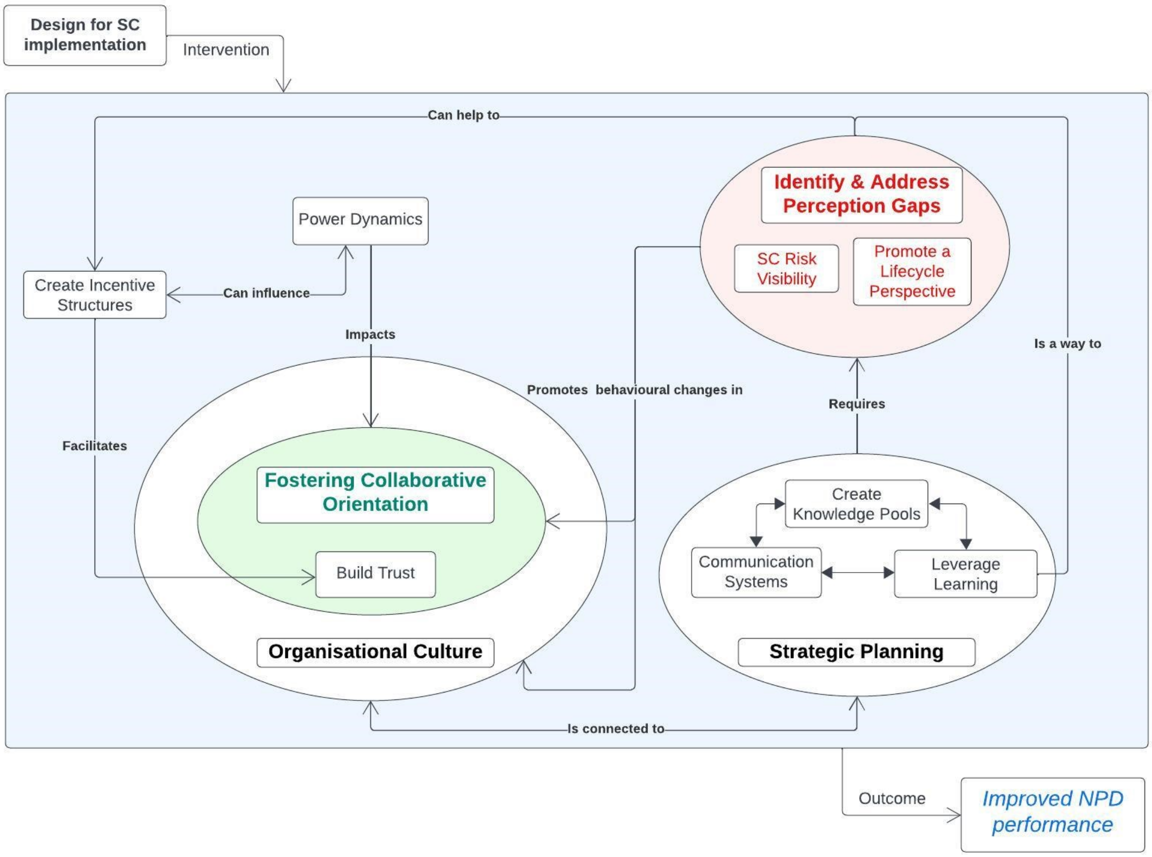


Figure 3.6 – A proposed roadmap for DfSC implementation

Organisational culture, as illustrated by Liu et al. (2010), shapes the company's values and beliefs. Nested within those is the concept of collaboration orientation which, as pointed out by Patel (2013) and Eslami and Melander (2019), is essential for successful DfSC implementations. Completing this hierarchical structure are the trust mechanisms, which act as enablers for a collaborative orientation.

Trust, as discussed by Fawcett et al. (2012), is a catalyst to building and sustaining collaborative relationships. The cases of Ateş et al (2015) and Eisto et al. (2010) demonstrate how trust is essential for effective collaboration, leading to successful NPD outcomes. As highlighted by Lee and Kim (2011), without trust, the potential of collaborative orientation and its position effect in implementing DfSC in NPD project would remain unrealised. Ultimately, Caridi et al. (2017) and DeCampos et al. (2022) suggest that building trusts requires both partners to understand the benefits, risks and costs of the collaboration. Hence, the emergence of an interaction between trust mechanisms and incentive structures.

Fawcett et al. (2012, p. 172) advocate that collaborative trust require partners to share risks and rewards and that partners' needs are taken into account in the decision-making process. Yet, despite this requirement for trust-based relationships, they found that organisations do not actually cultivate such incentive structures. For instance, in the reviewed cases, Mello et al. (2017) established that understanding partners' needs is not sufficient, contractual arrangements that warrant risk-sharing should be re-thought to encourage collaborative working. Moreover, Hald and Nordio (2021) advocate for the creation of joint reward structures internally and with suppliers. They argue that often internal misalignments of those structures originate frictions that produce considerable setbacks in the project.

The existing power dynamics are a conditional factor to the relationships between the participants in NPD projects. The effects of power dynamics on trust and organisational culture are well documented. Ireland and Webb (2007) promote balancing trust with power, however Pulles et al. (2014) yield that the interplay between the two is often more complex than expected. Moreover, power can shape and reinforce organisational culture by influencing the values and behaviours that are rewarded or punished, with Cadden et al. (2013) stating that values such as organisational empathy and accountability can help to mitigate the effects of power imbalances between organisations.

In the synthesis, Khan and Creazza (2009) demonstrate the effects of these power dynamics in fostering collaboration, particularly with smaller organisations fearing loss of control over their processes. In this case, these power dynamics act as a barrier to collaboration. Conversely, Vayvay and Cruz-Cunha (2016) shows an organisation whose dependency to a limited number of raw material suppliers promote the development of strong partnerships and collaboration. Golrizgashti et al. (2022) recognise that a marginalised voice in the decision-making process, can lead to suboptimal implications in the product lifecycle. Hence, despite the existing power dynamics, balancing the diverse voices involved in the NPD team should be a priority.

Strategic planning is another one of the key underlying mechanisms identified in the system. This strategic approach is crucial in orchestrating the complex interplay of activities and decisions essential for successful product development. This planning process, underscored by Ellram and Stanley (2008), involves formulating clear plans that strengthen suppliers' capabilities, incorporating existing knowledge within the project. Therefore, inside this dimension three other mechanisms play integral roles: communication systems, knowledge pools and leverage learning. These parts, each significant in its own right, interconnect to contribute to the overall success of the intervention.

Communication systems, as a part of strategic planning, act as conduits for the flow of ideas and decisions in NPD projects. May et al. (2000) highlight how these systems, particularly computer-supported platforms, support collaborative working between product development team members. Similarly, Boardman and Clegg (2001) underscores the necessity of transparent and efficient communication for overcoming organisational barriers. This aligns with Mottonen et al. (2009) insights on the necessity of standardised communication systems for effective product development projects. Moreover, these systems allow for the creation of knowledge pools, another key mechanism under strategic planning. These essentially guarantee accessibility to a common understanding of capabilities and objectives present within the project. Lastly, applying the knowledge from one project to the next is critical to enhance the strategic and operational capabilities of the organisation involved. This mechanism, as illustrated by Khan and Creazza (2009) and Parmigani et al. (2022), underlines the implications of not developing fine-grained routines for sustaining strategic capabilities. Therefore, in this context, strategic planning is about cultivating an environment where learning, communication, and knowledge sharing are seamlessly integrated.

Fundamentally, this synthesis shows that the implementation of DfSC in NPD projects is intrinsically dependent of capturing, understanding, and closing perception gaps, both functional and organisational. This would not be possible without a strategic plan that cultivates the learned environment, previously described. Conversely, this endeavour is needed to promote behavioural change in the organisational culture, leading to greater collaboration. This mechanism is intertwined with the degree of visibility of supply chain risks and uncertainty throughout the product lifecycle. That is, the stakeholders involved in NPD projects should understand the future impact that their decisions have on the supply chain.

Sharifi et al. (2006, 2013) provide compelling cases where perception gaps stem from limited visibility of potential supply chain disruptions. They elucidate the challenges posed by a lack of pre-emptive consideration of supply chain design. The absence of a clear understanding of supply chain implications, compounded by an adversarial relationship with suppliers, and overestimation of organisations capabilities, exacerbated the perception gaps. Here, it is clear that visibility into future supply chain problems and a lifecycle view towards product development can mitigate these asymmetries.

In this research synthesis, the cases examined highlight the emergence of frictions or disruptions. These are typically triggered by the limited understanding of perception asymmetries. For instance, the creation of functional guidelines that overlook their impact on other design areas, as noted by Johansson and Johansson (2006), or the inconsistencies in how firms engage with suppliers on a project basis (Van Echtelt et al., 2008). As such, the significance of his perception mechanism, along with its connection to the other components of the suggested roadmap, is clearly demonstrated. Consequently, the focus of the forthcoming research work is to grasp and design a solution to close the perception gaps in product development, in the journey towards embedding DfSC behaviours. To this end, Chapter 6 presented a scenario-based experiment to pinpoint these perception asymmetries within the original 3-DCE concept. Following this, Chapter 7 proposes a gamified version of the scenario, serving as a tool to effectively address these gaps.

3.7 Anticipating the Next Chapter

Soft-Systems methodologies are applied in a broad range of areas, from organisational structure to policy assessment (Mello et al., 2017). In this chapter it was used to guide the debate of DfSC implementation using a structured model to identify its underlying mechanisms so that actions can be taken. Therefore, despite the alignment with Design Science Research, it is important to note that this is not the overall research methodology used to solve the research problem. As stated by Checkland and Scholes (1999), this approach facilitates the improving of perceptions about the problems, which is at the core of the overall approach taken in this Thesis. In fact, the proposed conceptual framework is used to guide this research towards tacking the perception gaps inherent in NPD projects.

Ultimately, this research synthesis developed a conceptual framework that, largely, encourages organisations to address the diverse perspectives, leading to a shared understanding of the product development process. In short, the synthesis demonstrated that comprehending the decision-making behaviour of the actors involved is critical for the success of intervention that aim to the incorporation of DfSC principles in product development. Therefore, well-established theories of organisational behaviour are needed to explain those behaviour, as discussed in the ensuing chapter.

4 THEORECTICAL PERSPECTIVE

4.1 Overview

Thus far, this research has asserted that grasping managerial decision-making behaviour in relation to the adoption of DfSC principles equip organisations with useful insights to effectively integrate these principles into their routine activities. In fact, the proposed conceptual framework underscores the importance of identifying and addressing perception asymmetries, both within functional domains and across organisations. Consequently, the aim of this chapter is to identify well-established theories of organisational behaviour that can enrich this research and emerge as a fitting theoretical foundation for addressing the research problem at hand.

The chapter is structured into two parts. The following section engages with a set of well-established theories of organisational behaviour in the field of Operations & Supply Chain Management (O&SCM) that can be applied to understand how individuals behave in operational settings, with the aim of identifying the most pertinent theoretical approach for tackling the research question. The final section elaborates on the pragmatic application of boundary objects and serves as an effective theoretical lens to facilitate the practical and political adoption of DfSC principles. Moreover, this final section highlights how a Design Science Research (DSR) strategy enhances the development of the proposed boundary object, setting a solid foundation for the forthcoming Research Methodology chapter.

4.2 Forms of Theory

A theory contribution is at the core of academic research. The development of concepts and ideas that are rooted on "a systematic body of knowledge grounded in empirical evidence" and can be confirmed, refined or contradicted is an essential element of the academic work (Saunders et al., 2023, pp. 47–50). Influential works from Whetten (1989), Sutton and Staw (1995) or Weick (1995a) shaped the forms of making a solid theoretical contribution.

In the field of organisational sciences, Whetten (1989) argues that a complete theory should likely influence the area of interest by containing four essential elements. The first element are the concepts that the theory examines. The second element are the relationships among those concepts. The third element seeks to justify those relationships. The fourth element regards the context in which this theory applies. These elements are better summarised with the following questions: 1) "what are the concepts that the theory examines"; 2) "how are these concepts related"; 3) "why are the concepts related"; 4) "who does this theory apply to / where and when does this theory apply" (Saunders et al., 2023, p. 49).

Sutton and Straw (1995) offer another important contribution to theory building by defining what theory is not. They argue that references, data, variables, diagrams, and hypotheses do not constitute theory. In fact, the authors argue that to produce strong theories academics are required to focus on a small set of conceptual statements and build a logically detailed cases that is both simple and interconnected. Ultimately, their perspective is that strong theories need to reach the underlying mechanisms for the particular phenomena that they study.

Conversely, Weick (1995a) complicates this debate stating that theory is a complex and nuanced process that is often uncompleted. Taking a closer look at this process, he (Weick, 1995a, p. 389) writes that "theorising consists of activities like abstracting, generalising, relating, selecting, explaining, synthesising, and idealising". The main argument is that a complete theory is unlikely to be developed in a single manuscript, and that the process of theorising should be shared in the organisational science field.

A recent article from Cornelissen et al. (2021) understands that despite the previous definitions of theory as an explanation for set of relationships is valuable, there are distinct forms of theoretical contributions. However, they argue that conceptualisation is the building block for all these forms. Conceptualisation consists of an activity that frames a “topic” that exists in the *real* world in terms of a theoretical “resource”. For instance, the study of concurrent engineering adoption through the lens of operational behaviour. In short, the different forms of “theorising” relate to the distinct ways researchers achieve the integration between topic and theoretical resources.

Cornelissen et al. (2021) identified three forms of theorising. The first form is a more traditional style, branded explanatory theorising concerned with identifying and exploring the underlying processes and structures. The second form is a more pragmatic style, branded interpretive theorising that should read into the context of the topic. The third form refers a more political style, branded as emancipatory theorising, which is concerned with bringing critical forces upon ideals and values in theory and practice. Again, regardless of their distinctions the authors advocate for pluralism in the forms of theorising. They defend that different forms are rotted in different aims and knowledge interests that can lead to better research and broadened usefulness.

Maintaining a pragmatic approach to the research problem, the theoretical style of this thesis is an interpretive one. As such, the aim of this section is to identify opportunities for knowledge development from operational behaviour theories in O&SCM. The ensuing subsection provides an argument for the need of understanding organisational behaviour, followed by briefly acknowledging the theories that were considered to support a pragmatic approach to boundary objects as tools for developing the suitable theoretical perspective.

4.3 Theories of Organisational Behaviour in SCM

4.3.1 The case for including a Behavioural Perspective

Previously, this research has expressed that its primary focus is to solve the research problem as the examination of decision-making processes through the lens of decision-making behaviour. Organisational behaviour, as a subject of academic interest, as a rich history of interdisciplinary research domains that examine the influence of individual and group behaviour on organisational performance, decision-making paradigms and team dynamics (Buchanan and Huczynski, 2019; DuBrin, 2013).

Within the broader field of management science, several seminal works have underscored the importance of organisational behaviour. For instance, Forrester’s (1965) pioneering work advocated for a new type of enterprise, leveraging then-contemporary electronic technologies to enhance information flows that allowed behavioural changes. With similar importance, Kurt Lewin contributed to the wide range of social and organisational interventions on organisational change (Burnes and Bargal, 2017). Additionally, Woodward (1994) conducted studies in multiple British industries on the interrelationships among organisational structure and behaviour, particularly aligning process manufacturing to structural characteristics.

Miner (2006) highlights the essential theories pertinent to organisational decision-making, from Simon and March's administrative behaviour and organisations theory, Cyert and March's behavioural theory of the firm, March's theory of organisational learning, and Weick's theory of organisational sensemaking. Central to Simon and March's (2015) theory are variables such as motivation, group behaviour including intergroup conflict, and leadership dynamics. Cohen (2007) indicates that Cyert and March's behavioural theory of the firm, as articulated in 1963, represents a culmination of Simon's seminal work, incorporating elements of bounded rationality, goal formation, expectations and choice, alongside mechanisms for learning and conflict resolution. Similarly, Miner (2006) interprets March's organisational learning as "*in fact another extrapolation from his behavioural theory of the firm*". Particularly, focusing on the dynamics of rules that regulate individual behaviour, their interactions with other inside the firm, as well as retaining organisational lessons learned from past experiences (Miner, 2015). Furthermore, Miner (2006, p. 87) describes Weick's sensemaking theory as diverging into a distinct *"world"* within the domain of organisational decision-making, a theory that will be covered later on in this chapter.

Moving towards the context of concurrent engineering, Haque et al. (2003) assert that understanding organisational behaviour is crucial for managing and improving the overlapping tasks and dynamics of the collaborative effort. In fact, their analysis proceeds to identify that the root cause for difficulties or problems in the collaborative effort steam from missing organisational behaviour information. For them, organisational behaviour is intertwined with individual and organisational response to change.

In a similar fashion, Collins and Browning (2019) explored the transfer and implementation of process improvement programs through the organisational behaviour literature stream. They conducted an in-depth field study and examined how the engineers experienced the change message and which of those factors impeded implementation. They cite several human behaviour factors as a primary reason for failure in process improvement implementation, with particular emphasis in creating a culture for change. A framework for successful implementation was then developed, drawing upon Levin's (1951) three-phase change sequence of unfreeze, change, and refreeze. Their framework, depicted in Figure 4.1, establishes the need to reduce conflicting environmental interpretations, adjust tailored principles to new context, reduce distant believes to close perception gaps between symbolic and substantive success.

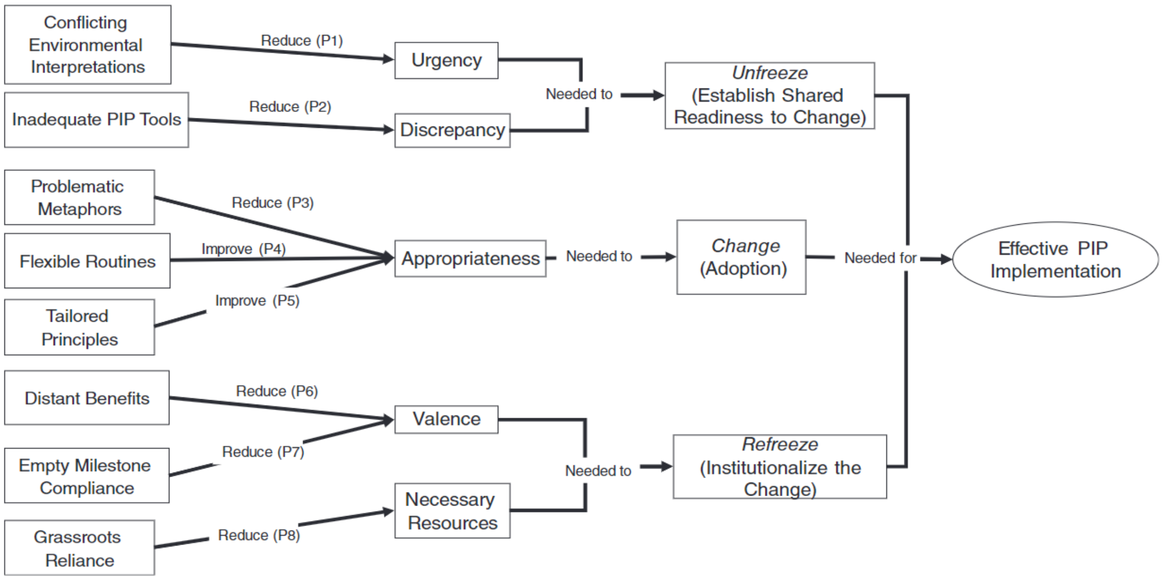


Figure 4.1 – Organisational Behaviour factors impacting process improvement programmes sourced from Collins and Browning (2019)

Inspired by the theoretical contributions of Haque et al. (2003) and Collins and Browning (2019), it becomes apparent that the successful application of DfSC principles in product development contexts is predicated upon a sound foundation of organisational behaviour theory. Subsequence sections will investigate established theories that align with this conceptual orientation.

4.3.2 Sensemaking Theory

As previously mentioned, Weick's organisational sensemaking is regarded by Miner (2006, p. 91) as a controversial and intricate theory of organisational decision-making. Distinct from other theories of organisational behaviour, Weick asserts that organisational actions often precede goal formulation. He underscores the importance of understanding small groups within the organisation as a critical element in comprehending broader organisational behaviour. Thus, Weick (1995b) endeavours to provide a bridge between the small-group level to the organisation by emphasising the need to grasp coordinated actions alongside the intersubjective understandings of the people within the organisation, with the aim of minimising the loss of these shared understandings. Miner (2006) reviews this approach, highlighting the necessity for a reconciliation processes, achievable through well-established routines and action patterns, as well as through continuous communication activities within the organisation.

A growing body of research drawing on sensemaking theory has been established in O&SCM (Comes et al., 2020; Skowronski et al., 2020; Wang et al., 2019; Bendoly, 2016; Gralla et al., 2016). In the sensemaking process, individuals or organisational members, seek to clarify and "make sense" from cues in their environment, based on past experience with similar cues, and through which they take appropriate actions that continue to generate This theoretical proposition by Weick (2005; 1995b) is also referred to enacted sensemaking.

Sensemaking and problem-solving are deeply interconnected. In fact, the iterative process of problem formulation and the unidirectional process of sensemaking, where the actions taken produce new cues that modify the initial state, are based on similar self-reinforcing learning cycles (Maitlis and Christianson, 2014; Rudolph et al., 2009). Moreover, sensemaking does not functions in isolation but rather is influenced by emerging coordination structures and fluctuating information flows, as highlighted in Figure 4.2 from Comes et al. (2020).

The stream of information shapes the ongoing decision-making processes and by, extension, the coordination structures, and roles within an organisation. As a result, organisations are required to adapt and continuously collect new information. Hence, enacted sensemaking is not just a mechanism for action but a dynamic cycle involving the formulation of priorities, mandates, and responsibilities (Comes et al., 2020, p. 2487). The cycle depicted in Figure 4.2 captures this ongoing interplay between sensemaking processes and decision-making.

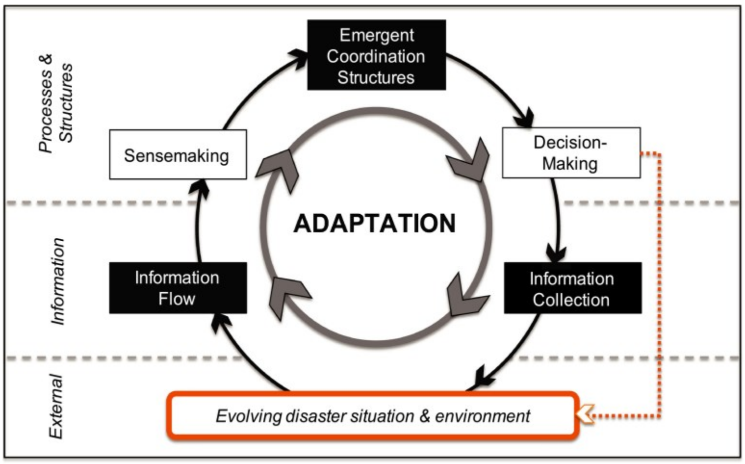


Figure 4.2 – Cycle of Sensemaking sourced from Comes et al. (2020)

According to Gralla et al. (2016), the application of sensemaking is particularly useful to solve urgent and ill-defined O&SCM problems. In such scenarios, goals and constraints are ambiguous, and actions must be both formulated and executed swiftly. This is notably evident in humanitarian response settings. Also, Wang et al. (2019) argue for sensemaking in contexts where organisational members encounter new and unexpected situations, especially where the tangible benefits are unclear, as in the case of adoption of new disruptive technologies.

For these reasons, sensemaking theoretical concepts appear to be a reasonable avenue to explore the incorporation of DfSC principles into managerial decision-making. However, Sandberg and Tsoukas (2015), in their critical review on the sensemaking perspective, point to important limitations. An important limitation for this research is the exclusive focus behind disruptive episodes over more mundane. It is worth remembering that the adoption of concurrent engineering is a well-established practice with routine activities between the members of the project. Hence, a distinct theory to understand and modify the behaviour of organisational members could be better suited in the proposed research problem.

All in all, Weick (1995b, p. 110) explains sensemaking as a "cue within a frame, not the cue or the frame alone", signifying that sensemaking is rooted equally in internal aspects of individual reasoning and in the external factors that shape the sensemaking processes. Showronski et al. (2020) further elucidate this by explaining how published narratives, whether in popular or academic literature, exert a substantial influence on individual perceptions.

As mentioned in the literature review chapter, there exists a plethora of publications highlight the tangible benefits of 3-DCE with detailed models for its successful adoption. Hence, viewed through the lens of sensemaking theory and based on these existing narratives, the implementation of similar principles should, theoretically, already be a well-embedded practice, as is the case with concurrent engineering. The observation, in Chapter 3, of the struggles of adopting DfSC principles, appears to suggest that an alternative theoretical perspective is required to untangle the complex behavioural decision-making that restrain their implementation.

4.3.3 Prospect Theory

Prospect theory, originally formulated by Kahneman and Tversky (1979), serves as a pivotal framework for understanding individual risk-taking behaviour within the context of decision-making processes that involve both gains and losses. The findings of prospect theory support the claim that people exhibit "loss aversion", meaning that they are more sensitive to losses than to equivalent gains, often leading to behaviours that seek to minimise such losses relative to a reference point (Hoskisson et al., 2017). As described in Chapter 3 of this thesis, the successful incorporation of DfSC principles is critically shaped by underlying mechanisms such as functional trade-offs and accurate risk visualisation. Therefore, this theory which describes how individual decision-makers select between alternatives that involve risk and conflicting behavioural biases could provide a solid basis for addressing the research problem.

Developed as a counterpoint to Expected Utility theory in decision making, prospect theory features an S-shaped utility curve that encapsulates complex risk-taking behaviours (Shimizu, 2007). In this curve, the concave section represents risk-averse disposition when faced with potential gains, while its steeper convex section represents a tendency for risk-seeking when confronted with potential losses. An illustration for this is provided by Collman (2015, p. 608), who describes experimental data from Tversky and Khaneman to reveal that 84% of undergraduate students opted for a certain gain of $240 over a gamble with a 25% change of gaining nothing, this manifesting risk aversion for gains. Conversely, 87% of the same students favoured a gamble that posed a 75% change of losing $1000 over and a 25% change of avoiding any loss, over a certain loss of 750$, thereby revealing risk-seeking tendencies when faced with potential losses.

Craighead et al. (2020) point out that prospect theory is well-suited for explaining supply chain decisions under uncertainty, such as those taken during and after the COVID-pandemic. Consistent with this theory, supply chain managers are more likely to make risk-seeking choices when confronted with situations involving potential losses, particularly during a pandemic where the losses can be enormous. In these circumstances, Craighead et al. (2020) underscore the role of positive and negative frames. They argue that "the use of lose frames may be warranted to galvanise managers to take the aggressive actions necessary to combat a pandemic's extreme effects" (2020, p. 856). Similarly, the consideration of different frames can influence managerial behaviour for inter-organisational and functional cooperation. For instance, describing the potential supply chain costs that the organisations can incur if cross-collaboration is not achieved.

Nonetheless, while prospect theory appears to be well suited to explain the adoption of DfSC principles in an isolated project, its fit for the research scope of this thesis may be less straightforward. In fact, when considering the broader research focus, namely the embedment of supply chain design into the behavioural rationale of team members engaged in product development projects, a more tacit explanation is due. However, this theory has been found applicability in O&SCM mainly to study specific phenomena, such as buyer abusive behaviour (Kim et al., 2022), optimal inventory decisions (Bai et al., 2021; Schultz et al., 2018), or consumer acceptance of remanufactured products (Wang and Hazen, 2016). So, to capitalise on the strengths of this theory to explain decision-making processes under uncertainty, and in alignment with recommendations from Craigstead et al (2020) and Wang and Hazen (2016), Chapter Six of this thesis will employ a vignette-based experiment to assess the behavioural perceptions of decision-makers in product development.

4.3.4 Theory of Planned Behaviour

The problem of adopting new practices can be investigated through the lens of the theory of planned behaviour (TPB). A theoretical endeavour by Fishbein and Ajzen (1985, 1991) to predict and explain human behaviour. The theory postulates that individuals hold salient beliefs that determine their intentions and actions. These beliefs are distinguished as behavioural beliefs that influence attitudes towards the behaviour, normative beliefs that constitute the underlying mechanisms for subjective norms, and control beliefs that are the basis of perceptions of behavioural control (Ajzen, 1991, p. 189). The evolution of the theory has led to a dual conceptualisation of normative beliefs, distinguishing between injunctive norms, which reflect what individuals perceive as appropriate societal behaviour, and descriptive norms, which capture what individuals perceive other are actually doing (Gold, 2011).

This theory extends their (Fishbein and Ajzen, 1977) original theory of reasoned action (TRA) by adding perceived behavioural control, this enabling prediction to be made of actions that are not entirely within one's conscious control. Fishbein and Ajzen (2011) proposed a further extension to TPB by incorporating background factors into the model. These are a multitude of variables that can potentially influence people's beliefs. Notably, these factors are not identified by the theory but rather by the examined behaviour, giving a contextual dimension to the theory. In fact, different backgrounds can form different beliefs with respect to one behaviour but the same with respect to another. The schematic representation of this new theory dubbed Reasoned Action Approach is depicted in Figure 4.3. All in all, at the core level the TPB and its variants seek to distinguish the individual beliefs and background factors to design effective behavioural interventions to perform the practice of interest.

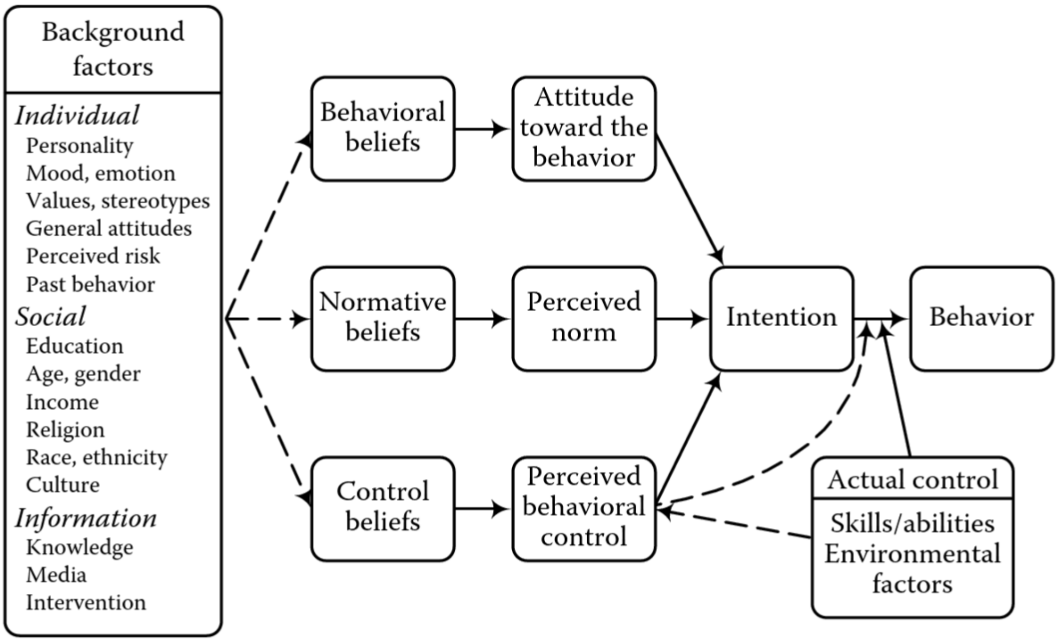


Figure 4.3 – Reasoned Action Approach model sourced from Fishbein and Ajzen (2011)

The TPB is an instrumental theoretical framework for understanding behavioural intentions at the individual level, with background factors shaping the individual intentions in distinct ways towards the behaviour of interest. Its overall proposition is that human behaviour can be best predicted from a person's intentions. This theoretical model has garnered widespread attention in various domains. For instance, in the domain of information technology studies have explored consumer intent to use personal computers (Venkatesh et al., 2003, 2012) or engage in online-baking (Yousafzai et al., 2010). Likewise, this theoretical model was modified to analyse environmental consciousness among managers (Mancha and Yoder, 2015; Cordano and Frieze, 2000). Straatmann et al. (2018) extended its applicability to organisational change, suggesting that change-supportive behaviours are largely dependent on the employees' behavioural intentions regarding the required changes. Next, in the field of O&SCM, Arellano et al. (2021) utilised TPB to investigate the factors that drive operation managers commitment to adopt new operational practices.

In essence, the TPB framework has proven its efficacy and versatility to explain the central role of behavioural intentions in guiding operational practices adoption. By considering 3-DCE as an operational practice to be implemented by individual members of a team, this theory might offer explanations about the intentions of managers and those individuals involved in the NPD project to adopt 3-DCE principles in the first place. As mentioned above, Arellano et al. (2021) show that managers have individual and multidimensional belief configurations that often contribute to their engagement towards implementation of new concepts. From a fsQCA (fuzzy set qualitative comparative analysis) they categorised different profiles of highly committed managers regarding practice adoption as *Followers*, *Pragmatist* and *Reformers*. Table 4-A presents the descriptive analysis of the three categories from Arellano et al. (2021) and Netland et al. (2021).

Table 4-A: The belief profiles for high levels of practice adoption commitment, adapted from Netland et al. (2021) *and Arellano et al.* (2021)

Type of Profile	**Main Exhibited Beliefs**	**Description**	**Quotation from Netland et.** (2021)
Followers	**Normative beliefs** (Legitimacy-related beliefs) **Control beliefs** (self-efficacy-related beliefs)	Primarily motivated by external pressures both injunctive (coercive pressures) and descriptive norms (mimetic pressures) but confident in their own abilities to adopt the new practice.	*"This is modern production best practice. We have come a short way in our journey (…) but the benefits will undoubtedly come. The working environment is changing visibly, and attitudes are changing too. I have little doubt that all this work will pay off in the long term."*

Pragmatists	**Control beliefs** (efficacy-related beliefs)	Primarily concerned with the value and the fit of the given practice. They have a utilitarian approach to supporting change as potential gains for the team and/or for them.	*"The new corporate boards required us to get rid of the old. But this is no problem; we can place our old figure on our new boards. This way, we achieve renewed visibility and support for my strategy and can boost performance further."*
Reformers	**Behavioural beliefs** (belief in discrepancy) **Control beliefs** (self-efficacy-related beliefs)	Primarily driven by a desire to improve operations as they believe that change is necessary and, further, that they possess the skills and knowledge required to implement the new practice.	*"Improvement with or without the corporate board template is honestly the same. We would have done it anyway. We come up with a project idea and work it out."*

Likewise, adopting a TPB perspective to categorise managerial beliefs towards DfSC principles could improve its implementation process. The merit of such categorisation lies in the insights these categories provide into the different ways managers approach such concepts across various departments or organisations. Specifically, exploring the perceived attitudes and intentions that managers have towards the core dimensions of product, process and supply chain design could help understand the varying levels of readiness different teams or organisations have for the incorporation of DfSC. Armed with this understanding, organisations involved in the NPD projects could devise bespoke adoption strategies to meet the unique needs of their teams. This perspective will be revisited in Chapter 9, in which the results and contributions of this research work is discussed in detail..

For now, however, the focus remains on the research aim of facilitating the practical incorporation of a DfSC behaviour among the team members engaged in NPD projects. Earlier, it was highlighted the essential role of cross-functional integration for successful implementation of these principles. Consequently, relying solely on a theory like TPB, that primarily explains behavioural at an individual level, seems insufficient to achieve this broader aim. Subsequently, a complementary theoretical tool is required, one that transcends individual beliefs and focus on ways to foster interconnectivity among team members.

4.3.5 Boundary Object Theory

The concept of boundary object can be traced to Star and Griesemer (1989), as they sought to balance heterogeneity and cooperation in a team. These objects "allow different groups to work together without consensus" (Star, 2010, p. 602), as they are "plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star, 1989, p. 46). Consequently, the concept of boundary objects in theory has been employed by researchers across different disciplines as a mechanism for communication (Lindlöf, 2014).

Of particular relevance to NPD projects is the work of Carlile (2002, 2004), exploring the role of boundary objects in managing and transforming knowledge across different functions like engineering, marketing and production. Effective boundary objects possess both practical and political attributes, whose applicability is context dependent. On the practical side, these objects establish a shared language that enables individuals to represent their knowledge while specifying differences and dependencies at functional intersections. On the political front, the deployment of boundary objects creates a process of transforming embedded ideas from each function into new forms of knowledge capable of resolving the negative consequences within the changing process. Types of tools that Carlile (2002) identifies as pragmatic boundary objects include visual and computational models, such as sketches, mock-ups or computer simulations as well as organisational maps, such as process maps, workflow matrices or Gantt charts, all of which serve to clarify the interdependencies between different cross-functional objectives and project outcomes.

The approach to boundaries rotted in Carlile (2002, 2004) assumes a pragmatic process of transformation set on understanding the differences, dependencies and novelty of the generated knowledge. Furthermore, this approach recognises the importance of pragmatic capacity. That is, the need to build common ground for the object to have the capacity to represent the novel knowledge. This perspective requires significant practical and political effort but is well-suited for the DSR strategy of this Thesis. Carlile (2004, p. 563) developed a framework to support the design of effective boundary objects, so that the common knowledge is generated and transmitted across boundaries, as illustrated by Figure 4.4.

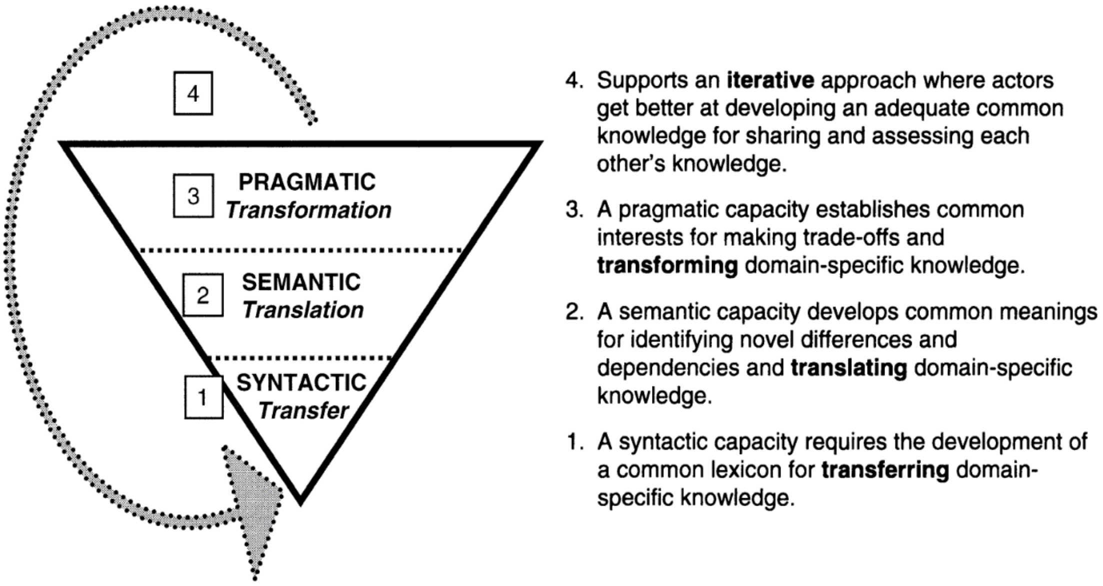


Figure 4.4 – Framework for Pragmatic Boundary Capability sourced from Carlile (2004)

Recently, Fabbe-Costes et al. (2020) employed a boundary objects perspective to examine the usefulness and value of supply chain (SC) mapping. They recall that the function of the SC map as a boundary object is to overcome syntactic, semantic, and pragmatic boundaries. To them, SC map is a systems of boundary objects, socially constructed to represent "an enacted common ground for coordinating the groups' work in absence of consensus" (2020, p. 1480). Their study of Renault Group's outbound SC map finds that this map has characteristics of a syntactic boundary object, as it eases communication for their common lexicon. However, they are not considered an efficient boundary object, since the map does not clearly reflect the different stakes investigated in the focus group. From this study, Fabbe-Costes et al. (2020) derives an important proposition: encourage a pluralist and participative approach to boundary object development, where no voice is louder than others.

Norman and Prataviera (2023) added their support for the increased need of effective boundary objects to face the challenges of cross-functional decision making. Their insights from a case where an organisation implemented a novel boundary object to improve the communication of tax implications across strategic, architectural and execution boundaries show its capability to create a common ground where "risks can be minimised and compliance maximised". However, a word of caution is owed regarding the successful outcome of these objects; although they may facilitate collaboration in some contexts, given their paradoxical nature they can constitute roadblocks in others (Oswick and Robertson, 2009; Carlile, 2002).

4.4 Deployment of Boundary Objects to solve the Research Problem

4.4.1 *Artefact design and Gamification debate*

Within the context of Design Science Research (DSR), which is set to be expanded in the following chapter, the employment boundary objects as artefacts emerges as a particularly appropriate approach for addressing the complex challenges, such as facilitating the embedding of DfSC behaviour. The adoption of artefacts as problem-solving tools can be traced back to Simon's (1969) seminal work on the creation of the artificial. Such an approach sets DSR apart from methodologies like action research, as outline by Holmström et al. (2009). Van Aken (2004, p. 226) eloquently emphasises the role of artefacts, indicating that they should be a "representation of a system or process to be realised". Like boundary objects is the advancement of these artefact to be functional tools for professionals.

Building on this premise, Naim and Gosling (2022) advocate for the "V-model" conceptualised by Stevens (1998, p. 8) as an exemplar for artefact development. Cavalieri and Pezzotta (2012) describes this model as a sequence of steps in a product development process. Beginning with requirements and system specification, these elements are broken down into individual parts and represented on the left side of the "V". The right side is then dedicated to the integration and verification of these parts. Carlile's (2004) boundary object development framework parallels this, endorsing an interactive approach that follows a V-diagram. Figure 4.5 provides a visual representation of the necessity of designing artefacts that effectively bridge the intricate boundaries that span the 3-DCE model.

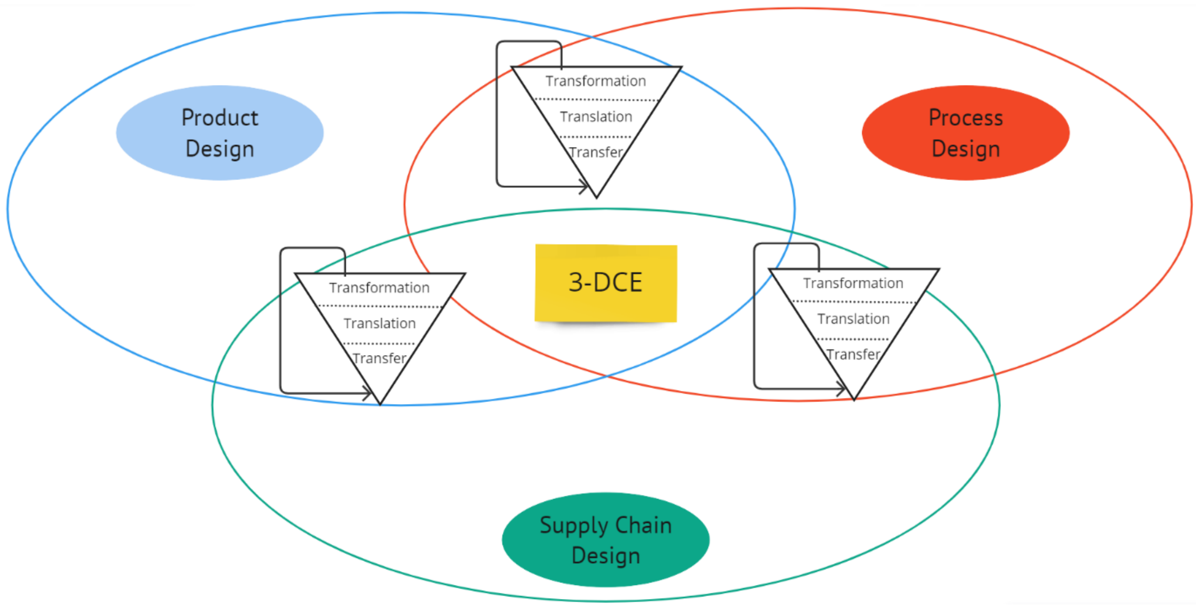


Figure 4.5 – Using Pragmatic Boundary Capability to connect 3-DCE dimensions

Recently, Wiegmann et al. (2023) illustrated the application of DSR in developing prescriptive knowledge for social-political work in the Dutch Geothermal Energy (GE) niche. Central to their approach was the deployment of boundary objects to translate knowledge between research and practice. In the context of DSR, they distinguish between two levels of boundary objects: design principles and design solutions. The former, design principles, serve to structure knowledge into generic solutions which are relevant for relatively broad context. On the other hand, design solutions draw on such principles to apply this knowledge to a specific context where the field problem occurs. In the case example, Wiegmann et al. (2023) crafted CIMO-based design principles by synthesising existing articles on the methods of socio-political work within niches and refining these findings in light of the Dutch GE context, achieved through semi-structured interviews and extensive analyses of relevant documents. Their work culminated on an evidence-based self-assessment tool; a design solution developed to facilitate the application of the knowledge embodied in the design principles. In practice, this solution clarifies the stakeholders involved in the niche network, pinpoints the activities of social-political work that can be undertaken and evaluates the perceived performance of each activity.

Likewise, the “Powertrain Game” emerges as a design solution, drawing from the underlying mechanisms of DfSC implementation delineated in Chapter 3’s Research Synthesis and corroborated by the scenario-based experiment in Chapter 6. The purpose of the design solution is twofold: First, the participants will have an individual understanding of the consequences their decisions for product, process, and supply chain designs. This can help managers identify their own behavioural beliefs towards these concepts. Second, to spark the debate within and across the organisations involved in the NPD project about their cross-functional integration needs. This can allow the development of bespoke strategies for team and partner selection in NPD projects. In sum, drawing from the TPB, this boundary object offers a solution to the problem of embedding DfSC into teams involved in NPD projects.

Games can serve as a powerful boundary object, seamlessly integrating diverse functional voices and fostering consensus aligned with the 3-DCE approach. In a related way, Sydelko et al. (2023) introduced a board game to facilitate the design of a collaborative interagency organisation. Conducted within a workshop setting, senior managers participated in this game to co-design their interagency. According to this study, the game enabled inclusiveness of all necessary perspectives, cultivating cross-agency learning as well as a shared understanding of their intricate challenges. Similarly, Van Pelt et al. (2015) elucidate how game used as boundary objects can bridge different social worlds, allowing participants to share experiences and discuss lessons learned. Their findings reported changes in the participants’ perception of uncertainties, underscoring its potential for enhancing science-practice communication.

Following this line of thought, Whalen et al. (2018) argue that games serve as an appropriate tool as facilitators of systems thinking. Such objects allow participants to think holistically, recognising the importance of multiple actor perspectives when addressing issues such as material criticality. Thus, these examples strengthen the rationale for developing the "Powertrain Game" in the journey of enabling a DfSC behaviour.

4.4.2 *Development path and Theoretical discourse*

For the purpose of this Thesis, the research follows a design-oriented and theory informed strategy for problem solving in organisations. The present subsection outlines the path from artefact design towards theoretical discourse, rotted in a design-science paradigm.

The development path in DSR follows a Bunge's logic of technological rule, that is "performing a finite number of acts in a given order and within a given aim" (van Aken and Romme, 2009, p. 8). The process of artefact designing in management fields, such as O&SCM, is referred by Van Aken and Berends (2018) as social system design. The main characteristic of this systems is the amount of realisation freedom of the actors in the system. In other words, human agency plays a significant role in the artefact contributions towards real-world solutions. That been said, Van Aken and Berends (2018) mentions tow redesign levels, the first is a representation of the new formal system, while the second is an appropriation of the system by the actors involved. Managing the second redesign involves intense communication and persuasion from the designer to make their second redesign accord with the first. Finally, since the artefact influences behaviours, dealing with political and ethical issues is a key part of the design process for social systems.

In information systems research the balance between artefact design and theory in DSR is a topic of ongoing debate (Baskerville et al., 2018; Gregor and Hevner, 2013). Baskerville et al. (2018) understands that theory is embodied within the artefact, thus the dissemination of the artefact is a vehicle for knowledge generation. This type of theoretical discourse is of a prescriptive taxonomy, which emerges from a process of maturation in a body of knowledge (Gregor and Hevner, 2013). According to Van Aken and Berends (2018, p. 232), in management, "generic solutions are the end of DSR". Specifically, the core of generalisation in DSR is determined by the strength of the body of knowledge, presented to support the claim and the rigour of the process of collecting this body of evidence.

The research paradigms that this thesis wants to address justifies a theoretical discourse based on DSR. The research is driven by the problem of facilitating the incorporation of DfSC behaviour in NPD projects. Hence, the artefact solution as the gamification of a scenario comprised on decision around the 3-DCE concept is intertwined with both boundary object theory and theory of planned behaviour.

4.5 Anticipating the Next Chapter

The foundation of the research problem at hand lies in the diverse functional and organisational voices in product development design decisions. This research work has emphasised the importance of understanding the practical decision-making behaviour of cross-functional teams in NPD projects. Therefore, this chapter necessarily maintains that an organisational behaviour perspective is crucial for grounding the theoretical positioning of the research. Specifically, the application of boundary object theory to facilitate cross-boundary consensus among varied actors, alongside a theory of reasoned behaviour aimed at predicting and explaining the individual behaviour behind these decisions.

The subsequent chapter argues that the adoption of a DSR strategy, rooted in a pragmatic philosophical perspective to problem solving, as well as an addictive approach to theory development is best positioned to translate the theoretical contributions into practical solutions. The focus will be on designing an artefact-solution that incorporates DfSC principles, with the aim of improving NPD outcomes.

5 RESEARCH METHODOLOGY

5.1 Overview

The purpose of this research is to facilitate the adoption of DfSC principles by focusing on closing managerial perception gaps and enhancing the visualisation of supply chain implications throughout the product lifecycle (PLC). Moving from the specific research problem, this chapter explains the research methodology that guided this study and provides a clear understanding of DSR as both a strategy for producing solution-oriented knowledge, but also as a pragmatic philosophical approach for problem-solving.

The chapter starts with a general discussion of the importance of philosophical assumptions in the research work, as well as the justification for the philosophical stance considered best suitable to address the research problem. Afterwards, the fundamentals of the research process lead towards the debate between relevance versus rigour in academic knowledge generation. Then, the DSR strategy is expanded alongside examples in the Operations & Supply Chain Management (O&SCM) literature and a proposed framework for the implementation of this research strategy. Next, the adopted research methods are explained in line with the previous framework, together with the data collection process and measures implemented to ensure validity and reliability. Finally, the ethical considerations that govern the research methodology are presented to conform with the agreed standards of good practice in academic research.

5.2 Philosophical Positioning

The philosophical assumptions of the researcher are a fundamental part of the research strategy as they guide the way evidence is gathered and interpreted to respond to the research questions. Huff (2009), for one, states that these assumptions are deeply rooted in the researcher's own experiences, its views about the problem at hand, as well as the scholarly field in which the researcher inserted. Similarly, to assist researchers situate the philosophical assumptions that inform their decisions, Creswell and Poth (2016) advises the researcher to reflect on the perspectives and experiences that are brought towards the research process and how those beliefs guide their actions.

Specifically, these beliefs are about the nature of reality, or ontological assumptions, what constitutes acceptable knowledge, or epistemological assumptions, the values and ethics within the research process, or axiological assumptions. Saunders et al. (2023) names positivism, critical realism, interpretivism, postmodernism, and pragmatism as five major philosophies in business and management. Table 5-A captures the assumptions and research methods typically employed and the contribution of each of these philosophical approaches.

Table 5-A: Philosophical positions in management research sourced from Saunders et al. (2023)

	Ontology	Epistemology	Axiology	Research Methods	Contribution
Positivism	One true reality	Scientific method, observable and measurable facts	Researcher is detached, neutral and independent	Deductive, typically quantitative	Causal explanation and prediction
Critical Realism	Layered (the empirical/ actual/ real). External, independent.	Epistemological relativism. Facts are social constructions	Researcher acknowledges but seeks to minimise historical & cultural bias	Retroductive, Range of different methods	Historical causal explanations
Interpretivism	Complex, rich Socially constructed. Multiple meanings.	Focus on narratives, stories, perceptions. Rather than theories and concepts	Researchers are part of what is researched. Subjective, reflexive	Inductive, typically qualitative	New understandings and worldviews

Postmodernism	Nominal, complex, rich. Socially constructed through power relations. Some meanings.	Knowledge is decided by dominant ideologies.	Researcher and research embedded in power relations Radically reflexive	Deconstructive, typically qualitative	Exposure of power relations and challenge of dominant views
Pragmatism	Complex, rich, external Reality is the practical consequences of ideas.	True theories and knowledge are those that enable successful action. Focus on problems.	Research initiated and sustained by researcher's doubts and beliefs	Abductive, range of different methods with emphasis on practical solutions and outcomes	Problem solving and informed future practice

The classic pragmatism paradigm was established by the work of Charles Pierce (1839-1914), William James (1842-1910) and John Dewey (1859-1952), suggesting that "reality can and should be changed through reason and action" (Kelemen and Rumens, 2008, p. 40; Cherryholmes, 1992). Kelemen and Rumens (2008) point out that the central concern of pragmatic research is on the usefulness of the generated knowledge, particularly on two accounts. First, knowledge should be credible, well-founded, reliable, and relevant. Secondly, the generated knowledge should help advance theory by improving the chances of solving the research problem.

Furthermore, pragmatism is a research philosophy that focus on understanding social relationships in various contexts. It is rooted in a social model of knowledge where truth is not theoretical but practical, focusing on the impact that generated knowledge has on future experiences (Elkjaer and Simpson, 2011). Pragmatic research challenges universalistic assumptions, encouraging research to use various methods and strategies to handle situation "situational indeterminacy" (Creswell and Poth, 2016; Kelemen and Rumens, 2008). However, as stated by Saunders et al. (2023), this does not mean that multiple methods must be used, pragmatists can choose methods that enable credibility and are well-founded with reliable data. Pragmatic research also emphasises emancipatory ethics, in which pragmatists "have a moral responsibility in presenting knowledge that has consequences for future applications" (Kelemen and Rumens, 2008, p. 43). Finally, the pragmatic paradigm embodies rationality with experiences, a recuring theme of this thesis where the aim is to better understand behaviours and interrelationships that occur in the context of NPD projects.

5.3 Modes of Knowledge Generation

The next step to define the research strategy is to determine ways to generate knowledge. Gibbons et al. (1994) wrote a manifesto where they proposed a new mode of knowledge generation. This new form was branded Mode 2 in contrast to the established form or Mode 1. As displayed in Table 5-B, Mode 2 goes from being governed by the academic context to the context of application or shaped by a disciplinary approach to a transdisciplinary one. This new form is to be characterised by heterogeneity, organised in heterarchical structures, accounted by the researcher's reflexibility, and controlled by multidimensional criteria.

Table 5-B: Mode 1 vs Mode 2 of Knowledge Generation

	Mode 1	**Mode 2**
Governed by	Academic Context	Context of Application
Shaped by	Disciplinary approach	Transdisciplinarity approach
Characterised by	Homogeneity	Heterogeneity
Organised in	Hierarchical structures	Heterarchical structures
Accountability	Autonomy	Reflexivity
Quality control by	Peer Review	Multidimensional Criteria

The characteristics of Mode 2 knowledge generation emerge as a clear inclination for the pragmatic paradigm. For instance, Hessels and van Lente (2008) argue that this mode allows for the creation of a knowledge system that is "socially distributed" towards some practical goal. Furthermore, research must be reflexive on the impacts that the knowledge creates on all social actors.

However, some critics argue that scientific research cannot directly impose organisational change (Kieser and Leiner, 2009; Godin, 1998). In a critique of Mode 2 research, Kieser and Leiner (2009) expresses that because of the inherent differences between scientific and practical systems, communication elements of one system cannot be authentically integrated into the other, suggesting that researchers and practitioners can only provoke each other. That is, they argue that types of Mode 2 research, such as Action Research, cannot possibly succeed in producing research that is both rigorous and relevant. Contraposing, Hodgkinson and Rousseau (2009) challenge this assertion by referencing Simon's (1969) characterisation of management as a *science of the artificial*, meaning the design of something human-made. Thus, supporting the idea that a scientific system can in fact gain both quality and relevance with a more practical orientation. Building on these insights, they advocate that a design science perspective allows researchers to generate knowledge that acts as boundary objects that narrow the communication gap between science and practice.

The exploration of this pragmatic stance to knowledge generation led this Thesis towards a Design Science Research (DSR) based on an abductive reasoning approach to design better boundary objects that manage to bridge the gap between the tangible benefits of 3-DCE with the struggle of practical DfSC implementation.

5.3.1 Abductive Reasoning Approach

Before delving into DSR as the selected research strategy, defining the logic of the research inquiry is needed to explain the approach to knowledge development. The logic of abductive reasoning is “known premises are used to generate testable conclusions” (Saunders et al., 2023, p. 153). Contrary to the deductive approach where the research strategy starts by testing a theory, or the inductive approach where the research starts by collecting data to build theory, the abductive approach seeks to modify existing theory with additional data collection. Adopting an abductive approach fits the research strategy, since DSR promotes the back and forth between theory and data with generalisations being made from the interactions between the specific and the general.

Furthermore, abductive reasoning gives the researcher flexibility to “suggest” general rules, focusing on the particularities of the specific context rather than determining what conclusions are generalisable (Kovács and Spens, 2005). This is particularly useful in situations where there is theoretical knowledge in place but limited capabilities to explain the practical observations, such as in the research problem, where despite the considerable research around the topic of 3-DCE its practical implementation is still lacking as seen in Chapter 3. Figure 5.1 depicts the reasoning behind the abductive approach.

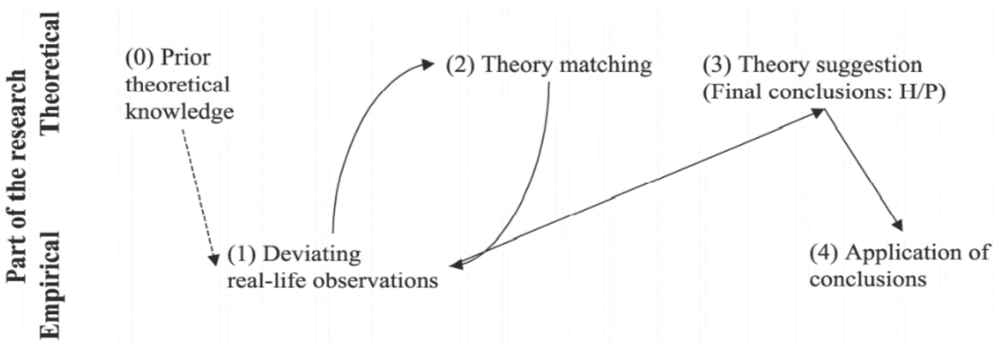


Figure 5.1 – The abductive research process sourced from Kovacs and Spens (2005, p. 139)

5.4 A Design Science Research Strategy

5.4.1 A Hybrid mode of knowledge generation

The complexity and dynamism of O&SCM urges academics to develop new knowledge that produces practical solutions supporting practitioners in their problem-solving efforts (Holmström et al., 2009). With Governments and practitioners trying to build back more resilient post-Covid 19 supply chains, academics are also called to create not just more knowledge in the field, but knowledge that matters and that can make a difference (Knight et al., 2022; Sharma et al., 2022).

The focus on managerial implications is nothing new in O&SCM research. Academics in this field recognise that relationships in the field are more complex than simply claiming that '*a* leads to *b*' (Helmuth et al., 2015) as reminded during the pandemic. This complexity requires a shift in research strategy and Van Aken (2004) calls for facing the relevance problem in O&SCM research by using 'design sciences'' like engineering and medicine as an attractive proposition. Design Science Research (DSR) is an approach that seeks to produce practical solutions that improve the problem-solving process in the broad field of O&SCM (Holmström et al., 2009). Van Aken (2005) supports the potential of DSR to create solution-oriented knowledge that allows both the creation of good theories and relevant knowledge for practitioners, urging O&SCM research to produce more solution-oriented knowledge.

The features of DSR are connected with Gibbons et al.'s (1994) proposal of Mode 2 research as a research approach that focuses on transferring knowledge to different contexts, aiming to create knowledge that can be used in designing solutions to field problems. It follows the action research of Eden and Huxham (1996) and aims to create knowledge that can be used in designing solutions. Van Aken's (2005) design science perspective emphasises the importance of a transdisciplinary approach involving connections across disciplinary and hierarchical boundaries. He also emphasises the importance of cross-case analyses and improving communication with practitioners. Reflexivity is a key aspect of DSR, as it allows for the transfer of general rules and solution concepts based on observable patterns of behaviour. The quality of field testing determines the scientific rigour of DSR research, and its production is judged by editors, reviewers, and academia, as well as its broader social impact.

Overall, despite moving closer to Mode 2 knowledge generation important features of Mode 1 research are not abandoned. In fact, DSR should be regarded as complementary to explanatory research, having both descriptive/explanatory and design/testing components, and the outcome validity should incorporate both explanations of the truth and effectiveness of the design (Van Aken et al., 2016). Hence, DSR could be considered a hybrid mode of knowledge generation. Perhaps, DSR can be viewed as a Mode 1.5 of knowledge generation, described by Huff (2000a, 2000b) to tackle the limitations of both modes.

5.4.2 Design Science position for theory building

In their discussion on the modes of knowledge generation, Hessels and van Lente (2008, p. 757) understands that scientific practice does not occur in either Mode 1 or 2 forms, rather those are “extremes of a continuum” not “two mutually exclusive categories”. Likewise, DSR positioning for knowledge generation appears in the continuum between “pure” explanatory research and action research, as depicted in the figure fellow. As stated by Holmstrom et al. (2009, p. 67) *“design science is research that seeks to explore new solution alternatives to solve problems, explain this explorative process and improve the problem-solving process”.*

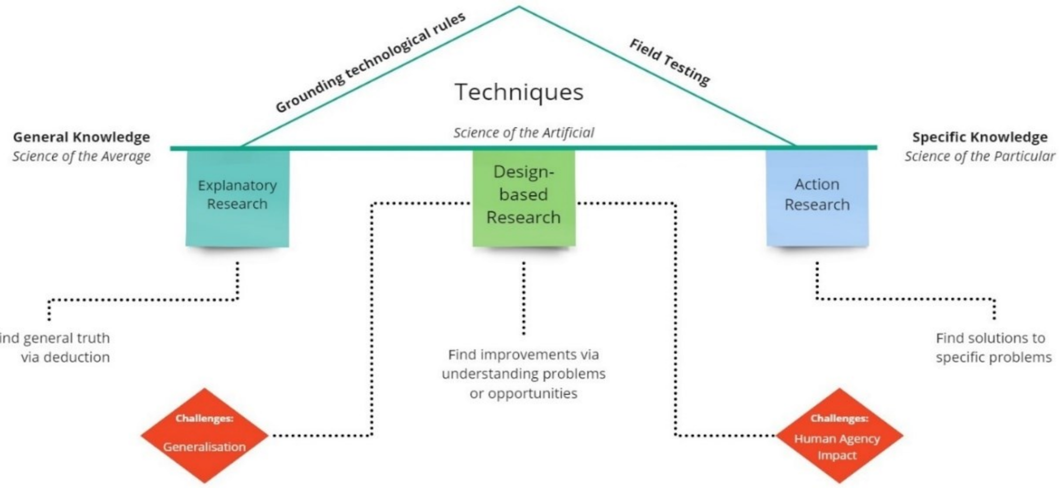


Figure 5.2 – Positioning of DSR in the continuum of Knowledge Generation

Action research is described as the ‘science of the particular’. Researchers that pursue this mode of research are concerned foremost with the implications of their research project. Eden and Huxham (1996) indicates six outcome and process characteristics that represent this strategy. Notably, the presentation of the research should be appropriate to the consumer and their interpretation must contemplate the context of the intervention. However, they do warn researchers to be aware of the key validity issues, and the design of methods must be related to the theory. Their core point is that although action research is, by its very nature, an experimentation that cannot be repeated in the same context, each intervention must draw new knowledge and from that make emerge theories that go beyond the domain of the project.

There are some common ideas between DSR and action research, as proposed by Eden and Huxham (1996). Both seek to intervene in a specific field problem, but ultimately move its outcomes from the particular to the general. However, the formulation of Van Aken et al. (2016) design propositions follows the so-called “CIMO” logic, as presented by Denyer et al. (2008). This means that in DSR, an understanding of the initial case context (C) is needed, for which the design proposition suggests a certain intervention (I), to produce, through specified generative mechanisms (M), the intended outcome (O). This logic has some parallels with research strategies that employ middle-range theory (MRT) to generate knowledge.

According to Russo et al. (2021), "middle-range theorising produces a detailed narrative of causal processes and the conditions under which those processes generate outcomes". For them, the main elements of this approach consist in using empirical evidence as to the starting point to ground theory, providing a detailed casual narrative that links context with mechanisms and outcomes. However, contrary to DSR, Stank et al. (2017) state that the starting point for MRT is not necessarily empirical evidence. Knowledge may be deduced from research that was originally motivated by general theory. General theories are framed in abstract terms and intend to explain regularities (Pawson and Tilley, 1997), meaning that any subject in a particular discipline can be explained through the lens of that theory. Those general theories are critical if one needs to understand how the mechanisms work and conduct rigorous research. As noted, "good" theory is crucial for any prescriptive research, as it is in DSR, since accurate prescription can only be based on sound understanding. Without it, researchers would most likely end up with incomplete solutions or counterproductive results (Fawcett and Waller, 2011). Therefore, DSR can be viewed as a combination of the explanatory power of MRT with the interventionist nature of action research while feeding on established knowledge developed by general theories to create new design-orientated knowledge. These interrelationships are represented in the Figure 5.3.

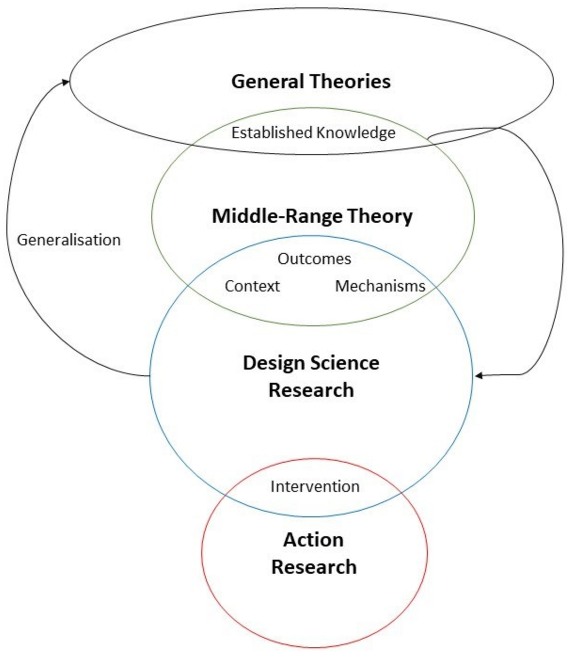


Figure 5.3 – Theory Building in DSR strategy

To defend a middle-range approach in supply chain management research, Stank et al. (2017) reference Fawcett and Waller (2011, p. 5) call for “research that accurately and confidently describes the world around us, explains how key relationships work, prescribes appropriate strategy and behaviour, and sets the stage for further inquiry”. The belief when selecting DSR as the appropriate research strategy of this Thesis was that given its characteristics, a design science approach is best to allow both explanations regarding the underlying mechanisms of 3-DCE adoption, but also influence behavioural change in practical projects.

5.4.3 DSR in O&SCM research

Van Aken et al. (2016) offered advice on how researchers might approach DSR. They advocate the natural approach should “analyse a problem, design a solution, develop in further cycles of testing and redesign it” (2016, p. 2). Nevertheless, they avoid delineating specific research methods for applying DSR, empathising that DSR serves more as a research strategy rather than a concrete methodology. Hence, to identify a suitable framework for applying DSR in this Thesis, a systematic literature review (SLR) of DSR in O&SCM research was conducted.

The SLR followed the guidelines introduced by Tranfield et al. (2003), then adopted by other authors (Matopoulos, Barros, et al., 2015; Seuring and Müller, 2008). Figure 5.4 explicitly states the review process. This review included all articles published until the end of 2021 on the databases illustrated in that figure. From a very early review, it was understood that a significant number of articles referenced Hevner et al. (2004) and Peffers et al. (2014). Those articles were removed from the final selection due to being from the Information Systems field. To guarantee high quality of information and minimise errors, only scholarly peer-reviewed articles written in English were included. A full analysis of the final 16 articles was conducted to identify the main methods employed in DSR strategies in O&SCM, as well as the main problems and opportunities that were tackled. The analysis of the selected articles can be consulted in the Appendix of this Thesis.

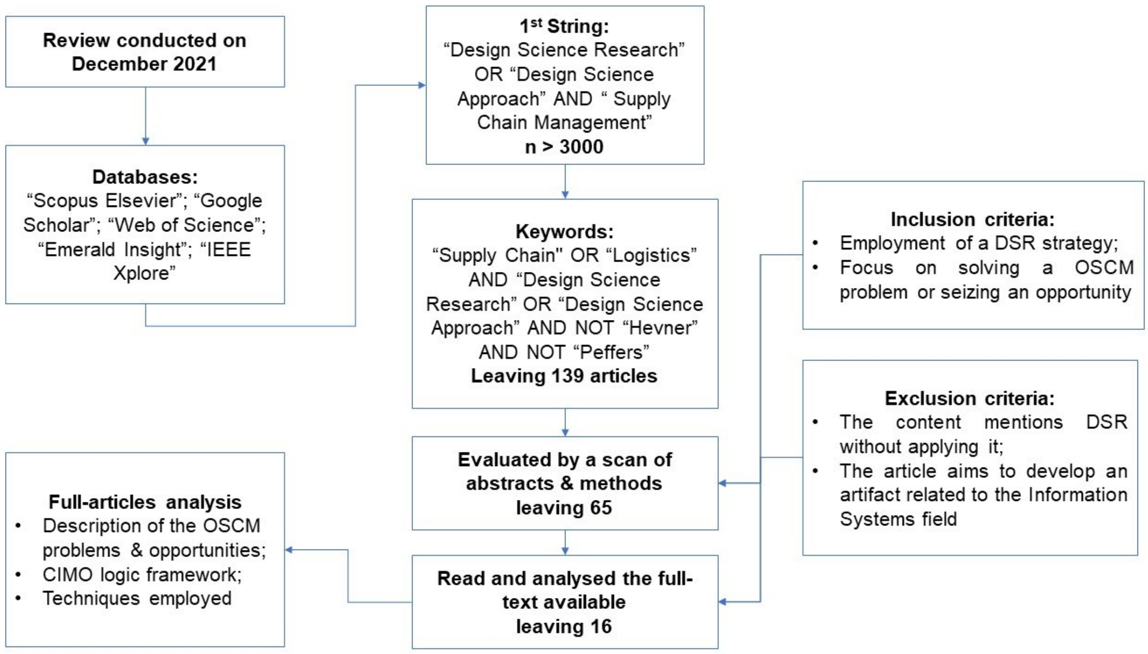


Figure 5.4 – Systematic Literature Review on DSR in O&SCM

The number of articles using a DSR strategy to solve real O&SCM problems. The use of DSR frameworks is providing impactful intervention outcomes that are be grounded in existing theory. Still, Van Aken et al. (2016) warned that using DSR requires particular effort on the part of the research team. Moreover, the correct philosophical assumptions are critical for the successful implementation of this strategy. Above, the argument for the selection of this strategy in this research project was clearly established.

As expected, no fixed set of methods were identified in the reviewed studies that followed a DSR strategy. Nevertheless, a significant number followed some combination of a literature review on the topic at hand, complemented by a stage of in-depth interviews with participants involved in the researched problem, and setting up some type of case research to field test the designed intervention. Some of the selected articles elected to conduct collaborative research under the umbrella of DSR (Wang et al., 2021; Akkermans et al., 2019; Chaudhuri et al., 2013). Others did not label their methodology selection as DSR, but their research strategy followed a design science philosophy (Messina et al., 2020). Most reviewed articles only reported their field test in one context, raising concerns about generalisation or the validity of their grounded technological rules. Particular exceptions are Wagner and Thakur-Weigold (2018) who implemented their educational intervention for a period of three years in ten different locations and Messina et al. (2020) who collected data from three different organisations in from different sectors. However, it is important to note that the reality of academic publication can lead to this outcome. For instance, the reviewed article of Kunz and van Wassenholve (2019) is the final part of a full DSR project that was first published elsewhere (Kunz et al., 2015).

As discussed, the DSR strategy is particularly well-suited to devise scientific solutions for problem solving. The main problems tackled in the reviewed articles can be defined as ill-structured problems. Those are problems that are not encountered in the same form, for which there is no definitive formulation, and their solutions are either good or bad based on their unique outcomes (Wagner and Thakur-Weigold, 2018; Mintzberg et al., 1976). This finding is consistent with Holmstrom et al.'s (2009, p. 67) understanding of design science, *"which specifically focuses on tackling ill-structured problems in a systematic manner"*. In their journey to solve these problems the researcher needs to address the underlying systems and behaviours that led to the problem.

Therefore, the CIMO logic presents a valuable means for conducting DSR. Yet, distinguishing between context and mechanisms is not straightforward. Well defined contexts and mechanisms will help that the design interventions can produce the desire outcomes (Denyer et al., 2008; Pawson and Tilley, 1997). However, this logic does not follow a fixed direction. For instance, Akkermans et al. (2019) first reviewed the outcomes and then they analysed the mechanisms when applying this logic. Their approach is aligned with Dunbar and Starbuck (2006) claim that the designers should let themselves be surprised with the outcomes before making any assumptions about the components of design. Furthermore, the context is not the sector of activity but rather the dynamics that existed prior to the intervention and would be changed by the former action on the mechanisms, as clearly shown by Reich et al. (2021).

Reich et al. (2021) designed an intervention by understanding the mechanisms, constructing the design framework, field-testing, feedback, and refinement. Furthermore, Naim and Gosling (2022) consider a systems approach to design science embracing methodological pluralism. Adapting their views on DSR, a framework was developed based on the CIMO logic to operationalise the research strategy in this Thesis. The framework consists of four pillars. Starting with a reasoning approach for this type of research strategy. Then, the identification of the context and mechanisms of the research problem. Followed by the development of an artefact or design to solve the problem. Finally, the combined research findings are grounded in technological rules or instructions for embedding DfSC behaviour into NPD projects. Figure 5.5 depicts the proposed research strategy framework.

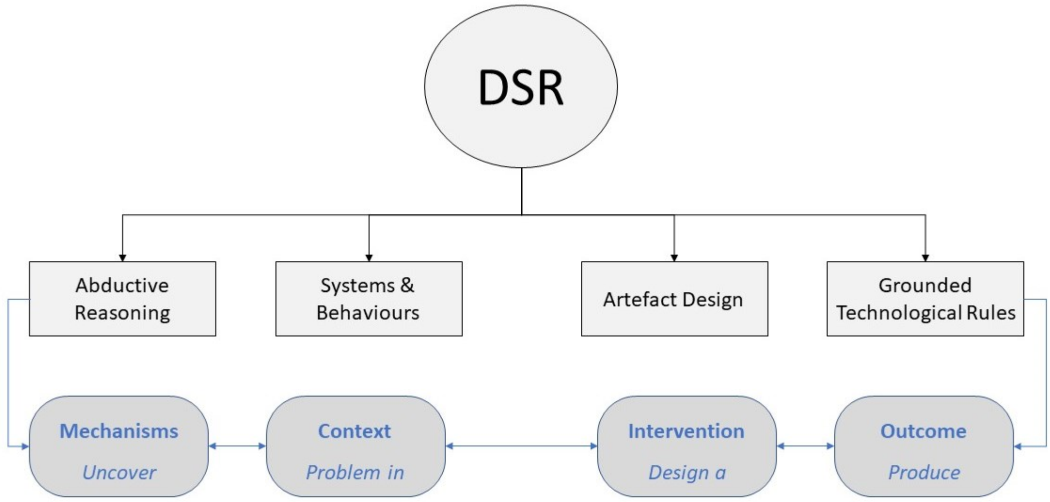


Figure 5.5 – Framework for DSR operationalisation

5.5 Operationalising DSR

The research methods to operationalise this research strategy were selected based on each stage of the framework depicted in the figure above. The proposed solution for DSR strategy works through an iterative-creative process, in which the researchers combine literature with their observation in case contexts to prescribe propositions for practitioners (Busse et al., 2017). Thus, the research strategy comprises different research methods structured in a multi-stage format to address the complexity of 3-DCE in the pursuit for a solution to the research problem.

Introduced in Chapter 3, the first stage comprises a comprehensive synthesis of case studies related to the scope of this research that elucidate the mechanisms that trigger the research problem, thus offering preliminary insights into RQ1. Simultaneously, Chapter 6 details a vignette-based experiment founded on a product development scenario where variables related to product, process and supply chain design decisions are manipulated. This experimental approach enables the investigation of managerial perceptions of 3-DCE trade-offs and their implications for decision-making.

Following this, the methodology enters the artefact design stage with the gamification of the previous scenario. This stage is presented in Chapter 7, elaborating on how the gamified elements shape the psychological experiences and states of the participants, thereby exerting a direct impact on their behavioural decisions. In addition, two workshops were delivered centred on both the initial scenario and its gamified counterpart.

The final stage of this research aims to extend or generalise its contributions beyond the immediate context, targeting the advancement of a general theory for practical adoption. Specifically, Chapter 8 proposes a revised roadmap for “Design for Supply Chain” implement and how organisations can embed such behaviours within their teams, which is posited as a pivotal addition to the existing body of knowledge around 3-DCE research.

Next in this section, the rationale behind the selected research methods is explored, delineating the general principles of each method. The specific details pertaining to the data collection process, as well as assessments of reliability and validity, are presented within the respective chapters.

5.5.1 Research Synthesis

The research synthesis is a systematic review methodology developed by Pawson (2002), referred to as realist review. At its core, this method aims to focus on understanding the mechanisms through which a programme or intervention works, as well as the contexts in which it is successful or unsuccessful. The process is methodologically structured by Pawson et al. (2006) into five key steps. The method starts by clarifying the scope of the review, which frames the review question, refining the purpose of the review, and articulating the key intervention to be implemented. Next, the searching for relevant evidence ensues, involving a thorough search for evidence that contributes to the understanding of the intervention. Also, the researcher involves appraising the quality of the evidence, meaning testing its relevance and rigour. The fourth step is the synthesis and extraction of the findings, ensuring that they resonate with the purpose of the review. Finally, drawing from these findings, the research should provide actionable conclusions and recommendations. Emphasising its utility, Pawson states that such reviews should be made relevant for decision-making.

Traditional systematic reviews and Pawson (2002)'s realist reviews bear differences in their purpose. While the former aims for completeness and comprehensiveness, the latter adopts search strategies designed specifically to make deliberate use of purposive sampling, aiming to retrieve materials purposely to answer the specific research question. The appropriateness of this type of review for a DSR strategy lies in its interactive or abductive reasoning, constantly weaving between literature and the research problem. Denyer et al. (2008) capture this argument, by emphasising that this approach is a valuable way of conducting literature reviews, for their ability to integrate diverse information sources, thereby providing an effective analysis of the interventions.

Despite its merits, conducting research synthesis is a challenging process. For instance, Denyer et al. (2008) suggest that given the diversity or content and methodology in management and organisation studies, achieving synthesis through aggregation can be a daunting task. Nevertheless, drawing on Pawson (2006) key steps, Denyer and Tranfield (2009) offer general guidelines to assist researchers in this task. The first step is to formulate review questions using the CIMO logic. That means, identifying the aspects of an organisational setting that are of interest; defining the intervention of interest; to identify the reasons that certain mechanisms are activated or not, and what are the relevant outcomes in reference to the setting. They advise that the location of the studies needs to be reported in some detail, reporting on the databases and Boolean logic for the searching process. Furthermore, the criteria for inclusion and exclusion must be communicated. Finally, the analysis step should provide a comprehensive summary of the studies, by cross tabulating the studies and identifying key issues that emerge.

Moreover, there are different forms that have been developed to help research cope with this. Rouseau et al. (2008) name four forms of research synthesis based on the aim, method, and data required for the synthesis. The aim of synthesis by aggression is to combine effects to increase sample size and reduce bias in answering specific questions. The aim of synthesis by integration is to synthesise across different methods to answer specific questions and to explore when interventions are more likely to succeed. The aim of synthesis by interpretation is to synthesise and interpret research to build higher-order constructs, including patterns of social construction. The aim of synthesis by explanation is to create explanations and generate theory. Table 5-C presents these forms including their strengths and weaknesses.

Table 5-C: Forms of Research Synthesis
adapted from Rousseau et al. (2008, pp. 492, 493)

Synthesis by	Goal	Method	Data	Strengths	Weaknesses
Aggregation	Predict intervention results; Reduce bias	Combination of primary studies	Published and unpublished studies	Minimal method bias, precise, systematic, replicable	Not useful in complex/ diverse contexts
Integration	Explore the appropriate contexts of an intervention	Triangulation, Reviewer judgment	Typically published studies	Highlights promising interventions	Difficult to replicate
Interpretation	Create tentative theories of the phenomena	Compilation of studies, transform existing concepts into new categories	Published studies with qualitative data on the subject	Takes context into account, using multiple qualitative studies	Coding relies on reviewer skills
Explanation	Generate theory	Discern patterns behind	Multiple forms of evidence accepted	Pragmatic focus on why and where	Highly dependent

		explanatory claims		interventions lead to outcomes	on reviewer skills

The research synthesis conducted in Chapter 3 to uncover the underlying mechanisms of DfSC implementation follows mainly a synthesis by interpretation. That is, a process of reinterpretation of the existing case studies in the pursuit of a new understanding of the challenges and requirements for the successful implementation of similar practices to the proposed DfSC concept. An illustrative example of this type of synthesis is Campbell et al. (2003). They conducted a meta-ethnographic analysis in health research, that preserves the interpretive qualities of the original data, still leading to an extension of the studies' findings. Similarly, this review analysed different case studies in NPD projects with different purposes, extending the original qualitative data to grasp the pivotal mechanisms for the effective introduction such behaviours in organisations.

The primary goal of the research synthesis was to propose roadmap for DfSC implementation, thereby establishing the conceptual framework that underpins this Thesis. To organise the underlying mechanisms into this proposed roadmap, a Soft-Systems Methodology (SSM) was employed. Specifically, the holonic template of the PrOH modelling technique were used for this purpose. Echoing the research synthesis by interpretation, Clegg and Shaw (2008) state that enrichment or re-interpretation is an essential property of this method. Furthermore, the construction of a PrOH model follows a process orientated philosophy similar to the DSR strategy. In essence, this approach encompasses defining a process objective, gathering, and enriching the data, then implementing changes that improve the original process.

In conclusion, Checkland and Poulter (2020) endorse SSM as an effective approach to unravel complex, "messy situations" across various contexts. This endorsement underlines the soft system's capacity to facilitate learning that guides practitioners towards behavioural change. Hence, the utilisation of a SSM technique to construct the conceptual framework aligns with the objectives of this research. The effectiveness and applicability of this framework will subsequently be affirmed through the upcoming research stages.

5.5.2 Scenario-Based Experiment

The conceptual framework, in the research synthesis, underscores the importance of grasping the perception asymmetries of the individuals involved in product development projects. Hence, the next phase of the DSR strategy is to conduct a vignette or scenario-based experiment. Rungtusanatham et al. (2011) supports that these experiments are particularly well suited to understand how and why managers, when dealing with complex issues, form their judgments and behaviours that impact their decision-making processes. This method introduces an event or scenario to the participants while manipulating the variables the research aims to study. In this research the manipulated variables are the three dimensions of the 3-DCE model. Eckerd et al. (2020) warn that any manipulation of different scenarios should be realistic, therefore there is a clear connection between the use of this technique and realistic evaluation goals.

Lonati et al. (2018) offers a constructive criticism for experiment research, particularly by identifying the several threats to internal and statistical validity. Foremost, they doubt the ability of experiment research, such as vignettes, to determine if the decision-making of its respondents would translate into real actions. For one, they argue that participants often make decisions that have no real-world consequences. Likewise, they stress the importance of considering demand effects, those are “changes in behaviour by experimental subjects due to cues about what constitutes appropriate behaviour” (Zizzo, 2010, p. 75). In other words, the effects where participants change their behaviour based on what they believe the researcher wants to see.

Nevertheless, Lonati et al. (2018) concede that researchers can mitigate demand effects by using non-consequential manipulation checks conducted after the measurement of the main experimental outcome. Furthermore, researchers should make an effort to improve realism and avoid confusing the participants. In practice, what they are saying is when conducting a vignette study, researchers must correctly design their experiments and take into consideration the best practices and their trade-offs (Eckerd et al., 2020).

Eckerd et al. (2020) suggest addressing the challenges raised by Lonati et al. (2018) by applying the appropriate experimental methodology for the specific research question. In terms of designing a scenario-based experiment, the scenario needs to contain the essential information for the participants to understand the context, to avoid the participant to project their own experiences or prior knowledge to fill in the gaps. Regarding the effective manipulation of the variables, they advocate to keep the different treatments as similar as possible, while making the manipulations salient to the participants. They referenced Sommer et al. (2020) as a well-designed research experiment: they kept the research context as simple, they provided live feedback to enhance the realism process, and they clearly justify the target population. Eckerd et al. (2020) recommend reading Rungtusanatham et al. (2011) for further guidance on the best practices for conducting a vignette study,

Rungtusanatham et al. (2011) constructed a three-stage method for designing and validating a scenario-based vignette. Their work has influenced researchers that used scenario-based techniques (Mena et al., 2020; Wiedmer et al., 2020; Murfield et al., 2016). This research will consider this method for the design of the vignette of the Powertrain Scenario. Figure 5.6 illustrates the stages and their connections.

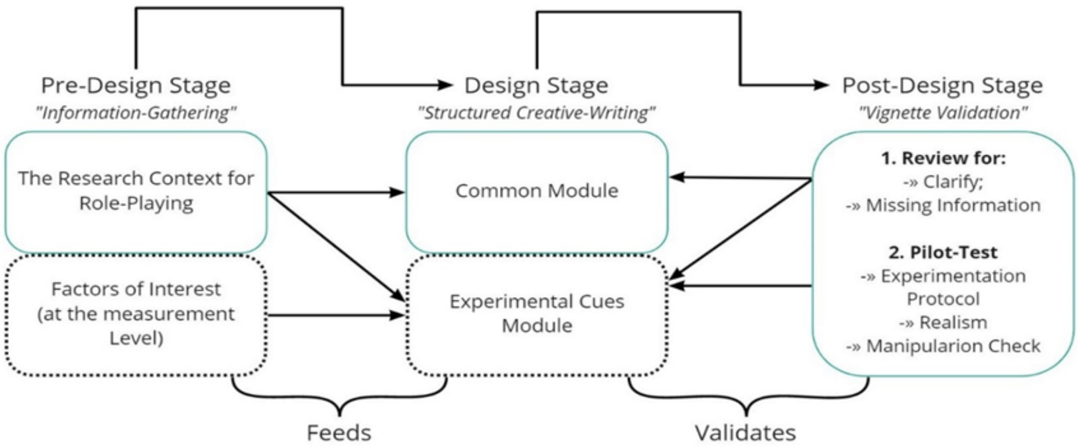


Figure 5.6 – Stages of Scenario-based Experiment design sourced from Rungtusanatham et al. (2011)

In the pre-design stage, the researcher needs to collect information on the topic that will be investigated, as in the theoretical design of evaluation research. In this phase, the researcher will establish familiarity that will resonate with the subjects of the experiment. The literature review on the topics addressed in Chapter 2 was critical to gain this familiarity.

In this stage, the researcher needs to understand how it will measure the results of the vignette experiment. Rungtusanatham et al. (2011) advised researchers to consult other academic in the relevant field that employed the same type of experimental studies. Following this advice, some studies that employed scenario-based experiments in O&SCM research were explored to determine how to treat the manipulated variables in the Powertrain scenario. Table 5-D summarises the consulted articles by type of technique to analyse the findings.

Table 5-D: O&SCM articles employing Scenario-based Experiments

Authors	**Journal**	**Problem Description**
Chen et al. (2016)	Journal of Purchasing and Supply Management	How buyers and suppliers perceive each other's behaviours and reaction in face of a critical supply disruption event
Murfield et al. (2016)	Journal of Business Logistics	How supplier role conflict impacts customer and supplier relational perceptions and future accommodation expectations

Ro et al. (2016)	Journal of Supply Chain Management	How the perceptual differences between buyers and suppliers affect the management of the existing business relationships in a situation of labor strike at the supplier's plant
Mena et al. (2020)	Decision Sciences	How decision-makers respond to situation involved risk and resilience in procurement and supply chain management
Wiedmer et al. (2020)	Journal of Supply Chain Management	How resource scarcity uncertainty impacts buyers' perceptions of scarcity threats affecting buyer-supplier relationships
Nagel et al. (2021)	Journal of Business Research	How trust is formed in the early-phase of the purchase-supplier relationship
Mir et al. (2022)	Journal of Supply Chain Management	How the supplier's tactics influence the perception of the buyer towards relationship restoration
Chen et al. (2022)	International Journal of Operations & Production Management	How the perceived future dependence influences the supplier motivation to share knowledge with a buyer, mediate via economic, relational, and learning motives

In the field of O&SCM, Ro et al. (2016) and Chen et al. (2016) conducted a scenario-based experiment to study buyer-supplier perception asymmetries. They argue that this approach offers several advantages, allowing participants to dissociate from their specific circumstances and reveal behaviours that they might otherwise conceal. In addition, Chen et al. (2022) follow the same method to study the supplier motivation to share knowledge. A scenario-based experiment was also employed by Murfield et al. (2016) to study conflict in the customer-supplier relationship. Also included were Wiedmer et al. (2020) which studied buyers' decisions on resource scarcity threats and Mena et al. (2020) which investigated supply chain risk at a decision-making level. Finally, Nagel et al. (2021) studied trust formation in the early phase of buyer-supplier relationships and Mir et al (2022) investigated the buyers' perception towards supplier's relationship restoration tactics. The methodological examination of these articles in the field of O&SCM allow the researcher to conduct its own rigorous experimental design.

For the Design Stage, Rungtusanatham et al. (2011) suggest the application of the principle of form postponement, separating the vignette into invariant written statements to provide contextual information (common module), and specific written statements about the factors of interest (experimental cues module), necessarily obtaining versions of the vignette. Pragmatically, they advise the researcher to construct and describe the setting that the respondent is intended to be inserted into. The final version of the Powertrain scenario is presented in the Appendix.

In the Post-Design stage, the vignette was reviewed in detail with the supervisors of this research project. Additionally, the vignette was test-piloted with former professionals involved in product development decisions in a large Automotive organisation. To avoid unclear, confusing, contradictory sentences and all necessary information was included in the pilot. Moreover, the vignette includes realism checks, adapted from Dabholkar (1994), to ensure plausibility and that the participants' selections are likely to reflect their decisions in the real world. These checks were added at the end of the experiment and assess the respondents' familiarity with scenarios as described in the vignette, if the respondents have encountered a similar scenario during their professional life, and if the respondents assumed their roles seriously during the completion of the experiment. Following Rungtusanaham et al. (2011) suggestion, the expected outcomes were measured using a five-point Likert response scale, from strongly agree to strongly disagree.

The Powertrain scenario was conducted throughout survey participation sent electronically via mail or direct message on LinkedIn and the findings are presented in Chapter 6. The experimental cues were manipulations of the 3-DCE concept at two extreme levels: product modularity (highly modular/ highly integral), manufacturing process changes (little change/ new core process), supply chain visibility (high/low), resulting in eight different experimental treatments. Furthermore, using Google Forms and Typeform, the participants were randomly distributed across the different treatments. As stated, a more detailed explanation of the data collection process is included in Chapter 6.

5.5.3 Gamification Process

The purpose of the next DSR stage is to design an artefact that facilitates behavioural change towards the implementation of DfSC principles, by closing perception gaps and allowing a better visualisation of design implications on the product lifecycle. The gamification of the original Powertrain Scenario was deemed appropriate as a boundary object that works as a mechanism for functional collaboration. Gamification is a term first coined by Nick Pelling, defined by Marczewski (2013) as the "application of gaming metaphors to real-life tasks to influence behaviour, improve motivation and enhance engagement". Therefore, an argument can be made that a Powertrain Game would retain the necessary characteristics to work as this boundary object.

Wood and Reiners (2012) provide some examples of the potential of gamification to improve the learning experience of logistics and supply chain students. Most notably, the Beer Distribution game, a role-playing board game that simulates a manufacturing supply chain and demonstrates the “bullwhip effect” (Sterman, 2002; Lee et al., 1997). But also, they mention the Fresh Connection, where teams compete to make strategic and tactical choices in the fruit-juice industry that demonstrate the supply chain impact on company profitability (Cotter et al., 2009). Similarly, Bahr et al. (2022) suggest gamification benefits for improved work engagement and productivity in warehousing activities.

The benefits of gamification lie primarily on the motivational properties. Gamification breaks down large tasks into small, manageable parts that provide a sense of accomplishment. This is then combined with the rapid feedback to create a structured way to increase effort, engagement, and attention. The immediate feedback can be enabled with IT systems for automated assessment (Wood and Reiners, 2012). The Powertrain Game was developed as an extension of the previous scenario with the help of the logic properties of Typeform. The game is explained in detail in Chapter 7 and the version that the participants saw can be consulted in the Appendix.

Hamari et al. (2014) break down the conceptualisation of gamification into three main parts: the implemented affordances to the game, the psychological motivations to engage with the game, and the behavioural outcomes that result from the game. Affordances refer to the various elements and designs that structure games and aid the induction of game-like experiences within the systems. According to Koivisto and Hamari (2019), the most common affordances in empirical research papers are achievement-oriented, involving various forms of points and scoring that result in rankings, challenges and clear missions. Also popular are social-oriented affordances, involving social networking elements, such as commenting and profile pages, or cooperation and team-based activities. Less popular are immersion-oriented affordances, involving the use of narratives or role playing to engage the player into a non-game scenario. The design of a game is a complex process which entails an understanding of the psychological motivations of the participants, since the goal of gamification is to affect behaviours.

Koivisto and Hamari (2019) relate psychological motivations to the general attitude towards the use of the gamified system. That means studying the perceptions of using such a system or practice (e.g., using 3-DCE principles in NPD projects). In large part they mention the affective physiological aspects associated with perceived enjoyment or user experience that captivates feelings of engagement. Additionally, the acceptance of the game is usually associated with the ease of use or effort required (Venkatesh et al., 2003). Further psychological aspects are associated with the cognitive side of psychological outcomes. Those are related to the perceived usefulness of playing the game, or the perceived ability to learn or discover something new and useful. Finally, social interactions or subjective norms influence the participants perceptions towards the behavioural outcomes of the game. In the preceding chapter provided a thorough analysis of subjective norms within the framework of Ajzen's (1991) Theory of Planned Behaviour, which asserts that these norms shape individual beliefs that in turn impact adoption behaviours.

The process of employing game features in non-game settings is met with numerous challenges. Notably, these are complex and multifaceted processes that require a great deal of motivational information. Deterding (2015) underscores this notion, advancing that game designers are unable to fully control or predict the goals and entailed challenges of their users and that there is a dominant expectation among scholars for positive outcomes from gamification, coupled with a deficit in empirical studies to detect potential negative effects. Yet, Wamelink et al. (2020) include some of these negative effects, suggesting that gamification holds the potential to be coercive or exploitative, by detaching workers from their intrinsic motivations. Consequently, they advocate for a nuanced approach to devising gamification strategies, taking into account individual, group, and cultural differences in motivation when designing gamification strategies, as one size does not fit all.

The most common behavioural outcomes that justify the gamification of real-life scenarios are to increase participation with the system, improve willingness to use, and promote enhanced performance. In fact, education is the main domain for gamification efforts, with Koivisto and Hamari (2019) calling for more studies of gamification in management and business contexts. They argue that contextual factors affect the outcomes of the gamification process, referring particularly to the domain of collaborative approaches in managerial contexts. In the case of the Powertrain Game, the goal is to close perception gaps between the three dimensions of product development by promoting collaborative learning. Therefore, the approach for the game's development adopts the mechanics, dynamics, and emotions principles from Robson et al. (2015), as well as Riar's et al. (2022) framework for game cooperation.

Riar's et al. (2022) framework, presented in the Appendix, is based on Chen et al. (1998) value driven cooperation theory, which states that people are motivated to cooperate based on both individualist and collectivist goals. Therefore, the affordances should be adapted to the target population. For instance, participants with greater needs for relatedness may appreciate a collective design approach, whereas people with greater needs for autonomy or competence may find individualistic or hybrid design interventions more appealing. The collective approach motivates participants by emphasising on social-oriented affordances, such as social rewards or social recognition. The individualist approach motivates participants by focusing on achievement-oriented affordances, such as rewarding individuals for engaging in cooperative behaviour via personal progress. The hybrid approach blends the social aspects of gamification with achievement-oriented goals, such as team competitions. Moreover, Riar et al. (2022) speculate that the game design features can influence the individualistic or collectivistic attitude, particularly relevant to the purpose of the Powertrain design.

The Powertrain Game, introduced in Chapter 7, was crafted utilising a hybrid approach, aiming to establish a boundary object grounded in the Theory of Planned Behaviour (Arellano et al., 2021; Ajzen, 1991). Moreover, the game design is in anchored on a combination of narrative, goal, and score features, offering a multifaceted approach to gamification. A detailed expansion of this gamification design process is delineated in the aforementioned chapter, providing an in-depth exploration for the problem of embedding *"Design for Supply Chain"* behaviour into collaborative NPD projects.

5.5.4 Workshop Delivery Sessions

The findings derived from the previously mentioned stages of the DSR strategy, encompassing both the scenario and the game, have been completed through discussions with industry representatives in workshop settings. These workshop sessions are pivotal to operationalise the abductive reasoning process as they represent what Kovács and Spens (2005, p. 139) refer to as "theory matching", or linking theory with practical observations. Additionally, these sessions play a critical function in establishing pragmatic validity, since in a DSR, validity is fundamentally anchored to the effectiveness of the artefact design in yielding the desired outcome (Van Aken et al., 2016, p. 5). Figure 5.7 denotes the positioning of these workshops within the overarching research strategy, following Kovács and Spens' (2005, p. 139) framework for the abductive process.

The workshop sessions were organised as focus groups. Similar to using focus groups, the participants of the workshop focus on a particular topic, in this case the scenario or game design to explore DfSC implementation (Saunders et al., 2023, p. 484). The aim of conducting the workings in a focus group setting is to enable interactive discussion that goes beyond the pre-held views about these principles. Participant interaction is the hallmark of the method, allowing participants to challenge and support one another, leading to dynamic and potentially insightful discussion (Belzile and Öberg, 2012). Macnaghten and Myers (2007) highlight the roles of the moderator to facilitate this interaction, by managing the conversation and ensuring that it stays on track. The consultation of focus group members in workshop settings was used elsewhere (Rawboon et al., 2021; van Capelleveen et al., 2021; Nascimento et al., 2019) to explore the usefulness of a designed prototype for practical recommendations.

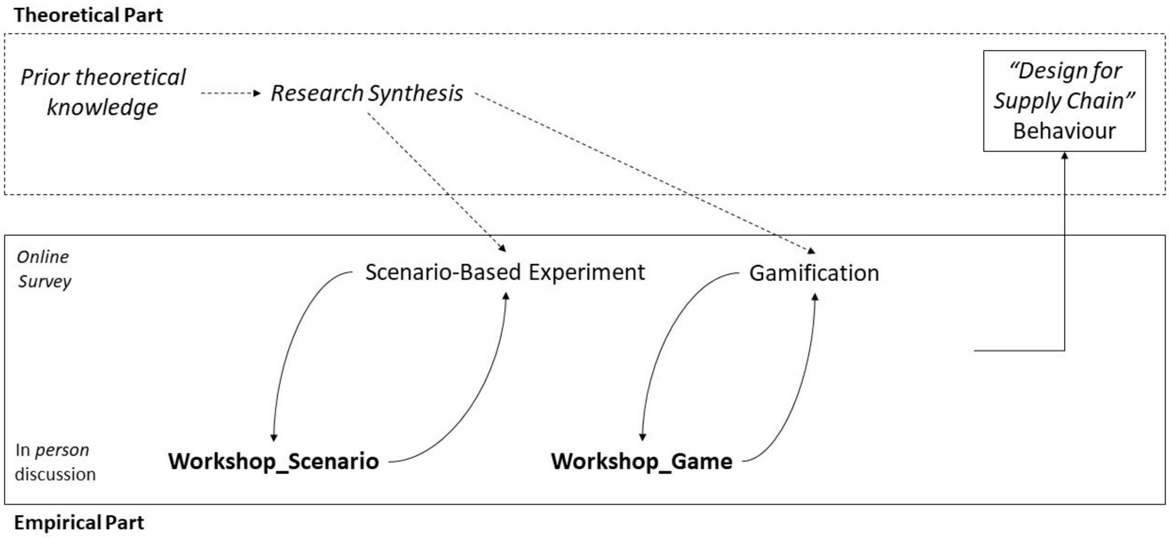


Figure 5.7 – Workshop positioning within the DSR strategy

The two workshop sessions were conducted with representatives from two large manufacturing organisations: a global player in the aerospace-defence sector, referred as WORK_AEROD, and an OEM in the automotive industry based in the UK, referred as WORK_AUTO. The first session, lasted 90 minutes and was conducted onsite, introduced, and discussed the results of the Powertrain Scenario with ten (10) members from WORK_AEROD. While the second session, lasted over 60 minutes and was conducted at Aston University, introduced, and discussed the Powertrain Game to fifteen (15) members from WORK_AUTO. Table 5-E provides information on the composition of the members of the focus groups that participated in these workshop sessions.

The emphasis on the automotive and aerospace sectors facilitates an in-depth understanding of the decision-making processes in NPD projects within discrete industries distinguished by distinct lifecycle speeds. The automotive industry pioneered various best practices, including "Design for X" and product life cycle management (Gmelin and Seuring, 2014; Hauser and Clausing, 1988). The accelerated clockspeeed, marked with increased competition and technology advancements (e.g. electrification), make it an ideal sector to study the implementation of DfSC principles. Likewise, the aerospace industry distinguished by its complex programmes, which require high levels of innovation, coordination of strategic alliances, management of long product lifecycles, and knowledge transfer (Matthews and Al-Saadi, 2021; Chaudhuri et al., 2013; Hobday, 1998), rendering the promotion of DfSC behaviours vital for the sector.

Both sectors involve highly complex decisions related to product, manufacturing, and supply chain designs. Additionally, they exhibit a global distribution of partners and significant levels of uncertainty throughout the product lifecycle. These characteristics make them ideal settings for examining the implementation of the proposed definition of DfSC principles in NPD projects within discrete manufacturing industries. Finally, their relevance for studying such topics is attested as these two industries collectively represent the majority of the peer-reviewed papers included in the Research Synthesis of Chapter 3.

Table 5-E: Details from Workshop sessions participants

<table>
<tr><th>Workshop Session</th><th>Industry</th><th>Company</th><th>Role</th><th>#</th></tr>
<tr><td rowspan="6">Powertrain Scenario</td><td rowspan="6">Aerospace & Defence Sector</td><td rowspan="6">WORK_AERDef</td><td>Supply Chain Executive – Defence Future Programmes</td><td>1</td></tr>
<tr><td>Project Manager</td><td>1</td></tr>
<tr><td>Programme Manager (Small Engines)</td><td>1</td></tr>
<tr><td>Commodity Lead</td><td>1</td></tr>
<tr><td>Strategic Buyer</td><td>5</td></tr>
<tr><td>Additive Manufacture Lead</td><td>1</td></tr>
<tr><td rowspan="7">Powertrain Game</td><td rowspan="7">Automotive Sector</td><td rowspan="7">WORK_AUTO</td><td>Project Analyst (Packaging)</td><td>1</td></tr>
<tr><td>Project Analyst (MP&L)</td><td>1</td></tr>
<tr><td>Programme Manager (MP&L)</td><td>5</td></tr>
<tr><td>Senior Project Analyst (MP&L)</td><td>1</td></tr>
<tr><td>Senior Programme Manager (SC Planning)</td><td>1</td></tr>
<tr><td>Programme Manager (SC Planning)</td><td>5</td></tr>
<tr><td>Supply Chain & Logistics (Degree Apprentice)</td><td>1</td></tr>
</table>

The Gioia methodology, as delineated by Corley and Gioia (2004) and further expanded by Gioia et al. (2013), served as the principal analytical framework for the empirical data derived from the workshops. This method represents a systematic approach to qualitative research, striving to balance the innate creative potential of such research with the demands of academic rigour. The data collected is systematically categorised, facilitating the emergence of themes and concepts, as illustrated in Figure 5.8. This process involves the construction of a data structure that aids in the formulation of a grounded theory model, aiming to synthesise empirical data with advanced theoretical insights. Notably, the selected methodology mirrors both the synthetic work from Chapter 3, but also the process towards grounded technological rules integral to the DSR strategy.

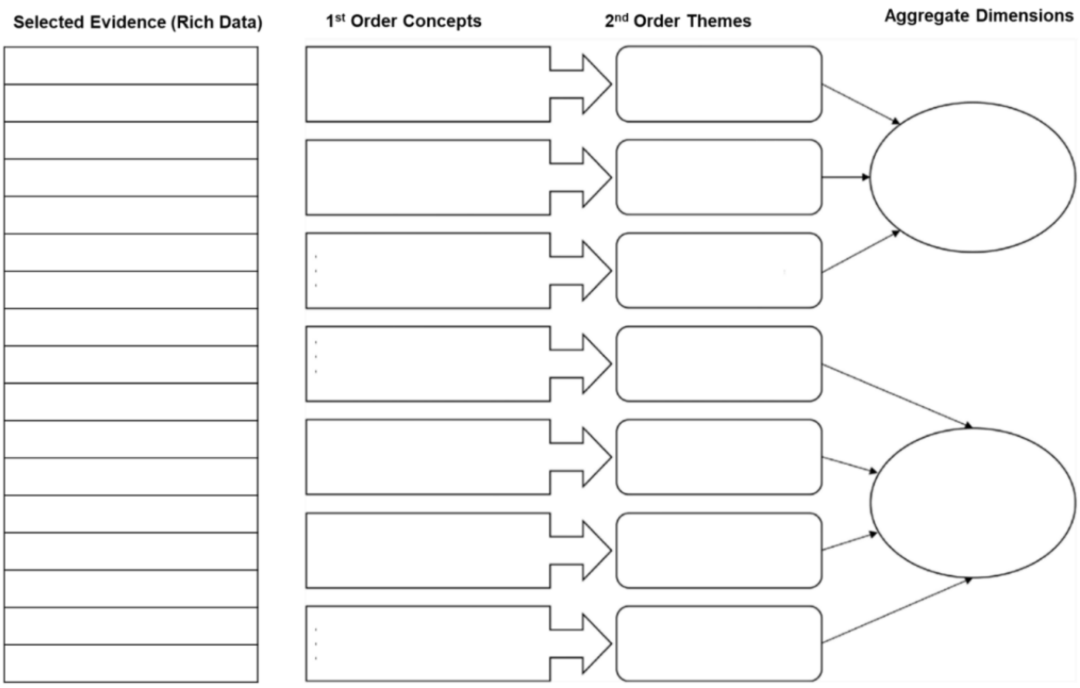


Figure 5.8 – Gioia's data structure
reproduced from Corley and Gioia (2004) and Gioia et al. (2013)

5.6 Validity and Reliability

The measures to ensure methodological rigour, high reliability and validity of data collection and analysis are presented in each of the Chapters where each of the aforementioned methods are explained in detail. Notably, the results from the focus group of the gamified scenario were validated with post-interviews with experts on the field. Moreover, for each stage, this research followed guidelines and recommendations from several academics (Clottey and Benton Jr, 2020; Schoenherr et al., 2015; Gioia et al., 2013; Rungtusanatham et al., 2011; Denyer and Tranfield, 2009; Craighead et al., 2007). Finally, following the lead of Ellram et al. (2020). Table 5-F presents a summary of some of the key actions that were applied to ensure validity and reliability.

Table 5-F: Key actions that ensure validity and reliability

Factor	Description	Actions Taken in this Thesis
Internal Validity	Establish a causal relationship as distinguished from spurious relationships	• The conceptual framework was derived from evidence synthesis. • Theory triangulation was used with theories of organisational behaviour (such as theory of perceived behaviour and boundary object theory).

		• Different bodies of literature were used as a means to interpret the findings
Construct Validity	Establish correct operational measures for the concepts being studied	• Data triangulation using survey data, interview data, and observations in workshop settings. • Drafts of the workshop and interviews were reviewed by the key informants. • Establish a clear chain of evidence. • Clear explanation on how the data was collected and stored. • Explanation of data analysis procedures.
External Validity	Establish prove that research findings can be generalised	• Empirical data collection from different organisations in diverse sectors. • In the Experiment and Workshops, collecting data from multiple respondents inside each organisation. • Data provided on the context of the individual cases.
Reliability	Establish that the research methods can be repeated, with the same results	• Developed both workshop and interview protocols. • Detailed report on how the each of the research stages were conducted. • Created, managed, and maintained a research database.

5.7 Ethical considerations

This Thesis has considered the ethical issues inherent to academic research, from formal rules, such as the Data Protection Act 2018 ("DPA") and the General Data Protection Regulation (EU), to informal rules, such as ethical and moral standards. Moreover, to comply with Aston University's regulation, an ethical application form was submitted and approved to the School Ethics Committee. The ethical approval process aims to ensure that the research methodology conforms with commonly agreed academic standards of good practice and to Aston's Ethics Framework. This process requires the researcher to share all relevant information regarding the research methodology, the interview and workshop protocol, to provide a template for participation information sheet and informed consent form. The data collection process only started once the School Ethics Committee approved the ethical application, which happened in November 2021.

The participants in this research were informed how their personal data will be kept confidential, the potential benefits for taking part on this study, as well as the possible risks and burdens of participating in this research. Furthermore, the participants were given access to a transparency statement by Aston University as sponsor of this study with access to the link of the regulations and statutes of the University: https://www.aston.ac.uk/about/statutes-ordinances-regulations/publication-scheme/policies-regulations/data-protection. Additionally, prior to participate in the research, the participant had to agree that they read the study information, that their participation is voluntary, that they agree that their data would be processed as described in the Participant Information Sheet, that they have the opportunity to opt out of the research invitation at any time, and that they agree to take part in the study.

Overall, the research methodology was designed to maximise the good outcome of the research, while mitigating any potential risk or hazard to the participants. The following factors were considered: protect the privacy of the participant and associate data, ensure that the participants are not coerced, carefully store, handle, analyse and disseminate the data. Most notably, this research endeavoured to protect and honour the rights and dignity of the individuals that agree to participate, and balance the benefits of the participants in the study (Sieber, 1998),

5.8 Anticipating the Next Chapter

This chapter attempted to outline the diverse methods adopted in this research, explaining the rationale for the selection of the specific methods in line with the Design Science Research (DSR) strategy. Furthermore, the chapter demonstrated how the chosen research strategy, together with the researcher's philosophical stance, and abductive approach to theory building are in line with the main objective of this thesis. Therefore, this chapter acts as a critical point of connection between the theoretical underpinnings and the practical aspirations of this research, establishing a solid foundation for the comprehending the thesis.

The thesis now progresses into its empirical stage, following the establishment of the research objectives, theoretical perspective, strategic methodology and conceptual framework in the previous chapters. The next chapter presents the findings from the scenario-based experiment aimed at comprehending the managerial perception gaps within NPD projects. These asymmetries, crucial underlying mechanisms identified in the research synthesis, are pivotal in understanding the dynamics at play in the effort to develop a DfSC behaviour.

6 FINDINGS FROM THE PERCEPTION ASYMMETRIES IN DFSC

6.1 Overview

The primary aim of this chapter is to unpack the managerial perceptions regarding the original 3-DCE framework and how they impact their decision-making within NPD projects. As stated, this investigation was conducted through a scenario-based experiment, a well-suited method to study this perception by placing the participants into a potential real-world scenario of the development of a powertrain of a new electric vehicle (EV). Overall, this chapter is a first effort to empirically comprehend the crucial role of perceptions in O&SCM research.

The first part of this chapter centres around the scenario-based experiment, which uncovers the intricate behavioural dynamics in aligning product and supply chain designs. The experiment's results highlight persistent gaps in functional perceptions, as revealed by their responses to the manipulations of the scenario. These findings lead to the recognition of certain patterns, potentially enabling researchers to devise more effective solutions for bridging these discrepancies. The analysis extends to offer a deeper understanding to these nuanced results.

The second part of the chapter transitions to applying the scenario in a practical context. Specifically, the scenario was tested during a workshop, formatted as a focus-group session, involving members of an integrated project team from a leading Aerospace and Defence organisation. This critical section of the chapter serves a dual purpose: to validate the findings from the data collected in the scenario-based experiment and to set the stage for the subsequent phase of this research. The discussion generated from this workshop setting provided valuable insights towards fostering DfSC practices within this kind of NPD projects.

In summary, this chapter acts as a bridge, connecting the perception mechanism within the conceptual framework and the theoretical dimension of the DSR strategy as described in the previous chapters with the real-world behaviour towards the adoption of 3-DCE in NPD projects. It is here that the complexities and intricacies of functional perceptions within this context are brought to the fore, offering novel insights for both academics and practitioners.

6.2 The importance of perception asymmetries

Earlier, within the conceptual framework, the importance of understanding perception gaps in NPD projects was established. These perception gaps, acting as friction mechanisms, hinder the nurturing of DfSC behaviours in NPD teams. From the reviewed cases, Mikkelsen and Johnsen (2019) study on an innovative project showcases the importance of perception asymmetries. Particularly, the transition of the purchasing team of the focal company, traditionally focused on cost optimisation, towards a more proactive role in new technology sourcing. The team was faced with initial challenges due to a lack of maturity and competences for this new role. This case also illustrates how different organisational perceptions impact investment cycle decisions, with the main supplier and the focal company contrasting investment approaches due to their differing perceptions regarding the technology uncertainty of the project. This example underscores the significant impact of functional and organisational perception differences on cross-functional integration and investment strategies.

This chapter emphasises the critical role of addressing perceptual gaps in achieving successful NPD outcomes. Particularly, this research argues that misaligned behaviours constitute the major barrier to adopting DfSC principles. Knowing where those perceived differences manifest within the three boundary dimensions of the original 3-DCE framework might contribute to a better understanding of each dimension and clarify decision-making behaviour. Recognising and addressing these asymmetries is therefore key to successfully implementing DfSC principles in NPD.

6.3 The Powertrain Scenario

6.3.1 Introduction to the Experiment

The purpose of this chapter is to complement the 'Systems & Behaviours' stage of the DSR strategy by addressing and answering the investigative question: *How do decision-makers perceive changes in product, process, and supply chain design in NPD projects?*

The scenario-based experiment enables researchers to manipulate the variables of interest and accurately assess their effects on the studied outcomes (Eckerd et al., 2020; Ro et al., 2016). This method was deemed particularly useful in studying perceived differences within the 3-DCE concept's dimensions. Moreover, it addresses one of significant the research gaps identified in literature review. As Hansen and Ahmed-Kristensen (2011, p. 223) state, there is a sharp contrast between how theory portrays solutions for NPD, such as 3-DCE, and the practical experiences in organisation. Therefore, studying managerial decision-making attitudes is essential to bridge this gap. The scenario-based experiment, in this chapter, is employed as an empirical tool to bridge this gap.

This method, also referred to as the vignette experiment, presents a realistic scenario to the participants in which the experimented variables are manipulated. According to various authors this approach is particularly suited to the study of attitudes and perceptions (Eckerd et al., 2020; Eckerd, 2016; Rungtusanatham et al., 2011). Elsewhere, in the previous chapter, concerns from Lonati et al. (2018) were raised about ensuring that the decision-making behaviour of the respondents correspond to real actions. Eckerd et al. (2020) addressed those by proposing some suggestions for rigorous experimental research. For one, vignettes should be realistic and relevant to the research objective. Additionally, the variables of interest should be manipulated in a clear and consistent manner. The experiment should be matched as close as possible to the research context being studied. Therefore, the sampling approach should be specific to the context of the experiment, meaning generalisable only to specific samples.

The manuscripts from the consulted articles, in Table 5-D, contributed for the design of the vignette for the Powertrain Scenario, despite not studying manipulations in the context of NPD projects. On top of that, the articles provided a significant contribution towards the analysis of the manipulation checks. Like this study, they also aimed to understand how different factors influenced the decision-making process of their participants. Therefore, the techniques these articles employed were a valuable source of information on how to improve sample quality, construct validity, measure verification and reliability of the selected techniques used to analyse the results of the experiment.

6.3.2 Vignette Design

The experimental design followed the thee-stage process recommended by Rungtusanatham et al. (2011), outlined in Figure 5.6. For the predesign stage, the review of the literature in the fields of product development, cross-functional integration, and 3-DCE was conducted to include the appropriate context for the possible vignettes and scales, described in the previous section. Additionally, at this stage, this study used a number of manuscripts that employed vignette studies to familiarise with the design process of these experiments, namely those in Table 5-D. For the design stage, a baseline vignette was developed where participants assume the role of a project manager responsible for the design of a new Electric Vehicle (EV) powertrain.

The designed vignettes are structured in two groups, an initial common module and ending with an *experimental cues module*, following Rungtusanahtam et al. (2011) recommendation and as implemented by Mena et al. (2020). The common module, presented to all the participants, a high-value manufacturing OEM, recognised for luxury and high-performance cars, which decided to introduce a fully electric sports car. The role of the project manager is to lead a cross-functional team responsible for designing the new EV Powertrain. The metrics for success of team are to ensure reliable supply, mitigating any potential bottlenecks at the production state, while assuring cost efficiency, targeting the cost of the new powertrain below

51% of the total cost of the EV. Finally, the experimental cues module, which differed for each vignette, included the manipulation of the three dimensions of 3-DCE: product modularity, changes in manufacturing processes, and supply chain visibility.

As explained in the previous section, these dimensions were selected to ensure that participants are cognisant to the practical implications of 3-DCE in NPD projects. Therefore, in the experimental cues module, each dimension was manipulated to constitute a between-participants research design with a 2 x 2 x 2 independent factorial design. That is, a total of eight different treatments were presented: 2 product modularity (highly modular/ highly integral) x 2 manufacturing process changes (little change/ new core process) x 2 supply chain visibility (high/ low). The vignettes with the different treatments were randomly allocated to the participants. Finally, the participants were asked to respond to a questionnaire that evaluate their perceptions on the degree of supplier participation, the ease of component interface, and NPD performance in terms of cost, quality, and delivery. These manipulation checks were implemented using a five-point Likert scale questions (Strongly Disagree – Strongly Agree) to determine if the treatments elicited the expected responses (Mena et al., 2020; Murfield et al., 2016). The vignettes and questionnaire for the different treatments can be found in the Appendix.

For the post design stage, the initial design and the questionnaire was test-piloted and discussed in-depth with an independent academic with over twenty years of professional experience in the automotive industry in strategic planning related to the launch of new vehicles, as well as continuous feedback from colleagues in the Engineering Systems & Supply Chain department at Aston University. Besides, the questions included for the manipulation checks were drawn from relevant literature in the outcome variables (Salvador and Villena, 2013; Selldin and Olhager, 2007; Fixson, 2005). Additionally, similar to Murfield et al. (2016) and Chen et al. (2022), two realism checks items were adapted from Dabholkar (1994) to ensure that the different scenarios were perceived to be believable.

6.3.3 Proposition Development

In this section, the proposed model is constructed with baseline propositions regarding the embedded relationships as established by the relevant literature. The development of propositions rather than hypothesis is a conscious choice to underline that the goal in this stage is not to test a conceptual model, but rather to empirically evaluate the behavioural effects of manipulation of the dimensions of 3-DCE. Propositions are used here in a broad sense of the term, meaning serving as guiding statements that generate insights without the constraints of formal hypothesis testing. This approach is consistent with the reflection by Cornelissen et al. (2024) which make a case for a pluralistic system of knowledge production away from the hegemonic position of the propositional style. By using the vignette-design as a stage within the DSR strategy, the study remains open to exploring how decision-makers perceive and react to changes without the prescriptive nature of hypothesis testing, which is more suited to confirmatory research aiming for prediction and explanation.

The selection of variables to represent each dimension of the 3-DCE framework was informed by the revised articles in Chapter 3 as well as pilot testing and discussions with a professor experienced in product development projects informed the decision. Prioritising variables that were both relevant to the dimensions and easy for participants to undestand was essential to ensure the effectiveness of the scenario-based experiment. Therefore, while none of the selected variables are explicitly writing into scenario (see Appendix 11.4), they are informed by their definitions in the literature.

Previously, Eckerd et al. (2020) advised that scenario-based experiments must be clear to participants and reflect “real life” experiences without being overly dense or broad in scope. In the case of the proposed scenario, given the complexity and wide range of NPD decisions, the manipulated variables focused on a specific element of each dimension of the original 3-DCE framework. For example, modularity decisions were chosen to represent the product design dimension, given the critical impact of these decisions on manufacturing and SCM (Frandsen, 2017). Similarly, process flexibility, represented by the effects of changing manufacturing processes, was selected to represent the process decision dimension, as those effects are well-understood in manufacturing industries (Kumar et al., 2020). Finally, supply chain visibility was chosen to reflect the supply chain dimension of the 3-DCE framework because of the recognised role of information sharing in achieving supply chain alignment (Deng and Marsillac, 2019; Caridi et al., 2017). In summary, product modularity (PM), manufacturing process changes (MPc), and supply chain visibility (SCV) are the manipulated variables concerning each dimension of the 3-DCE framework.

The propositions were developed by considering the effects that each manipulated variables have on selected outcomes. For this experiment, the selected outcomes were supplier participation (SP) in the design process, the ease of component interface (IE) within the manufacturing process, and, most notably, the perceived effects on the manipulations on NPD performance (NPDPerf) in terms of quality, cost, and delivery. The proposed effects reflect the findings from the literature review presented in detail in Chapter 2 of this Thesis.

Modularity

The review on product design literature highlight product architecture as a key development decision from an engineering perspective. As seen, Ulrich (1995) define product architecture as the scheme for allocating the products’ physical components to a particular function. In essence, the degree of modularity of the product is consider the most important element of product architecture decisions. Modular products have one or a few components with well-defined functions and established interactions, while integral products have many components performing different functions, leading to complex interactions (Fixson, 2005).

Pashaei and Olhager (2015) highlight the relevance of modularity to both product and supply chain design decisions. In fact, Cutherell (1996) claims that integral architectures are often linked to increased product performance and reduced system cost, while modular architectures offer flexibility for changing the product and improving variety, delivery, and service requirements. While, Fine et al. (2005) developed a model which clearly displays the advantages of aligning modular products with modular supply chains. Similarly, Yassine and Wissmann (2007) argue that the design of a manufacturing process is often determined by the product architecture, as it significantly influences the flexible of assembly processes in response to product or interface alterations. Finally, Voordijk et al. (2006) claim that modularity in supply chain is characterised by greater autonomy granted to suppliers, implying that the need for supplier participation in the design stages of product development is reduced in more modular products. These, and other articles, contribute to the academic curiosity for the effects of modularity in product development decisions.

To showcase the effects of modularity, Gan (2023) created the figure below based on a dependency network model from Hackl et al. (2020). In short, product modularity enables flexibility by providing greater product variety without the need to completely redesign each component. They argue that modularity allows for greater process flexibility, therefore interface ease in the manufacture of the components needed for the different processes. Additionally, modularity associated with the supply chain domain allows for greater flexibility of transportation modes and inventory strategies, leading to shortening lead times. Still in the supply chain domain, they highlight that modularity can potentially provide greater resilience against supply chain disruptions. All in all, the effects of modularity in the different dimensions of product development are undeniable by the literature, the goal of the scenario-based experiment is to understand if those are perceived by decision-makers.

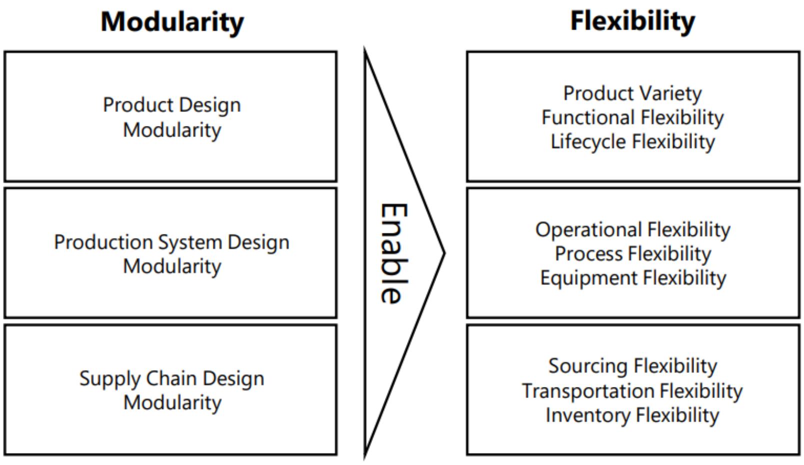


Figure 6.1 – Impact of modularity on flexibility sourced from TS Gan (2023)

Hence, the proposed expectation is that manipulations the product modularity variable would result in the following perceived outcomes:

> **P1:** A highly modular product will **(a)** decrease the level of supplier participation, **(b)** facilitate the interfaces between components, and **(c)** improve cost and delivery performance of the NPD project

Manufacturing Process Flexibility

The most common manufacturing process decisions, as delineated by Hayes and Wheelwright (1979b), include determining the appropriate mix of facilities, identifying the key manufacturing objectives such as batch size definition, utilisation capacity, plant layout, or production location. Manufacturing decisions play an important role in defining investment cycles since they are responsible for plant and equipment selection consistent with the process plans. Moreover, very early on, Slack (1983) recognise the role of flexibility as a manufacturing objective. Specifically, manufacturing flexibility aims to help organisations cope with uncertainties such as market acceptance of the product, length of product lifecycles, machine downtime, among others. Therefore, changes in manufacturing processes can cause significant effects on organisations.

Lu and Wood (2006) argue that the effectiveness of process design is contingent to the interactions between product designers and the factory. For instance, enhanced coordination can lead product designers to reduce meaningless changes and shorten engineering cycles, while process designers can make time-risk trade-offs more accuracy, thus adjusting faster to unexpected changes. In short, the authors realise that a practice and capable process engineering function can improve the performance of product realisation, particularly time-to-market. Additionally, Anderson (2003) states that successful interdependencies between product design and manufacturing process design are paramount to the definition of the quality strategy, given a significant part of quality costs occurs when the technical coordination is not achieved. Figure 6.2 illustrates these interdependence, based on a systemic map prepared by Clegg and Boardman (1996) of the manufacturing preparation process.

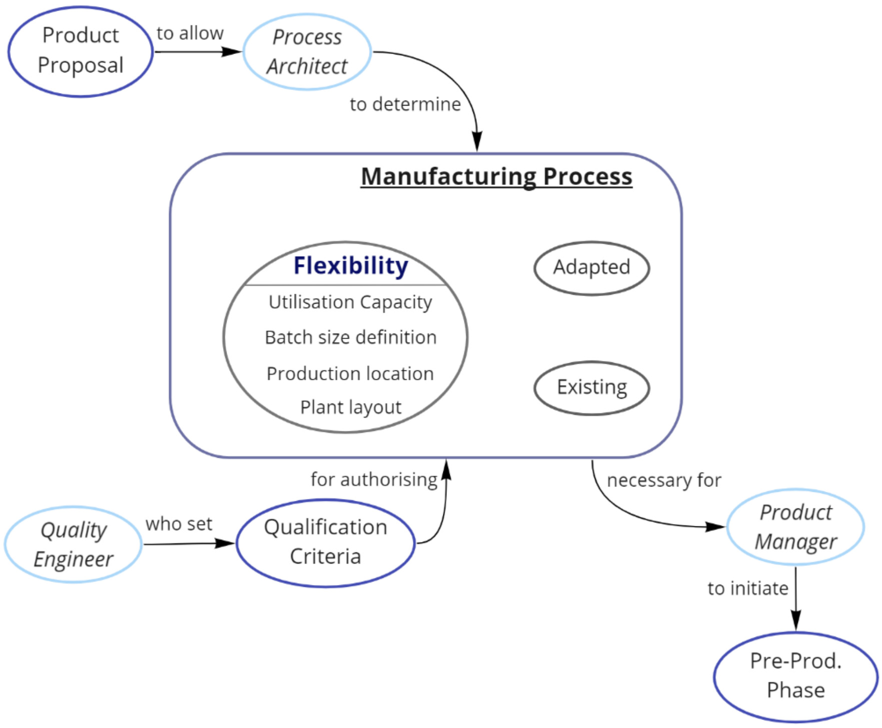


Figure 6.2 – Manufacturing preparation process adapted from Clegg and Boardman (1996)

Finally, Marsillac and Roh (2014) identified that product design changes substantially impacted process changes. The process design changes were particularly designed to improve flexibility and related to a firm putting more emphasis on collaborative supply chain practices and interactions. Kumar et al. (2020) support this claim arguing, for instance, that the adoption of small-scale distributed manufacturing process can lead to a more flexible supply chain that quickly adapt to market demands. Moreover, they argue that changing towards a distributed manufacturing requires a flexible and responsive supplier base that is able to delivery components to the new distributed network.

Hence, the proposed expectation is that manipulations the manufacturing flexibility variable, represented in the scenario by changes in the manufacturing processes, would result in the following perceived outcomes:

> **P2:** Changes in manufacturing processes are implemented to **(a)** increase the level of supplier participation, **(b)** facilitate the interfaces between components, and **(c)** improve the delivery and quality performance of the NPD project

Supply Chain Visibility

Francis (2008) conceptually address the lack of clarify and confusion surrounding the term supply chain visibility. The main characteristic highlighted in this study are about information, encompassing data visibility, process orientation, decision support, and the ability and respond to supply chain events effectively. Williams et al. (2013, p. 545) doubles down on the importance of quality information by defining supply chain visibility as the "access to high quality information that describes various factors of demand and supply". In the case of this scenario, supply chain visibility means the information upstream at the partner-level, for instance, lead time and delivery dates, demand forecasts, inventory levels, among others. In short, the concept of supply chain visibility posits that by having access to high-quality information, organisations can better anticipate and respond to change in their operations, such as product development.

Caridi et al. (2017), one of the reviewed case studies from Chapter 3, that the ability to access information across the supply chain facilitates the generation of resources and capabilities essential for NPD success. Furthermore, they report that when the degree of outsourcing in collaborative product development is high there is a need for more integrated information accessible by the players. Another key finding is that the among of shared information varies by the relevance of the partner in question, specifically the level of trust and integration between partners. That is, higher visibility positively affects supplier integration in cases where jointly product decisions are needed.

Additionally, Somapa et al. (2018) review on the impacts of supply chain visibility in business processes offer insights into its implications to NPD projects. They report that timely access to product specifications and updates in changes in product design significantly reduce the time needed to bring the new product to market. Furthermore, increased visibility can lead to a reduction in component stockouts, particularly relevant to NPD, where the availability of components can directly affect production costs and lead time.

Deng and Marsillac (2019) reinforce the vital role of information sharing, translated here into supply chain visibility, to achieve the incorporation of supply chain design into product design. Thus, the selection of this variable as the representation of this dimension of 3-DCE in the manipulated scenarios. The collaborative mindset promoted by Van Hoek and Chapman (2006; 2007) for aligning supply chain into NPD is based on leveraging capacities by increasing communication and information sharing to improve supply chain readiness, and value for the stakeholders involved in the project.

Hence, the proposed expectation is that manipulations in the degree of supply chain visibility of the proposed scenario would result in the following perceived outcomes:

P3. Increased supply chain visibility will **(a)** be linked with higher levels of supplier participation, **(b)** facilitate the interface between components, and **(c)** improve the overall performance of the NPD project

The visual representation of the aforementioned propositions establishes the proposed model for this scenario-based experiment, as illustrated in Figure 6.3. Once again, it is important to emphasise that the purpose of the scenario is not to validate the model per se. In turn, the experiment's objective is to evaluate the impacts of manipulations on the participants' perceptions. Specifically, this experiment aims to discern whether managers engaged in product development projects are conscious of the effects of 3-DCE. Consequently, in the proposed model, the variable pertaining to product design, product modularity, act a moderator, influencing the effects of the other two variables within the 3-DCE framework.

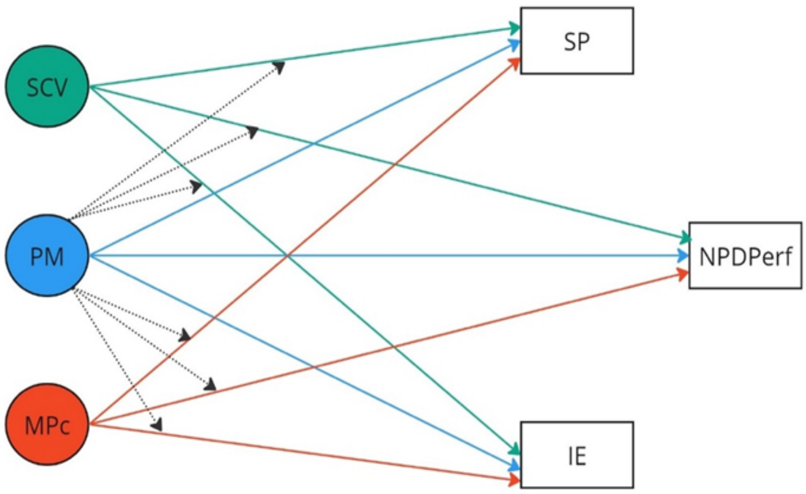


Figure 6.3 – Proposed Model for the Scenario-based experiment

6.3.4 Data Collection process

The selection of the target participants was carefully based on their relevant professional experience in projects akin to the scenario described. These individuals should hold decision-making roles in product development projects within the Automotive and Aerospace & Defence sectors. As highlighted earlier, these sectors are recognised for providing rich insights into the adoption of principles, similar to the one studied here, in their processes. In terms of data collection, most of the authors referenced in Table 5-D employed survey research firms, such as Qualtrics or MTurk. Nevertheless, there are important benefits and limitations associated with this type of platforms. After carefully consideration, it was determined that data would be gathered from personalised requests through relevant LinkedIn groups, together with other face-to-face recruitment at professional manufacturing conferences or exhibitions in the UK.

This approach to data collection is expected to result in more industry-specific responses, crucial for the validity of this research.

The selection of data collection methodology was informed by Schoenherr et al. (2015), who discussed the advantages and challenges of using survey research firms. A primary concern they raised pertains to the validity and reliability of responses. The difficulty lies in ensuring that the actual population characteristics are accurately represented in the sample. Additionally, they point out that while these survey research firms may offer panels of target respondents, the incentivisation, in most cases monetary, can influence the quality of the data collected. Despite Schoenherr et al. (2015) offering strategies to mitigate these potential biases, the specific nature of the target population for this experiment, experienced professionals with decision-making responsibilities in product development projects, required a more personalised approach to data collection. Details of the generic recruitment message utilised for this purpose are provided in the Appendix.

The design and distribution of the questionnaire was crafted to align with the objectives of this study. The questionnaire was administered using Google Forms and Typeform and disseminated to potential participants via email and LinkedIn direct messages. This approach culminated in a final sample size of 110 participants, out of a list of 338 participants who engaged with the survey, representing a response rate of 32.58%. On average, there were 13.75 participants per treatment cell. The platforms employed facilitated the random distribution of treatments among participants. Furthermore, to ensure an even response rate. any treatment receiving 15 valid responses was subsequently removed from the survey sent to new participants. Table 6-A presents the distributions of participants per treatment.

Table 6-A: Respondents per Treatment of the Scenario-Based Experiment

Treatment	Product Modularity	Supply Chain Visibility	Manufacturing Process Changes	#
1	Low	High	Low	13
2	Low	High	High	13
3	Low	Low	Low	13
4	Low	Low	High	15
5	High	High	Low	12
6	High	High	High	14
7	High	Low	High	15
8	High	Low	Low	15

The statistical power of the sample, to ensure the reliability of the findings, was calculated using the G*Power software. The analysis, which assumed a small effect size, the total sample size, the number of treatments and response variables, resulted in a power of 0.9115. The calculation can be consulted in the Appendix. Eckerd et al. (2020) warned that, in vignette-experiments, determining the effect size is a considerable challenge. The decision to accept a small effect size was grounded in the rigorous criteria used for participant selection, as argued by Forza (2002) and Verma and Goodale (1995). Therefore, the result of the statistical power of 0.9115 is over the acceptable benchmark for behavioural sciences proposed by Cohen's (2013), a standard adopted by many management researchers. Thus, the data collection methodology and samples size employed in this study are deemed appropriate and reliable for achieving its research purpose.

To ensure the rigour of this experiment, further checks were implemented. Initially, an attention check, advocated by Schoenherr et al. (2015), was included to enhance the quality of the data by warning inattentive respondents. This involved inserting a straightforward question about the role of the participant, placed in between the common module and the in experimental cues module. Incorrect responses to this question triggered the restart of the experiment. Additionally, as stated earlier, realism checks were incorporated to verify that participants perceived the scenario as realistic and believable. Two items, adapted from Dabholkar (1994), assessed the realism of the situation described and whether participants could envisage themselves in similar circumstances. The scores were measured on a five-point Likert scale, which with an average score of 3.53 indicated that respondents perceived the scenario as realistic. Moreover, a third item determined the respondents' involvement in similar projects, yielding an average score of 3.51. This score suggests that the target population was suitably representative for the aims of this study. Overall, these checks contributed to the validity and reliability of the experiment's methodology and future outcomes.

6.4 Results from the Experiment

As stated in the research method section, in Chapter 5, the multivariate analysis of variance (MANOVA) plays an important role in the treatment and analysis of the results of this experiment. According to Speier et al. (2011), the advantage of using this technique is the ability to conduct a single, overall statistical test when dealing with multiple correlated dependent variables. This is particularly beneficial as it minimises the potential for overstating significant relationships that might occur if multiple ANOVAs were conducted separately for each dependent variable. Furthermore, Clottey and Benton Jr.'s (2020) assessment of SCM research dyadic data, shows that the MANOVA test requires a significantly smaller sample size than other traditional approaches. All in all, the MANOVA allows for the comprehensive analysis of the manipulated effects on the dependent variables of this experiment.

MANOVA was reported to be used by four out of the eight articles consulted in Table 5-D to assess their experiment results (Mir et al., 2022; Wiedmer et al., 2020; Murfield et al., 2016; Ro et al., 2016). The remaining articles performed separate ANOVA tests. In addition to the consultation of these articles, the guidelines provided by Clottey and Benton Jr (2020) to perform rigorous MANOVA tests were followed. Their step-by-step flowchart, which aids in the practical application of this test, is available for reference in the Appendix. Earlier, the statistical power and effect size tests were conducted using the GPower software to determine the appropriate sample size. Next, scale purification procedures are put in place to scrutinise the validity and reliability of the constructs used in the experiment.

6.4.1 Construct Measurement and Scale Reliability

The experimental design requires rigorous assessment of the reliability and validity of the constructs constituting the dependent variables. These constructs or items were derived from the literature, Salvador and Villena (2013) informed regarding supplier participation, Fixson (2005) informed regarding interface ease, and Sellding and Olhager (2007) informed regarding NPD performance measures. In line with Mentzer and Flint (1997), a series of preliminary tests were conducted to confirm the reliability of the model constructs. These procedures, based in Confirmatory Factor Analysis (CFA) using SmartPLS4, are crucial to establish the robustness of the model before proceeding with the main analysis. The details of these tests are provided in the tables below, with further results in the Appendix.

According to the criteria established by Fornell and Larcker (1981), the constructs demonstrate both convergent and discriminant validity. This is evidenced by the factor loading of each construct, which by exceeding the 0.5 threshold confirms convergent validity. Discriminant validity is established as the squared root of the shared average variance extracted (AVE) exceeds their inter-construct correlations, as shown in Table 6-B and Table 6-C. Furthermore, the composite Rho values for reliability surpasses the 0.7 threshold. Notably, the 'perceived quality performance' construct, while falling below this threshold, still exceeds Bagozzi and Yi's (1988) minimum criterion of 0.60. Based on relevant product development literature, this construct remains a critical component for the experiment, thus was kept in the model for the final analysis.

Table 6-B: Confirmatory factor analysis and factor loadings

	C_Rho	AVE	SP1	SP2	SP3	PCP	PDP	PQP	IE1	IE2	IE3
SP	0.886	0.813	0.889	0.919	0.897						
NPDPerf	0.730	0.775				0.837	0.884	0.638			
IE	0.875	0.790							0.900	0.909	0.857

Table 6-C: Correlation table

	IE	MPc	NPDPerf	PM	SCV	SP
IE	1					
MPc	0.213	1				
NPDPerf	0.560	0.236	1			
PM	0.054	0.001	0.265	1		
SCV	0.288	0.002	0.157	0.017	1	
SP	0.434	0.138	0.419	0.029	0.369	1

6.4.2 Manipulation Checks

Before proceeding to the final analysis of the results, manipulation checks were conducted for each of the three manipulated factors: product modularity, manufacturing process changes, and supply chain visibility. The purpose of these checks is to verify the effectiveness of the experimental manipulations. This step is crucial to ensure the validity of the experimental design. The detail results of these manipulation checks are presented in Table 6-D.

The outcomes of the manipulation checks confirm that all manipulations worked as intended, as evidenced by the comparison for all three variables. That is, participants who were subject to opposite treatments reported significant perceptual differences in the outcome variables that were directly associated with the respective manipulated factors. This result indicates that the manipulation checks effectively validated the experimental manipulations, with no apparent threats to validity identified. Therefore, the experimental design can be considered robust in terms of its manipulation of the key variables under study.

Table 6-D: Manipulation Check Results

Manipulated variables	**Levels (#)**	**Mean (Std.Dev.)**	***F-value***	**Significance**
Product Modularity	Low (54)	3.083 (0.87)	5.712	0.019
	High (56)	2.705 (0.78)		
Manufacturing Process Changes	Low (53)	2.572 (0.94)	4.157	0.044
	High (57)	2.97 (1.09)		
Supply Chain Visibility	Low (58)	2.89 (1.07)	13.849	0.000
	High (52)	3.67 (1.01)		

6.4.3 Proposition Testing

As stated earlier, the analysis of the proposed mode was conducted via MANOVA. A summarised version of the results is presented in Table 6-E using Wilk's Lambda test. The proposed model reported a R Squared values of 0.914, 0.897 and 0.947, for the each of the outcome variables, meaning that the model accounts for a large proportion of the variance in the dependent variables. However, Supply chain visibility is the only manipulation that relevels a significant main effect of the variance (Wilk's Lambda = 0.8293; F=7; p <0.05), meaning that, in the overall model presented in Figure 6.3, the manipulation of supply chain visibility in combination with the other manipulations causes a significant perceived difference on the way the respondents perceived the outcomes of the Powertrain project. This result appears to suggest that the participants in this study are sensitive to the importance of supply chain design in NPD projects, however it tells little about the interrelationships between the variables.

Table 6-E: Analysis of the variance results, Wilk's Lambda effect

Effect	**Wilks' Lambda**	***F***	***Sig.***
PM	0.9423	2.081	0.1074
MP	0.9433	2.045	0.1122
SCV	0.8293	7.000	**0.0003**
PM*MP	0.9343	2.393	0.0729
PM*SCV	0.9829	0.591	0.6223

The primary purpose of this experiment is to explore whether the participants account for the three dimensions of 3-DCE into their individual decision-making behaviours. To fully provide a comprehensive answer to this purpose, it is essential to examine the impact of the manipulations on each dependent variable. Consequently, univariate tests of between-subject effects were conducted to assess the influence of these manipulations on the participants' perceptions of each outcome. This approach is instrumental in gaining insights that provide answers to the investigative question, RQ1.1. The results of this analysis are presented in Table 6-F.

Table 6-F: Tests of Between-Subject Effects

		Sum of Squares	**df**	**F**	**Sig.**
PM	Supplier Participation	0.007	1.000	0.006	0.937
	Interface Ease	0.214	1.000	0.224	0.637
	NPD Performance	2.823	1.000	5.201	**0.025**
MP	Supplier Participation	2.324	1.000	2.154	0.145
	Interface Ease	4.586	1.000	4.801	**0.031**
	NPD Performance	1.942	1.000	3.577	0.061
SCV	Supplier Participation	16.824	1.000	15.595	**0.000**
	Interface Ease	9.204	1.000	9.636	**0.002**
	NPD Performance	0.731	1.000	1.346	0.249

PM*MP	Supplier Participation	3.830	1.000	3.550	0.062
	Interface Ease	4.544	1.000	4.758	**0.031**
	NPD Performance	2.306	1.000	4.248	**0.042**
PM*SCV	Supplier Participation	0.040	1.000	0.037	0.848
	Interface Ease	0.373	1.000	0.391	0.533
	NPD Performance	0.297	1.000	0.547	0.461

The results belonging to the product modularity variable confirm that higher product modularity is associated with higher levels of perceived overall performance in the Powertrain project (F=5.201; p = 0.025). However, both supplier participation and ease of component interface, do not appear to have been affected by the manipulation of product modularity. These results could be an initial clue to show that the respondents see product design variable in a silo, they understand its importance to the overall performance of the project but not to the interface with components or suppliers.

A deeper analysis to the effects of product modularity manipulations in the different items of perceived performance outcomes, shows a significant influence on the perceived cost (F=3.843; p = 0.053) and delivery performances (F=4.519; p=0.036) but not on the perceived quality performance. Yet, when product modularity and manufacturing process changes have a moderated effect (PM*MPc), the new variable starts to have a significant interaction on perceived quality outcomes (F=4.575; p=0.035). These might indicate that, in the mindset of the respondents, concurrent engineering (product design and process design) plays a critical role in successful product outcomes.

The manipulations of manufacturing process changes have an expected significant impact on the degree of interface ease (F=4.801; p = 0.031). This result confirms that respondents understand the crucial role that process design plays in the functionality and the interface between component as well as the ability to face potential bottlenecks in logistics and manufacturing. Still, the results of this manipulation do not support a significant implication in supplier participation or perceived NPD performance. However, manipulation in the manufacturing factor support a significant effect in participants' perception of NPD cost performance. Thus, hinting that the respondents perceive manufacturing processes ultimately related to cost outcomes.

The association between supply chain visibility and supplier participation was clearly perceived by the participants of the experiment (F=16.824; p < 0.001). Interestingly, the results also support a significant result on the degree of interface ease (F=9.204; p=0.002). This appears to suggest that the participants actually understand that supply chain design plays an important role in NPD projects. Notably, contrary to what might be expected, there is no significant effect on the perceived overall performance of the project, only on the perceived delivery performance (F=5.925, p=0.017). Perhaps, the respondents perceive the role of supply chain design as an indirect variable in product development outcomes. This hypothesis is further sustained by the lack of moderation effect between product modularity and supply chain visibility (PM*SCV).

The interaction effects, as depicted in Figure 6.4, provide insight into the dynamics between the manipulated variables and their impact on the perceived NPD overall performance. This interaction plot indicates a significant interplay between product modularity and manufacturing process change in influencing decision-making perception. In essence, as discussed earlier, the effect of product modularity on NPD performance is contingent upon extent of manufacturing process changes. Considering these variables as proxies for product and process design, this suggests that original concept of Concurrent Engineering was well-perceived by the participants.

Conversely, supply chain visibility does not demonstrate significant interaction with product modularity or manufacturing process changes. This suggest that while respondents acknowledge the influence of product-process interaction on NPD performance, they may not fully comprehend the broader implications of the 3-DCE framework. Earlier, the MANOVA test demonstrated that supply chain visibility influences the perceptions of the participants. However, the findings appear to indicate that product modularity is not interacting with supply chain visibility. A plausible interpretation of these results is that respondents may view process design as more directly connected with product design decisions, while perceiving supply chain design to be more reliant on long-term strategic decision than immediate product design decisions.

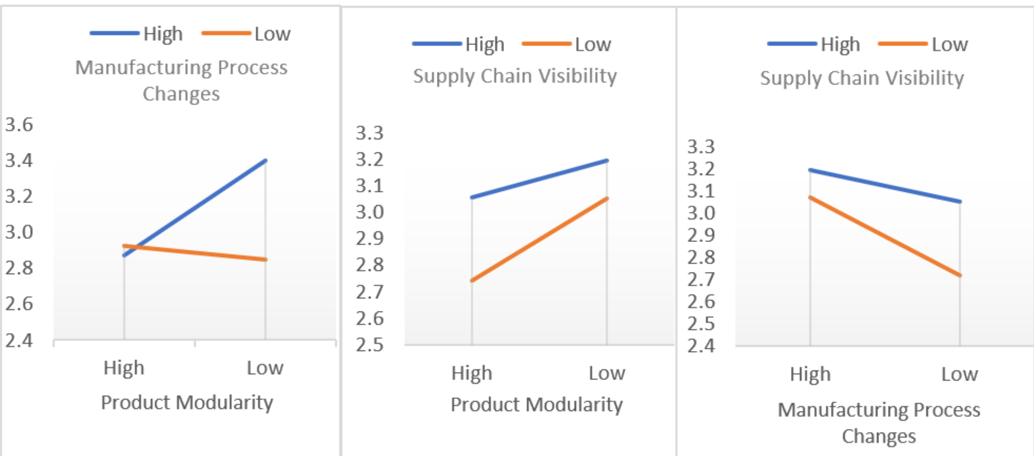


Figure 6.4 – Interaction Plots of the estimated Marginal means of NPD Performance

For the final step in the analysis additional interaction plots are presented, aimed at extracting deeper insights from the experimental results. Specifically, these plots examine the interaction effects between the manipulated variables and their perceived impact on the different measures of NPD performance: cost, quality, and delivery. These figures provide additional information that sheds light on how decision-makers perceive the 3-DCE framework. Notably, the analysis reveals that the interplay between product modularity and manufacturing process changes occurs, particularly in the context of quality and delivery performance perceptions. Meanwhile, the interaction between product modularity and supply chain visibility is pronounced in aspects related to cost and quality perceptions. This distinction might suggest a more nuanced effects of the managerial perceptions regarding 3-DCE on NPD performance.

Moreover, it is observed that the variables representing process and supply chain design do not show any significant interaction. This could indicate a lack of clear distinction in the participant's understanding of these two different concepts. If so, decision-makers might perceive that they are incorporating 3-DCE principles when in fact they are considering the product-process interplay. Supporting this interpretation, Khan (2018, p. 105) pointed out that the lines between traditional concurrent engineering and 3-DCE are often blurred. For instance, she argues that the management of containers within supply chain cannot be categorised as exclusively CE or 3-DCE. This conceptual ambiguity, also present in academic discourse, appears to extend to functional perceptions, possibly affecting their understanding and application of the 3-DCE framework, as envisioned by Fine (1998).

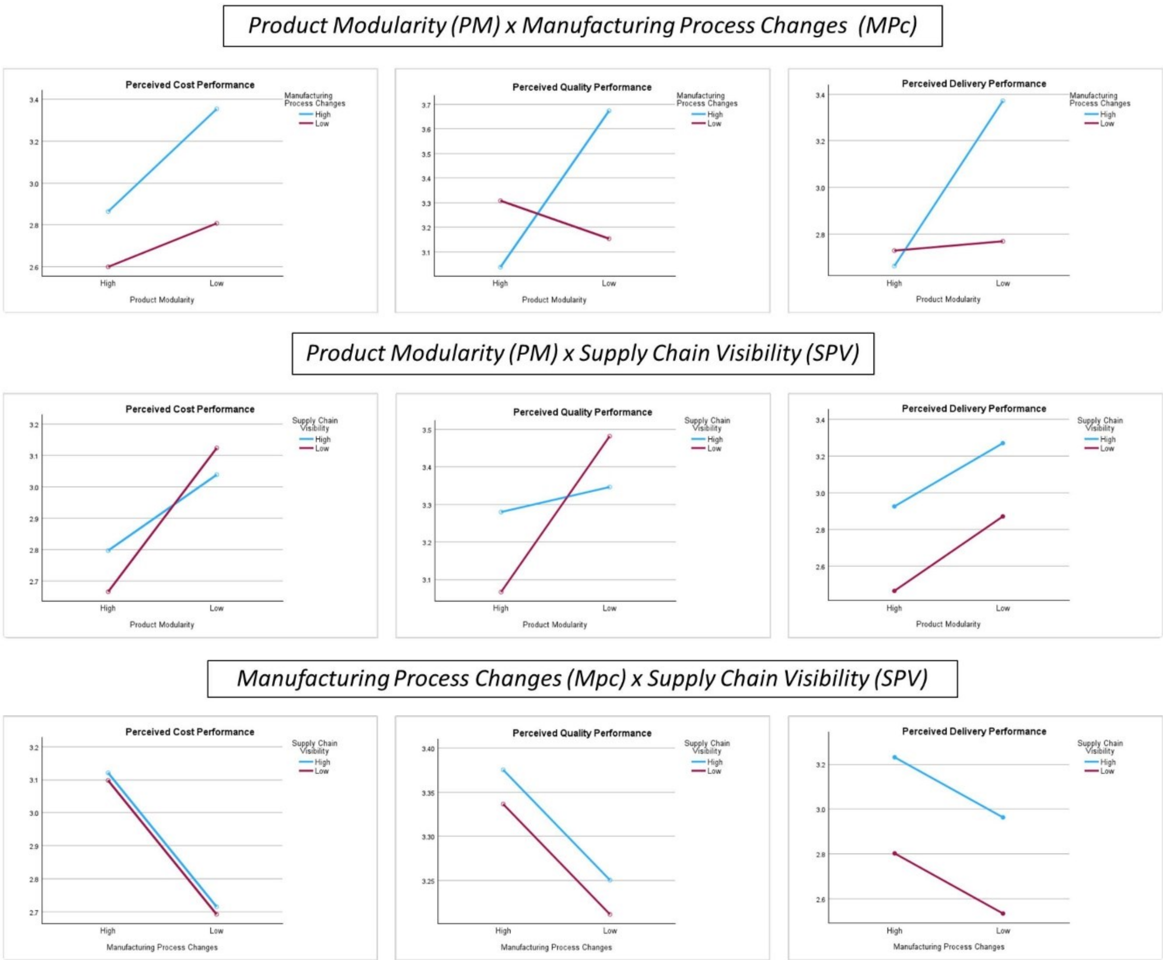


Figure 6.5 – Interaction Plots on the perceived NPD performance (cost, quality, delivery)

This experimental research contributes to the field of behavioural supply chain management (Mir et al., 2022). It confirms that the integration of supply chain design into product development is yet not perceived in the same extent as the product-process interplay, the original concurrent engineering. Furthermore, this scenario-based experiment clarifies the critical role of managerial perceptions, emphasising the necessity of closing perception misalignments to foster and embed a DfSC behaviour in NPD projects. Next, in the pursuit of validating and potentially enriching these findings, the same Powertrain scenario is explored in a Workshop setting.

6.5 Discussing the Scenario in a Workshop Environment

This section introduces and discusses the findings of the Powertrain scenario within a workshop setting, by engaging with a focus group in the Aerospace and Defence sector. Moderation was provided by the researcher, aided by a senior member from the case company and a supervisor of Thesis, ensuring objectivity and allowing participants to express their views freely. Each of the participants from the case company responded individually to the original scenario, which were then collectively discussed in the workshop setting.

6.5.1 The Case Company

The case company, labelled here as WORK_AEROD, is one of the World's largest aircraft engine manufactures. As of 2022, the company employed over 40,000 people across 48 countries. Renowned for over a century of innovation, as per their own public statements, WORK_AEROD has an established status as a global brand uniquely positioned to tackle complex engineering challenges. This reputation, alongside decades of collaborative relationships and embedded expertise, presents an exceptional opportunity for this research to explore the concept of DfSC.

WORK_AEROD operates in three core businesses: Civil Aerospace, Defence, and Power Systems, contributing, respectively, 45%, 29%, and 26% to its underlying revenue in 2022. The focus group participating in this workshop hails from the Defence programmes within the Supply Chain Executive department. These cross-functional professionals were involved in integrated project teams, and responsible for developing new power and propulsion systems. Before introducing the Powertrain scenario, the research team had the invaluable chance to listen to the team's reflections on deploying agile methodologies in a previous project. These insights, combined with the workshop participation, facilitated a rich discussion about practitioner perspectives on 3-DCE and DfSC.

6.5.2 Is Design for Supply Chain at the core of your business?

The research team was invited to listen to a discussion session among team members about the outcomes from a previous project, conducted prior to the workshop activity. This session enabled the research team to acquire a more comprehensive understanding of the current practices, methods, and terminologies employed in WORK_AEROD. Although the specific details remain confidential to WORK_AEROD, key concepts are shared here to illustrate the organisation's proficiency in working within principles akin to DfSC. The team elucidated their approach to the agile methodology, detailing the structure within the Integrated Project Teams and their own communication strategies with other scrum teams. Additionally, they delineated the Sprint process at WORK_AEROD, encompassing spring planning, deliverables, and retrospectives, as well as classifying the level of effort required to complete tasks. The team further explained on the buyer's role in integration, support, and strategic formulation. Finally, they outlined the successes and challenges encountered during this phase of the sprint, emphasising the integration of Design for Manufacturing (DfM) within their processes.

The reinterpretation of the internal team discussions highlights WORK_AEROD's significant advancements in fostering cross-functional teams, notably through the formation of Integrated Project Teams. Nevertheless, it was noted that the team encountered challenges, including insufficient planning at the project's initial stage and misapplication of the agile approach. This latter issue sometimes led to a diminished sense of accountability under the guise of alignment with agile principles. The primary concern for the team was to achieve delivery objectives, with cost considerations being secondary. Although delivery performance was exceptional, the implications for cost efficiency were unclear in this discussion. Additionally, the team acknowledges topics such as trust and power, promoting collaborative engagement with suppliers to enhance relationships. This preliminary analysis, prior to the workshop activity, underscored WORK_AEROD's prowess in embodying key principles of DfSC, such as collaborative orientation, despite facing certain challenges.

The workshop activity was structured in three parts to facilitate an in-depth exploration of the DfSC practices in the context of WORK_AEROD and to receive feedback on the scenario experiment. The initial part featured a brief presentation by the main supervisor, introducing the concepts around DfSC. This was followed by a 30-minute semi-structured conversation, focusing on the nature of WORK_AEROD's internal cross-functional integration. This interaction served as a prelude to the subsequent segment of the workshop. In this segment, each participant received a flyer containing a QR code, leading to the online Powertrain scenario, completed individually by the participants. A randomised symbol, linked to the specific treatment was allocated to each participant. Participants were instructed to record their respective symbols for future reference in the discussion as, at this point, they were unaware of the different manipulations involved in the experiment. The workshop's detailed protocol is available in the Appendix.

In the initial presentation centred around the DfSC concept, the team was asked to distinguish between *Supply Chain Design* (SCD) and *Design for Supply Chain* (DfSC). They perceive SCD as primarily concerned with strategic and planning aspects essential for establishing the supply chain for new products, thereby its aim is to capture a full view of the value stream. On the other hand, DfSC appeared to evoke concepts more aligned with readiness, delivery, and the proactive consideration of supply chain requirements very early on. The main contribution from this brief discussion was not to come up with definitive definitions but to recognise and affirm the team's understanding that SCD and DfSC are, indeed, two distinct concepts.

In the semi-structured discussion, participants were asked to identify WORK_AEROD's internal processes regarding cross-functional integration, their impact on business outcomes, and how the company discerns that this integration leads to successful results. The team agreed that while WORK_AEROD strives to implement integrated project teams (ITPs) across the organisation, they tend to function more effectively in NPD projects. They cited legacy issues and flexibility as challenges that impede the broader application of IPTs. These challenges stem from a resistance to change and difficulties in understanding decisions that were made in the past. The discussion underscored an inherent need for greater adaptability, determined in the ability to learn fast so that IPTs reach their full potential.

Another aspect of the conversation was the exploration of the limitation in the extent of cross-functional integration within WORK_AREOD. Despite successful implementations, participants noted that cross-functional interactions often do not reach later stages of the value chain, particularly in service. Furthermore, there was an admission of the absence of advanced metrics to effectively measure the success of DfSC activities, with current assessments relying heavily on modelling and simulation solutions. This part of the discussion highlighted an important gap in both the read and evaluation of cross-functional integration.

The dialogue further moved into the exploration of themes of accountability and lifecycle perspective within the context of WORK_AEROD's practices. A notable point was the misalignment in accountability, where teams responsible for addressing current problems were not always those who made the original decisions. This disconnect underscores the importance of DfSC in fostering awareness of potential risks and implications of decisions throughout a product's lifecycle. Effective mental feedback mechanisms and a culture of learning and curiosity were identified as crucial for the success of these practices. For WORK_AEROD, it was found that people who are open to learning and remain curious to try new things are often more successful in these IPTs.

This discussion, drawing on insights from a post-workshop documented provided by the company, facilitated a thematic analysis of the key factors behind WORK_AEROD's journey towards DfSC. Figure 6.6 depicts this analysis, employing the template for qualitative analysis proposed by Gioia et al. (2013). This template includes three main components: selected evidence, first-order concepts, and second-order themes. The selected evidence comprises direct observations gathered during the workshop, derived from both the shared document and participant comments. First-order concepts represent the initial labels applied by the researcher to represent the perspectives and terminologies of the participants. Second-order themes reflect the researcher's own constructions towards a theoretical understanding of the data. In this context, these themes correspond to the underlying mechanisms identified in Chapter 3, which constitute the initial conceptual framework. Chapter 8 will provide a more detail explanation, linking the WORK_AEROD's insights with the initial conceptual framework as well as elaborating on additional findings.

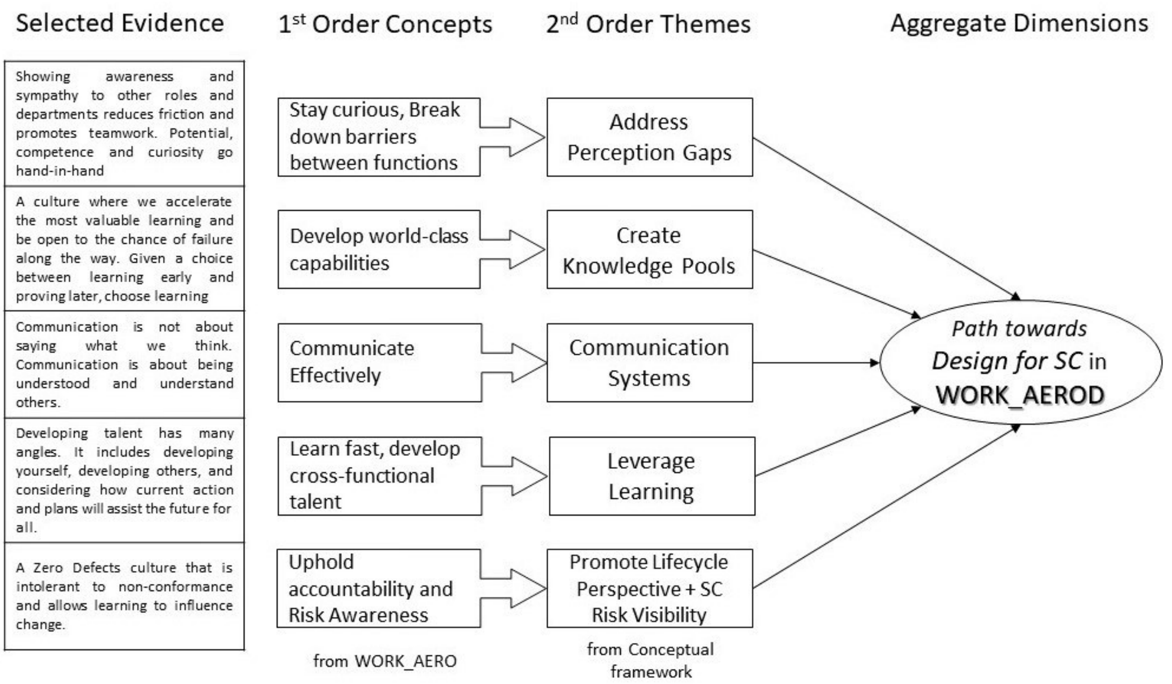


Figure 6.6 – Thematic analysis from WORK_AEROD's journey towards DfSC

6.5.3 Feedback on the Powertrain Scenario

At this stage of the workshop, the focus group participants individually completed the original Powertrain scenario. The nine participants, who submitted their responses, were randomly assigned to the various treatments of the scenario. Consequently, owing to the random allocation process, none of the participants were assigned to treatments 2 or 7. The distribution of participants across the different treatments is detailed in Table 6-H.

Table 6-G: Participants per treatment in the Workshop section

Treatment	Product Modularity	Supply Chain Visibility	Manufacturing Process Changes	#
1	Low	High	Low	2
2	Low	High	High	0
3	Low	Low	Low	1
4	Low	Low	High	2
5	High	High	Low	1
6	High	High	High	2
7	High	Low	High	0
8	High	Low	Low	1

The participants answered to the same five-scale Likert survey of the original scenario, aimed at evaluating the effects of manipulations in the 3-DCE dimensions to their perception of NPD outcomes: supplier participation, ease of component interface and overall performance measures. The session aimed to validate the experimental design and engage the participants in fruitful discussions. In fact, the scenario was employed to gain further insights into the participants perceptions and decision-making processes.

However, an initial assessment of the patterns reveals insights into the effects of the manipulation, as summarised in Table 6-H. Although the differences were not substantial, manipulations appear to have some impact on perceived NPD performance, as indicated by variation in standard deviations. An interesting observation was the influence of product modularity manipulations in supplier participation perception, perhaps suggesting a link between more modular products and increased supplier involvement, in the minds of WORK_AERO's team. Other manipulation effects appear to have been relatively consistent across all groups.

Table 6-H: Aggregated results from the WORK_AERO participants

				Supplier Participation		Interface Ease		NPD Performance	
		Treatments	**#**	Mean	SD	Mean	SD	Mean	SD
PM	Low	1, 3, 4	5	2.53	0.43	2.20	0.97	2.60	0.99
	High	5, 6, 8	4	3.17	0.14	2.33	0.58	2.67	0.78
SCV	Low	1, 5, 6	5	2.93	0.12	2.27	0.69	2.53	1.06
	High	3, 4, 8	4	2.67	0.54	2.25	0.92	2.75	0.62
MPc	Low	1, 3, 5, 8	5	2.80	0.20	2.20	0.78	2.73	1.03
	High	4, 6	4	2.83	0.43	2.33	0.81	2.50	0.67

The discussion around the Powertrain scenario yielded further insights post-survey completion. After collecting responses, each participant was given their original treatment on paper, asked to exchange it with a colleague, and then read again. This led to the realisation of different scenarios and a unanimous willingness to change their initial responses if initially given a different treatment. This willingness highlights the instinctive awareness of the impacts that variations in product, process, and supply chain cause in NPD outcomes. However, it was noted that their original responses did not always reflect this understanding, considering the relative consistency among responses. This newfound understanding emphasises the need to address perceptual bias, thereby underscoring the significance of this research in enhancing decision-making behaviours in NPD.

The group of participants provided further feedback on the employment of this scenario experiment as a learning tool to be used to spark the discussion around the implications of DfSC. In general, the participants appreciated the the use of a vignette to contextualise the NPD problem, noting its effectiveness in facilitating a focused discussion. They found the selection of a NPD project from a different sector of their own particularly interesting, as it allowed them to reflect without the influence of their professional biases.

However, they also identified areas for improvement. They considered the conclusion of the scenario lacking consequential depth and felt hurried, suggesting that a more complex set of decisions within the scenario could better demonstrate the consequences of their choices. the discussion would be better served if the scenario incorporated more complex decisions, with a better visualisation of the impact of their choices. Hence, the group proposed that transforming the scenario into an interactive game for future training session, would enhance the outcome of similar workshop sessions. This feedback aligns with the planned future direction of the research and the participants' endorsement and suggestion serve as a valuable input for integrating gamification elements into the scenario.

6.6 Summary of the Powertrain Scenario findings

This chapter attempted to unpack the perceived complexities involved in integrating the three dimensions of the 3-DCE framework into NPD decision-making processes. A scenario-based experiment involving 110 participants was employed to offer a fresh perspective by placing the decision-maker at the centre of the analysis and focusing on the perceived implications of design decisions. . This approach constitutes the first empirical step of this research. It allows us to answer RQ1.1 by showcasing how respondents react to manipulations in product, process and supply chain designs.

The survey results confirmed the presence of behavioural gaps that limit the integration of supply chain design, highlighting critical issues in the adoption of DfSC principles. Supply chain design appears to be perceived more as a strategic element that is not directly considered in decision-making processes for NDP projects. Additionally, there appears to be some ambiguity between supply chain and process design, with blurred distinctions between the two. These initial results revealed that decision-makers embedded the interplay between product and process design but do not equally incorporate supply chain.

Recognising the field-problem evidenced by the results from the Powertrain scenario, a subsequent application of the same scenario in a cross-functional department at a leading global aircraft engine manufacturer (WORK_AERO), further contributed to the understanding of DfSC in product development. Prior to the workshop, the team at WORK_AERO had already acknowledged the significance of DfSC, as well as its distinction to SCD. During the scenario discussion, the group consistently emphasised the importance of meeting project requirements by considering interdependencies and involving suppliers in a cost-effective manner. However, the responses to the scenario did not appear to exhibit the anticipated manipulation effects, suggesting a possible gap in perception even among those converted to the importance of DfSC. This outcome indicates that perception gaps regarding DfSC might still exist in managerial decision-making, even among its advocates, highlighting the need for continued research to break down those barriers.

6.7 Anticipating the Next Chapter

During the workshop activity, in which the Powertrain scenario was introduced, the focus group at WORK_AERO suggested that it could be more effective as a gamified experience. This recommendation emerged for the recognition that gamification could significantly improve the visualisation of the consequences of various decisions inherent to NPD projects. Thus, potentially enhancing learning across different functional and organisation boundaries. Within the ambit of the DSR strategy, this research is aiming to design an artefact solution that addresses the problem of misalignment within NPD projects. This artefact, envisioned as an advanced interaction of the original scenario is termed the “Powertrain Game”. The purpose of the game is to act as a boundary object to facilitate cross-functional and organisation learning. The following chapter introduces the gamification processes in greater detail, along with insights from a similar workshop where this game was effectively implemented.

7 FINDINGS FROM THE GAMIFIED SOLUTION

7.1 Overview

The purpose of this chapter is to design an artefact solution aimed at facilitating behavioural change in individuals and organisations towards the adoption of DfSC principles in NPD projects. Addressing these challenges in NPD projects at an early stage is crucial, particularly when considering the impact of design decision trade-offs. To this end, a gamified solution is proposed, drawing on the theoretical ideas of boundary objects and Theory of Planned Behaviour (TPB). In short, this solution is designed to engage participants in learning activities, thereby promoting organisational behavioural changes, and fostering the integration of DfSC practices.

The initial section unfolds the process of game development, based on Riar et al. (2022)’s framework and Robson et al. (2015)’s principles for gamification, and exploring the features of this gamified scenario. This section of the chapter also connects the gamified elements of the solution with the TPB to promote organisational change. Moreover, it details the pilot phase of the game, which helped to establish content validity (Saunders et al., 2023).

Moving forward, the following section explores the practical implications of the artefact solution. Repeating the approach of the preceding chapter, the Powertrain Game was presented and discussed in a workshop session with a cross-functional team from a UK-based OEM in the Automotive Industry. The session, structured as a focus group, generated knowledge through the analysis of individual responses and group discussions centred on the role of DfSC in their organisation. The outcomes of this workshop were instrumental in developing thematic process to embed DfSC behaviours, complementing the data previously gathered. This information will serve as a foundation for a refined roadmap towards DfSC in the subsequent chapter.

The concluding section of this chapter presents four semi-structured interviews conducted with members from four distinct organisations. These interviews, centred around their own experiments with the Powertrain Game as well as perspectives about the topic, aim to validate the findings across different stages of the research. The insights of these real-world practitioners, holding roles relevant to the discussion, enrich the empirical understanding of DfSc behaviour, contributing to the development of this concept.

In summary, this chapter signifies a critical stage in the field-testing or intervention phase of the proposed Design Science Research (DSR) framework. As an integral component of the research design, it enables the grounding of technological rules, in this case, the thematic findings, within theoretical constructs. This phase, that will be described in Chapter 8, tests the practicality of the proposed solution but also aims to bridge the gap between theory and real-world application of the topic of this Thesis.

7.2 The Powertrain Game

7.2.1 Developing the game

The aim of an effective boundary object, as described by Carlile's (2004) framework, is to develop an iterative approach that supports relevant stakeholders to manage knowledge across boundaries. That is, a boundary object should establish the relevant knowledge to be transferred across a domain-specific using common terminologies, but also it should translate this knowledge to generate common meanings. Ultimately, an effective boundary object transforms the old into new knowledge, equipping the different stakeholders to address the implications and dependencies that arise from this common understanding. However, Fishben and Ajzen's (2011) reasoned approach highlights the complexity inherent in bridging these boundaries, since individuals have unique backgrounds, behavioural, normative and control beliefs.

In the context of this complexity, The Powertrain Game, a gamified version of the scenario from the previous chapter, is designed to serve as a boundary object. It attempts to enable stakeholders across functional and organisational boundaries to comprehend the repercussions of their decision throughout the product development lifecycle, as they visualise their individual bias. Serious games, defined as those created for purposes beyond mere entertainment, have "played" a role in driving behavioural changes across various professional realms. Whalen et al. (2018) argue that, as boundary objects, serious games offer a shared space for stakeholders to engage with complex issues such as climate change or sustainability. This engagement, particularly in educational settings, facilitates systems thinking by allowing players to experience the consequences of their decisions within a controlled environment. Similarly, Wood and Reiners (2012) illustrate the potential of gamification in logistics and supply chain education. Finally, van Pelt et al. (2015) gives examples on how interaction games can effectively communicate complex scientific information, thereby bridging the gap between science and practical application.

Despite the goal of changing behaviours, designing an effective serious game presents several challenges. Not least, Warmelink et al. (2020) emphasise the difficulty of grasping the players' intrinsic and extrinsic motivations, which often differ across individuals, groups and cultures. Consequently, they argue that the game's design must align motivational affordances with desired behavioural outcomes. Furthering this notion, Robson et al. (2015) propose the Mechanics, Dynamics, and Emotions (MDE) framework. This framework encapsulates these concepts by selecting the game elements that enable effective gamified experiences.

At this point, it is important to acknowledge that the aim of this research work is not to create the definitive game that should be employed in all contexts. Indeed, it seeks to demonstrate that an effective boundary object can facilitate the embeddedness of DfSC behaviours in NPD projects by bridging perception boundaries. The Powertrain game was designed, as a practical example, to initiate this dialogue. Still, the researcher designed this game informed by the MDE framework, ensuring its effectiveness, as delineated in Table 7-A.

Table 7-A: MDE framework of the Powertrain Game based on Robson et al. (2015)

	Concept	Elements in the Powertrain Game
Mechanics	Specify the setup, the rules, and progression mechanics for the gamified experience	• The game is set up in the form of a decision-making process. • The player makes ten (10) decisions throughout different stages of the product lifecycle. • The challenge is to balance the inherent product, manufacturing, and supply chain trade-offs of the NPD project.
Dynamics	Consider the type of player behaviour that emerges from participating in the	• Despite it not being the case, the players might perceive that there are right or wrong answers.

	experience. These dynamics are not entirely under the control of the game designer.	• Consequently, players might engage in competitive behaviours. • Depending on their background, some players may feel more familiar with some decisions than others.
Emotions	Refer to the elicited emotions due to playing. The mental states of the game experience.	• The user experience in Typeform, combined with the selected template, makes the game more visually appealing. • The inclusion of expressions such as "I am ready!", "Hello! We're glad to have you here!" aim to promote positive emotions. • A motivational affordance was included by giving the players the opportunity to discover their "DfSC" thinking style. • The perceived realism and usefulness of the game might influence how players engage.

In developing the Powertrain game, key guidelines from Riar et al.'s (2022) framework for gamified cooperation were instrumental, particularly the importance of contextual understanding of the problem and the influence of design features on players' attitudes. To address the first insight, the game was adapted from the original Powertrain scenario, already deemed realistic in the previous chapter, ensuring relevance and engagement. Furthermore, the main decision-making topics within the game were derived from the literature review in Chapter 2 on NPD decisions. With regards to the second advice, the game is engineered to foster collaboration, underling the implications of design trade-offs and a lifecycle perspective in decision-making. This is embodied into the game's mechanics, where it is explicitly stated that "there is no right or wrong answer", encouraging players to showcase their own perceptions. Additionally, the decisions are made through the concept, development, and production stages, displayed throughout the game interface, highlighting the lifecycle implications. Ultimately, the Powertrain game, presented in full in the Appendix, carefully incorporates relevant gamification framework to enhance its effectiveness.

As stated, the game is structured around three product lifecycle stages, requiring players to navigate through a series of decision outlines in Table 7-B. Within each stage, players encounter two main project decisions, comprising a total of ten decisions. This design encourages players to apply their logic and reasoning, without the pressure of making the correct decisions. The game serves a dual purpose: for the players, it provides a platform for learning where they can experience the implications of their decisions in a controlled setting, for the organisations, it facilitates the identification of behavioural bias within their teams. Overall, engaging with the Powertrain game offers collective insights into organisational decision-making patterns and encourages boundary-spanning dialogues.

Table 7-B: Description of design decisions in the Powertrain Game

Concept Stage	
Decisions	Description
Team Composition	The player must select their team from a pool of 13 team members from multiple functions, one of whom is a key member of the engineering team from their supplier.
Supplier Participation	The player must decide whether an important supplier will be involved in the project at this stage.
Development Stage	
Decisions	Description
Manufacturing Processes	The player must make five manufacturing process decisions, including batch size, quality, sourcing, capacity, and platform strategies, each comprising two opposing options.
Product Design Changes	The player must decide whether to accept, at this stage, modular alterations to the original design decision.
Production Stage	
Decisions	Description
Supplier Disruption	The player must choose between two sets of measures on how to respond to a critical supplier disruption.
Learning Experience	The player must select a strategy, from a set of four, to mitigate exposure to similar disruptions in the future.

7.2.2 Linking the Game to Theory

Gamification research has often leveraged established behavioural theories to predict players behaviours. Zhang and Anwar (2023) reference theories, such as the TPB or reasoned action theory, as an established framework for this context. Koivisto and Hamari (2019) further attest that these theories are predominantly used to empirically investigate social influence or individual perceptions of others' opinions. Likewise, Wang et al. (2021) mention this theory to suggest that players' perceptions of gamified elements can be indicative of their behaviours Therefore, for the current game, this theoretical perspective was employed to connect the gamification elements to the "DfSC" behaviour of the participants.

The idea of classifying DfSC profiles as a result of the Powertrain game draws inspiration from the research by Arellano et al. (2021) and Netland et al. (2021). Adopting the TPB, they use fuzzy qualitative comparative analysis (fQCA) to identify three belief configurations associated with high levels of commitment to practice adoption. It is important to note that the profiles used in the Powertrain game have not been empirically tested; therefore, they should not be presumed as definitive. Nonetheless, these profiles, delineated in Table 7-C, serve a crucial role in the game's dynamics. They are intended not only to encourage discussion on the topic of DfSC but also provide players and organisations with a motivational incentive to engage with the game. While these profiles currently serve a hypothetical function within the game's design, future research could aim to validate and refine them.

Table 7-C: Type of DfSC profiles exhibited in the Powertrain Game

Type of profile	Main exhibited beliefs	Description in the Powertrain Game
Product & Technological Expert	Quality beliefs	You are in a great position to create a high-quality Powertrain, bringing increased customer satisfaction, and continue to build a positive brand image for your company. However, balancing quality with other factors, such as cost, relationship-building, and risk management, is essential to ensure long-term success.
Operational Master	Cost & Delivery beliefs	You will ensure that your team delivers on time and within budget, without any unexpected expenses. This will help your organisation stay ahead of competitors and maximise profits. However, balancing cost and delivery with other factors, such as quality and customer needs, is essential to ensure long-term success.
Collaboration & Relationships Manager	Collaborative beliefs	You will be looking to create products through collaborative efforts and strong relationships with internal and external stakeholders. Your project will benefit from the increased innovation of working closely with your partners. Moreover, your organisation will be better positioned to face future challenges. However, balancing collaboration and relationship-building with other factors, such as cost, quality, and delivery timelines, is essential to ensure long-term success.
Strategic Thinker	Alignment beliefs	You will be looking to create a Powertrain that balances quality, cost, and delivery timelines. Your team will emphasise trade-off analysis that can help them achieve goals whiles minimising risks and maximising opportunities. You will be able to identify bottlenecks and plan for contingencies reducing the likelihood of costly delays and errors. However, balancing strategic thinking with collaboration, relationship-building, and other factors, is essential to ensure long-term success.

The design of the decisions in this game were constructed to embody the trade-off implications in NPD performance outcomes. These outcomes, already discussed throughout this Thesis, include cost, delivery, performance, and collaboration implications. For instance, the manufacturing process decisions in the game were tailored to simulate the trade-offs between cost and delivery performance with product quality. Similarly, decisions involving supplier participation and responses to supplier disruptions were structured to evaluate player preferences and behaviour towards collaboration. This approach underscores the nuances inherent to NPD decision-making.

For assessing players' exhibited beliefs, a scoring system was defined and integrated into the game's backend. This system categorises players based on their decisions towards cost and delivery, quality, or collaboration. Additionally, players that preserved high levels of consistency to their selections were deemed to prioritise alignment beliefs. The score rules were not disclosed to the players, details can be found in the Appendix.

It is important to underscore two points: firstly, these categories do not intend to definitively define players beliefs, but rather to stimulate the cross-boundary discussion. Secondly, this classification serves to signal players for the emergence of their potential bias. That is, although each prolife carries a positive message, as seen in Table 7-C, they also alert players to other factors in product development decision-making.

7.2.3 Initial data collection

The pilot testing of the Powertrain game was conducted with a former VP-level executive from the aerospace industry, which resulted in insightful feedback. Most importantly, the executive recognises the emergence of 3-DCE or DfSC principles in the decisions of the game. Another positive remark was the game's smooth flow and the effective simulation of decision-making within product development context. However, it was suggested that more explicit information of the game's context (i.e., adding specific figures) would improve its realism. A notable limitation identified was the game's industry-specific nature, indicating that it would have to be adapted to be applied in sectors such as food manufacturing, for instance. Furthermore, the feedback recommended targeting the game at professionals with a relevant understanding of the pivotal concepts, ideally those in at least mid-level management positions. This raises an intriguing question about the potential differences in responses between junior and senior professionals. Most importantly, the former executive underlined that benefits and objectives of the game must be made clear to players beforehand. Subsequent modification to the game's design has been made to incorporate this feedback.

The data collection strategy for the Powertrain game followed a similar approach used in the Powertrain scenario discussed in the previous chapter. This process involved a targeted selection of participants, focusing on professionals with extensive experience in NPD projects and relevant industry backgrounds. The ideal candidates were those involved in complex manufacturing projects, with decision-making responsibilities. The recruitment was therefore conducted via personalised invitations on LinkedIn, ensuring that the targeted participants matched the criteria for this study.

For the Powertrain game, this study required, in comparison to the scenario-based experiment, participants with more in-depth knowledge of product development decisions. Consequently, the targeting criteria was even more strict, leading to a smaller, more specialised participant pool. At this initial stage, six professionals from various manufacturing industries were selected for data collection. Their contributions are reported based on their individual responses to the game, as they did not consent to follow-up interviews. However, they did complete an open questionnaire, shedding light on their decision-making reasoning. Details regarding each participant are provided in Table 7-D for future reference.

Table 7-D: Initial Powertrain game participants

ID	Role	Industry/ Company
P1	Product architecture manager	Refuse collection truck manufacturer
P2	Procurement Director	Motorcycle Manufacturer
P3	Senior Principal Engineer	Semiconductor Manufacturing
P4	R&D Director	Industrial Machinery
P5	Former Launch and PVT Manager	Large automotive OEM
P6	Manufacturing Strategy Consultant (Technical Specialist)	Appliances, Electrical and Electronics Manufacturing

To reinforce, the primary aim of the Powertrain game is to encourage players to consider perspectives different from their own. Ideally, this game is conducted in a workshop or focus group setting, as in the following section. Therefore, at this stage, the valuable insights from participants' responses to the subsequent questions will suffice to gain a deeper insight into their perspectives, enhancing the understanding of DfSC behaviour. These are the open questions:

1) Please explain your rationale for selecting these particular members for your team.
2) Reflecting on the decisions made during the development stage, could you describe your current Supply Chain? Do you consider your product is well-aligned with your Supply Chain?
3) Which paraments (quality, delivery, or cost) were primarily in your mind when considering a later change in Product Design? In making this decision, did you take into account the impact on your Suppliers?
4) What reasonable information would you require at earlier stages to effectively respond to the disruption encountered during the Production Stage?

The answers to the first question reveal insightful aspects of the participants' rationale. Notably, half of the participants chose only 5 out of the 13 available team members. In contrast, P5 selected all available members, citing the need for all available members due to the aggressive development timeline required in this project, not accounting for the potential challenges of managing larger teams. P6's response emphasised a delivery performance motivation, stating, "I felt that they were the best placed to focus on product delivery". Remarkably, every participant selected the 'Sr. Engineer, Advanced Product Quality', underscoring the importance of quality performance in powertrain development.

The response from P1 highlighted the value given to cross-functional integration, noting, “I needed a multidisciplinary team and when possible, with senior roles”. The importance of supplier participation was evident, as all participants, except for P3, chose to include a member of the supplier in their project team. Finally, the most comprehensive reflection on DfSC principles came from P2, who stated that the “key focus is on sufficient design and cost understanding in the early phases of development to avoid more costly changes during the production readiness phase. This must incorporate early engagement of suppliers and the assessment of supply chain risks”.

The decision-making logic of the players regarding manufacturing process selection prominently featured flexibility as a priority. For instance, P6 advocates for micro-factories, stating, “building where you sell gives flexibility and improves sustainability”. Echoing this sentiment, P2 stresses the “many unknowns in the development of these products”, so focused on decisions that can accommodate later design changes. While P1 balances “the focus on design requirements to assure quality” with the need to develop internal solutions for enhancing flexibility with suppliers. Additionally, P5 emphasised the preservation of quality in manufacturing decisions, supporting that in its selection “quality was not compromised”. These arrays of perspectives underscore that the participants prioritised flexibility while focusing on maintaining product quality.

The participants’ views on accepting late changes to product design were diverse. Four out of six participants accepted these changes. Perhaps, the most candid justification came from P4, who heightened the leadership role of the engineering team in product development by stating, “If the Lead engineer proposes that change, I follow or I exchange him”. P5 discusses the importance of robust change management in the supply chain, considering that the supplier’s lack of such skill “shouldn’t prevent an advantageous change from being implemented”. Likewise, P1 agrees that “pushing and action back” to the supplier is not as critical as the potential cost saving advantages. Conversely, both P2 and P6 express concerns over the hidden costs associated with late product changes, such as potential delays and quality issues. They advocate for a cautious approach, with P2 suggestion to “launch and introduce cost reductions once production is stable”, and P6 recommending that “improvements should be launched as a running change”. This diversity in responses reflects the inherent trade-offs involved in product design alterations, as well as potential bias towards the suppliers’ responsibilities.

Finally, the participants’ response towards the supplier disruption at the production stage was also mixed, with P1, P2, P3 and P5 opting for temporary measures that support the supplier through the disruption, while P4 and P6 focusing on internal options to address these disruptions. In responses to the fourth question about the information required at early stages, the answers did not yield particularly expressive insights. However, overall, the game facilitated a fruitful discovery of considerations that reflect on the implications of DfSC. It is then anticipated that these discussions in a workshop setting, in the ensuing session, would offer further information that expands into the perceptions and behaviours of the players involved in NPD projects.

7.3 The Game in a Workshop Setting

This section provides an overview of the findings from the workshop which featured the Powertrain game. In line with the approach taken in the previous workshop activity, the participants played the Powertrain game individually, followed by a group discussion. The detailed workshop protocol is available in the Appendix for reference. During this session, the researcher conducted a focus group discussion with professionals from the Automotive industry.

7.3.1 The Case Company

The case company, referred to as WORK_AUTO, is a distinguished UK-based original equipment manufacturer (OEM) in the automotive industry, known for competing in the high-end luxury vehicle market. WORK_AUTO combines a dual vision of delivering quality and excelling in high-end customisation production. Stressing their commitment to this vision, WORK_AUTO aspires, by their own admission, to be a leading agile creator of luxury vehicles. This ambition is backed by significant investments and extending product design time to ensure quality standards. According to them, such measures are critical to maintaining their promise of excellence in vehicle production. Consequently, WORK_AUTO’s dedication to quality and agility in production luxury vehicles sets the stage for a compelling workshop session.

WORK_AUTO is aiming to transition towards a more agile operational framework, with new cross-functional activities and a flatter organisational structure which empowers employees to create and deliver fully electric variants of its vehicles. In this effort, senior managers and various other team members participated in a learning event at Aston University. Within this event, members of the Global Material Planning and Logistics department, as detailed in Table 5-D, engaged in a workshop activity where the Powertrain game was introduced, and results discussed. The game is particularly well-suited to WORK_AUTO's operational context. Therefore, participation in this session enabled a practical understanding of their current DfSC behaviours. On the other hand, this focus group activity, through the lens of the Powertrain Game, provided essential insights for this Thesis, enabling a real-world evaluation of the designed artefact solution in embedding effective DfSC behaviours.

7.3.2 *Results from the Focus group*

At the start of the workshop session, as in the previous workshop session, the researcher initially outlined the fundamental principles of 3-DCE and DfSC to the attending members of WORK_AUTO. This focus group was characterised by different levels of professional experience and decision-making responsibilities in the organisation. This diversity meant that, while some attendees were already familiar with these concepts, others had yet to engage with them in a practical context. After this brief introduction, participants were invited to play the Powertrain Game individually. Next, a detailed analysis of their responses and interactions during the game is provided.

Concept stage:

- Team composition: The results indicate a preference for larger teams, with participants on average selecting 10 members from the pool of 13. Out of the 15 participants, 5 chose all potential project team members, while only 3 selected less than 50% of the available members. A common rationale for selecting larger teams was, in their view, the absence of additional costs, with one participant stating: “Why wouldn’t I want to have more skills in my team for free?”. This answer reflects a lack of concern for potential complexity costs about managing larger teams or even the seniority of the team members.
- Supplier participation: Only 40% of the participants decided to invite someone from their main supplier to join the project team. This decision was in stark contracts to the unanimous inclusion in the first question of the lead design engineer from the supplier. Upon addressing this inconsistency, some participants acknowledge a misunderstanding about the affiliation of this member. They maintained their decision not to invite the Supplier at this stage, suggesting that early supplier involvement is not a priority for these members of WORK_AUTO.

Development stage:

- Manufacturing Process decisions:
    - Batch size: 73% opted for smaller batch sizes.
    - Quality strategy: All participants (100%) chose to assure quality early on, rather than relying on later testing.
    - Sourcing strategy: 60% preferred off-the-shelf procurement, while 40% decided for in-house design.
    - Flexibility: 87% prioritised flexibility over operating their factories at maximum capacity.
    - Commonality: 80% chose to use more common components and processes.

- Late Product design changes: 53% accepted late changes for cost savings, whereas 47% preferred maintaining the original design.

A common thread across these decision-making processes was a preference for maintaining flexibility since it critically impacts their ability to anticipate future challenges. However, the participants recognise that priorities are adapted “depending on the complexity of the project”. Moreover, a substantial emphasis was placed on quality, emerging as a key concern for most participants involved.

Reflecting on the groups’ manufacturing process decisions triggered a debate about the inevitable trade-offs between functional goals, and decision-making authority. Notably, the focus group participants, mainly from WORK_AUTO’s Planning and Materials Logistics departments, reported frequent conflicts with the Procurement and Purchasing teams. According to them, these tensions arise as the latter teams prioritise cost-effective solutions, often overshadowing the logistics teams’ responsibilities on timely delivery, leading to the expectation that they will manage any arising issues effectively. There was a consensus in the room that functional trade-offs are a significant source of friction in NPD projects. An insightful remark from a participants encapsulated this notion, suggestion that such frictions are often overlooked or “swept under the carpet”.

Disruption to Supplier in the Production Stage:

- Supplier Disruption response: Faced with an important supplier disruption, 79% of the participants focused on measures that underscore internal solutions to the problem. Only 11% prioritised temporary support measures to assist the supplier facing the disruption.

During the follow-up discussion, the participants expressed concerns regarding about the measures proposed for temporarily supporting the supplier. Particularly, some participants felt discomfort about the idea of relaxing quality standards for any supplier, with many considering quality as non-negotiable. Additionally, there was a perception among some participants that the relationship with the supplier involved in the powertrain development project was still recent. This supposed new partnership raised doubts about adopting a supplier development approach at such an early stage of the relationship. However, when clarified about the intentions beyond these measures some participants were willing to reconsider their stance. They also acknowledge that in WORK_AUTO, there are existing programmes to temporarily increase suppliers’ orders to mitigate short-term financial disruptions.

- Learning Experience: For this workshop, participants were asked to rank strategies for mitigating similar disruptions. Figure 7.1 represents the average results. Increased visibility into their supply chain and internal processes was the top strategy for 10 out of 14 participants (1 participant did not respond to this question). On the other end, leveraging organisational capabilities to enhance the supplier was selected was least favoured by 6 out of 14 respondents.

To address future disruptions, there was a consensus on prioritising the development of internal procedures. Participants did acknowledge the potential benefits in risk reduction derived from enhanced supplier collaboration. However, they failed to clearly articulate how these benefits would be passed on to the suppliers.

14 out of 15 people answered this question

#1	Mapping out all the Product & Supply Chain Processes to better visualise the challenges of fulfilling the demand (with Supplier participation)	**#1.5** average
#2	Work on improving the alignment of internal goals (e.g. design specs. and production requirements) and the accuracy of information by using common understandings	**#2.64** average
#3	Establish relationships with more Suppliers to reduce dependency and meet production requirements	**#2.79** average
#4	Leveraging the Company's capabilities to help our key Suppliers to achieve their own goals	**#3.07** average

Figure 7.1 – Results from the Learning Experience

Subsequently, the researcher posed a question concerning the considerations of product lifecycle in their decision-making processes. The discussion revealed a limited focus on the product's entire lifecycle. Participants indicated that within WORK_AUTO, the responsibility for overseeing the product's end-to-end lifecycle predominantly resides with the Planning team. This suggests a compartmentalised approach to lifecycle management, contrary to the DfSC behaviour that this research aims to embed.

- Participant Profile Type: Of the 15 participants, 11 would be characterised with the 'Product Expert' profile, prioritising quality over other measures. Three members categorised as 'Operational Master', with a focus on cost and delivery performance. A single participant exhibited mainly collaborative beliefs, and notably, none were classified as 'Strategic Thinker', with the emphasis on alignment of essential NPD considerations.

The decision-making dynamics observed in the Powertrain game workshop predominantly reveal a focus on internal considerations among the participants. For WORK_AUTO, an ideal takeaway from the workshop would be to identify areas of improvement. In this case, the organisation could be looking into providing additional training to team members in the M&PL departments, emphasising the importance of fostering collaborative orientation, and aligning functional trade-offs. Alternatively, it might mean integrating new team members who bring a different set of beliefs and perspectives. However, it is important to acknowledge that the workshop participants work in departments that are inherently focused on internal processes. More general recommendations would only be possible with the participation of a more diverse set of departments. Nevertheless, this workshop provided a significant insight to this study: in the appropriate setting, a gamified-solution, similar to the Powertrain game, can be employed to devise strategies that instil DfSC principles within NPD teams.

7.3.3 Is Design for Supply Chain at the core of the business?

The final minutes of this workshop were dedicated to a broad discussion about the WORK_AUTO's approach to NPD projects. This was intended to replicate the dialogue from the workshop session with WORK_AEROD. Unfortunately, the discussion was dominated by a few senior participants, which seemed to marginalise those with less decision-making authority, leading to their relative alienation. This notable imbalance contributed to a clear sway of opinions in this part of the discussion.

As reflected by the results of the game, cross-functional collaboration is frail, impeding effective interdepartmental cooperation. Participants acknowledge a palpable "us versus them" mentality, particularly between the Purchasing and Logistics teams. Despite this, participation recognise the benefits of collaborating with suppliers, especially in terms of "gaining access to a wider pool of knowledge, thus reducing the need for R&D investments". Interestingly, in WORK_AUTO's logistics department, service suppliers are more integrated than component suppliers, possibly indicating that even in decisions regarding supplier participation there might be functional trade-offs involved.

In light of this apparent disregard of DfSC principles by these members of WORK_AUTO, a critical question was raised: what alternative strategies are being employed by your teams? A senior member's response highlighted their reliance on strong reengineering processes: "*changes to product design are nearly inevitable, often the logistics department works with assumptions, making strong reengineering capabilities essential*". This response highlights their core preference for flexibility, as reflected by their game decisions, but as well, a notable lack of visibility into product lifecycle or SC risks. It left open the question: "Is the strong capability of reengineering processes a substitute for developing DfSC behaviour or is it merely a consequence of these behaviours not being fundamentally integrated in the first place?”

In pursuit of addressing this question, insights were gathered from an internal post-workshop presentation at WORK_AUTO, accessed through a team member. This presentation, with parts publicly accessible, articulates the behaviours promoted by WORK_AUTO to empower their members towards their vision of being an agile creator of luxury vehicles. That is, it aims to communicate the purpose, vision, and strategic path of the organisation, and how its members could contribute to uphold these. Significantly for this research, the behaviours promoted in this presentation may be reinterpreted as WORK_AUTO’s journey towards cultivating DfSC behaviours, potentially assisting in the achievement of their NPD goals.

Employing the template proposed by Gioia et al. (2013), the themes emerging from WORK_AUTO’s presentation were systematically structured, as illustrated in Figure 7.2. The selected evidence for the analysis primarily focuses on the expectations WORK_AUTO holds for its members. Central in their expectations is the principal aim of enhancing customer experience, prompting an emphasis on quality. The presentation also encourages collaboration among employees with diverse perspectives to achieve common objectives, which is predicated on building trusting peer relationships. Moreover, it advocates for a culture of curiosity and continuous learning, enabling employees to grow and deliver effective outcomes.

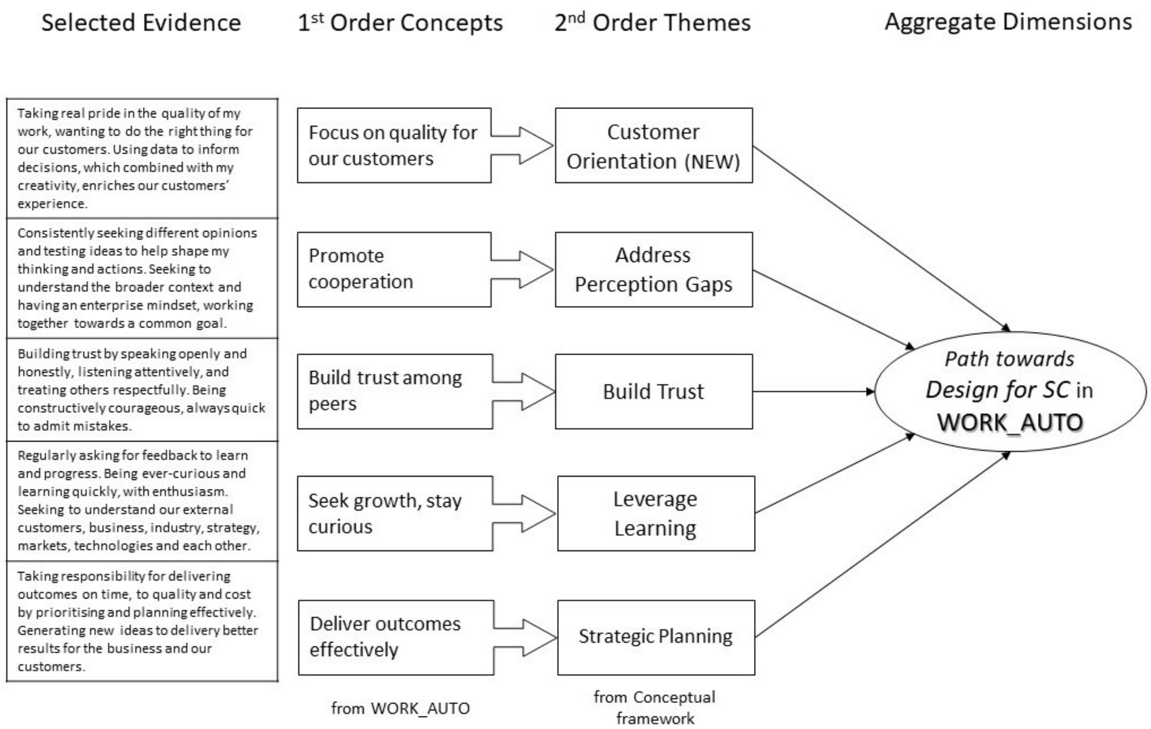


Figure 7.2 – Thematic analysis from WORK_AUTO's journey towards DfSC

The linkage between the concepts derived from WORK_AUTO's presentation and the original roadmap for DfSC, presented in Chapter 3, reveals a notable omission in the proposed roadmap: the emphasis on the fundamental objective of any NPD project, which is satisfying customer needs. Thus, the identification of a previously unconsidered mechanism: customer orientation (Ilyas et al., 2024). That is, having a clear understanding of the customers' needs at every stage of the project can help integrate strategic objectives with functional goals and operational activities.

Still, the previously identified concepts resonate on how to achieve that goal, such as highlighting the importance of addressing perception asymmetries through collaboration with diverse colleagues and acknowledging the pivotal role of learning in the transition to DfSC behaviours. As previously stated, WORK_AUTO emphasises the necessity of building trust among peers to facilitate that cooperation. However, it is critical that they recognise the NPD projects are not isolated within a single organisation; they are influenced by external relationships, which need to be strengthened for successful outcomes. WORK_AUTO aspires to foster purpose-oriented behaviours, underpinned by a strategic plan that requires team members' commitment. Likewise, strategic planning is a key underlying mechanism identified in the conceptual framework for the successful implementation of such behaviours.

The general ideas derived from the presentation outline the expected behaviours of WORK_AUTO's members. From the workshop session, it became evident that while some of these behaviours are cemented, others are not as prevalent. For instance, workshop participants acknowledge that prioritising quality is a well-established aspect of their professional beliefs, aligning with the organisation's objective of delivering excellence to customers. Furthermore, open and honest communication among members was noted, a factor that might contribute to building the trust necessary for mechanisms, such as collaboration, to function effectively. However, despite this, challenges in cross-functional cooperation and supplier engagement persisted in dialogue with WORK_AUTO's members. This finding appears to suggest that not all underlying mechanisms are triggered the same, thus compelling the creation of bespoke programmes for each of them. Yet, the presentation indicates a commitment to aligning with DfSC principles, aiming to enhance NPD outcomes.

7.4 Validating Interviews

At this stage of the research, four professionals from distinct manufacturing industries and countries, as described in Table 7-E, were specifically chosen to contribute to data collection.

This selection aimed to validate the importance of the artefact solution, in this case the Powertrain game, in enhancing NPD outcomes by promoting DfSC behaviours within NPD teams. These professionals have senior roles in their organisation and extensive experience with these topics in practical contexts. Crucially, all four consented to participate in the validation interview, after having engaged with the game outlined in the previous sections. They provided valuable insights which were geared towards a deeper exploration of the game's impact and a discussion on DfSC principles. This section offers the main ideas from these pivotal conversations regarding the practical application of this approach.

Table 7-E: List of participants in the Validation Interviews

ID	Role	Industry/ Company	Country
PV1	Head of Procurement	Aluminium Wheel Manufacturing	Germany
PV2	Supply Chain Manager	Industrial Machinery Manufacturing	UK
PV3	Distribution Operations – Director	Machinery Manufacturing	USA
PV4	Sr Director – Logistics & Materials Execution	Aerospace Component Manufacturing	USA

The participant profiles are crucial in understanding the rationale behind their contributions. Participant PV1, an experienced leader in the automotive industry, brings a wealth of knowledge as a purchasing manager of steel, aluminium, and energy. With a doctorate in risk management and price volatility, they have honed their expertise across Asia, Europe, and North America. Participant PV2, currently the Purchasing & Supply manager of a UK-based SME in engineering and manufacturing, has over twenty years of experience in purchasing management. Their company has a global export footprint in wide-ranging engineering services, such as aluminium honeycomb production and safety testing solutions. Participant PV3, the Director of Distribution Operations at a global multi-industrial manufacturing leader, has a 14-year career in this organisation encompassing various leadership roles in supply chain management. Particularly, in managing large-scale operational transformations globally. Lastly, participant PV4, the Sr. Director of Logistics and Materials at a leading aerospace component manufacturer, powering some of the World's most advanced aircraft, brings an extensive career in Global Supply Chain Operations across multiple manufacturing organisations. The collective backgrounds of these professionals highlight their significant experience, crucial for productive discussions on the topic at hand.

The approach adopted for the validation interviews reflected the format used in the workshop session with WORK_AUTO. Initially, the invited participants were offered the opportunity to independently submit their responses to the game. Participants V1 and V2 submitted their responses, whereas V3 and V4 engaged with the game but did not submit responses. This was followed by a one-to-one conversation centred around the game's utility as a learning tool and the relevance of incorporating DfSC principles within their organisations. The interview protocol, available in the appendix, was applied in a flexible manner and was designed to last one hour on average. The interview concluded with the presentation of the original conceptual framework to the participants, encouraging them to contribute towards formulating a practical roadmap for DfSC implementation. Some participants raised concerns about confidentiality, with only one interview being transcribed. Nonetheless, the researcher documented the key points and observations of these discussions, shared these notes with the participants for verification, and incorporated this feedback to validate the findings. This process sets the stage for the subsequent subsections that focus on the necessity of changing behaviours in NPD projects and evaluating the game's effectiveness for this purpose.

7.4.1 Changing behaviours in NPD projects

Participant responses highlight a pivotal link between the understanding of customer requirements and behavioural patterns in NPD projects. PV1 emphasises that, in their organisations, the design process initiates only after identifying the unique selling point (USP). That is, while some customers prioritise price, others may want a high-quality solution. This underscores the necessity of aligning functional trade-offs with customer orientation behaviours. A view echoed by PV2, who notes that their organisation's goals are determined by sales as the "voice of the client, directly influencing project direction. In this sense, the role of the project manager, as elucidated by PV1, is often close to sales to bring customer insights into the project's core objectives. The role of the supply chain, in PV2's view, serves to balance engineering and customer orientation. These observations illustrate the dynamic interplay that leadership poses on the various organisational functions in NPD projects.

The participants unanimously agreed that effective leadership is essential for managing behaviours in NPD projects. Once again, PV1 describes the project leader's role as critical in aligning team efforts with customer expectations and organisational capabilities. Thus, acting as a gatekeeper mitigating trade-off conflicts in line with the type of project. For instance, as PV4 observes, the engineering-driven approach in industries like aerospace prioritises product quality over other goals. PV3 shares this perspective, noting that in their organisation, project leadership often lies within the engineering teams, potentially leading to biases in decision-making. A rare example of leadership collaboration occurs between the engineering and marketing departments. Likewise, in their organisation, PV4 is the first leader with this level of seniority that comes from a background of Global Supply Chain Operations. With this unique position, they advocate for broadening team perspectives, emphasising the importance of diverse expertise in guiding NPD projects towards success.

As a result, organisational culture emerges as a significant factor influencing product development, particularly in cross-border projects, as highlighted in the interview with PV1. They articulate the challenges faced by traditional companies in fostering cross-functional collaboration, often hindered by entrenched department silos or “independent kingdoms”, as they called it. In contrast, innovative organisations, characterised by an open and egalitarian culture, tend to excel in cross-functional behaviours. Considering this, PV3 reveals that their organisation promotes a decentralised, entrepreneurial culture for that very reason, facilitating team autonomy and collaborative decision-making aimed at customer-centric goals. Meanwhile, PV4’s experience in engineering complex projects illustrates a more closed culture often restricted to the organisation within the ecosystem. Furthermore, PV2’s insights from an SME context provide a distinctive approach. Their company has a top-down approach to strategy definition, to which every function seeks to align, albeit without a concerted effort to assist other departments in achieving their own strategic goals. Such variances further underscore the impact of organisational culture in shaping the behaviours within NPD projects.

Integrating a lifecycle perspective into NPD projects has emerged in several validation interviews. PV4 emphasised its criticality, particularly in contexts where products undergo long design cycles, such as in complex engineering projects. To that extent, their organisation employs simulation tools which enable team members to visualise the long-term impacts of their design choices. Similarly, PV1 recounted a project aimed at avoiding product recalls, illustrating the importance of lifecycle management. Issues in the project arose four years post-launch, prompting the original design team to be brought back. Uniquely in the organisation, this team's responsibility extended beyond production to end-of-life considerations, necessitating incentives to encourage foresight into long-term trade-offs. That is, integrating lifecycle considerations into product design decisions. Additionally, for PV2's organisation, this perspective is intricately linked with flexibility and risk management. These insights are shared across the interviews and collectively underscore the lifecycle perspective's role in enhancing project success by anticipating and mitigating future challenges in NPD projects.

Ultimately, the discussion converged on the critical need for behavioural change within organisations to effectively integrate the principles of DfSC in NPD projects. This necessity is exemplified by an incident during the research, after a request to a PV2’s colleague for the inclusion of a distinct functional perspective was met with limited enthusiasm. The response from the engineering manager, “I am just dealing with R&D and at this stage supply chain is of less relevance so I am not sure if I can be of much help", underscores a prevalent siloed approach, where the intertwining of different functional areas appears to be overlooked. In contrast, PV3 states that their organisation actively endeavours to break down these functional silos. Despite this, they still face challenges, notably in reconciling conflicts between operations and sales, necessitating frequent internal collaborative sessions. For PV4's organisation, the concept of DfSC remains an "afterthought". For instance, departments like packaging engineering are routinely excluded from the initial stages of the design process, a practice PV4, as a leader, is striving to change. Collectively, these insights confirm a common theme across organisations: the critical need for change organisational behaviour towards DfSC principles. Such change would not only facilitate a more integrated approach to product development but also ensure that experts that perceive long-term supply chain implications are actively involved in the decision-making process, ultimately driving more efficient and effective NPD projects.

7.4.2 The effectiveness of the gamified solution

The final stage of the validation interviews focused on the application potential of the proposed Powertrain game within organisations to facilitate that organisational change. An initial reaction from PV4 reflects the game's potential challenges and potential for improvement. PV4's statement was, "I 'played' with the game as an individual, and I could see how much of a challenge a team would have playing the game so I look forward to learning more." This feedback from PV4 serves as a constructive critique, indicating that while the game has a promising foundation, its adaptability and effectiveness in a team context require further refinement to maximise its impact. Nevertheless, PV4 underscored the game's potential for its stated aim of embedding DfSC principles into NPD projects.

In response to the game's proposed solution, PV3 provided insightful recommendations for enhancing its effectiveness and capitalising on its identified strengths. The primary suggestion was to ensure participants understand that the game's objective is to change team dynamics. Furthermore, PV3 advocated for tailoring the game to the specific contexts of the organisations involved in the targeted product development project. That said, the proposal was for managers to assist in the game's redesign effort. Critically, this approach should underscore the non-punitive nature of the exercise, highlighting it as a platform for team members to express their perspective while addressing their own perception biases. Corroborating this suggestion, PV4 compared the game to simulation tools used by their organisation, emphasising its utility in expanding mental networks. Their suggestions reinforce the game's potential as a transformative instrument for improving team collaboration to develop DfSC thinking in organisational settings.

The participant PV2 expressed a favourable view of the proposed solution as an effective instrument for continuous learning, a critical concept echoed in the workshop session with WORK_AEROd and WORK_AUTO. These sessions highlighted the importance of continuous learning in cultivating a DfSC environment. PV2 noted their team members are encouraged to engage in new activities with the organisation, fostering a cross-functional mindset, and recognised the Powertrain game as a potential aid in this process. Additionally, PV1 pointed out a significant challenge: the general difficulty for organisations to document failures. PV1 suggested that the game could serve as a valuable tool for simulating and benchmarking experiences against the company's current standards and procedures.

Lastly, terminology plays a crucial role in addressing functional perception asymmetries, particularly in the context of the proposed solution. PV3 highlighted the importance of presentation, suggesting that the Powertrain game should be branded not as a game but as an assessment or calibration tool for product development behaviours. In this opinion, this marketability strategy would facilitate the engagement of practitioners with the exercise. Moreover, regarding verbiage differentiation, PV4 noted distinctions within their organisation between Procurement and Logistics, with only the former being integrated into product devolvement decisions. In practical terms, in this organisation, supply chain design stops in manufacturing and procurement decisions. PV1 expanded on this, distinguishing between advanced and operational procurement, each required distinct thinking processes, with the former typically more connected to the market while the former specialises more on the sourced component. Therefore, the successful implementation of the proposed gamified solution rests on clear communication and understanding of the roles, objectives and language across all involved participants and organisations.

7.5 Summary of the Gamified Solution findings

This chapter introduced a gamified approach as an innovative boundary object to enhance cross-functional and organisations learning of DfSC principles. Drawing on the Mechanics, Dynamics, and Emotions (MDE) framework by Robson et al. (2015) and key guidelines from Riar et al. (2022). The game integrates the Theory of Planned Behaviour (TPB) to categorise participant responses into four DfSC profiles: Product & Technological Expert, Operational Master, Collaborative & Relationships Manager, and Strategic Thinker. Initial data collection involving six participants suggests the game's potential suitability for reflecting managerial decision-making behaviours, offering a promising avenue for further exploration and validation.

In a practical application, the game was deployed in a workshop with members of the Global Material Planning department of a distinguished UK-based OEM in the automotive industry.

The focus group's feedback highlighted a unanimous inclination towards flexibility and maintaining product quality in decision-making, aligning with their organisation's DfSC values (refer to Figure 7.2). Once again, this consistency indicates the potential of the proposed solution.

Additionally, this chapter presented insights from validation interviews with four industry experts, delving into the broader implications of the DfSC and the proposed gamified solution. These conversations emphasised the need for behaviour changes at both organisational and individual levels. On the organisational front, they stressed the importance of cultivating a culture that incentivises continuous learning. At the individual front, they indicate the necessity for professionals to expand their mindset, for instance by adopting a lifecycle perspective on project implications. Crucially, these interviews further offered valuable recommendations for refining the artefact design's role as an effective boundary object.

7.6 Anticipating the Next Chapter

The next chapter synthesises the arguments, statements, and findings from this research, setting the stage to address the overarching research questions and delineate the novel contribution of this Thesis. It is structured into two main discussion cycles: the first aims to revise the proposed roadmap for DfSC implementation, and the second focuses on defining DfSC-oriented behaviours. This structure ensures a thorough examination of the research outcomes, paving the way for meaningful conclusions and practical implications.

8 DISCUSSION

8.1 Overview

This research project has been dedicated to investigating the effectiveness of the supply chain design decisions in NPD, with the predominant goal of developing a robust scientific argument that highlights the critical importance and often overlooked aspect of considering supply chain implication in such projects. Therefore, of utmost importance for this study is to bridge the gap between the theoretical benefits of cross-functional approaches, such as 3-DCE, and the practical challenges encountered in their implementation. These challenges often result in tangible inefficiencies, which resonate throughout the product lifecycle and exert impact across multiple organisations within the product's supply chain. Specifically, the following discussion seeks to provide answers to the two overarching research questions of this Thesis: 1) "How do underlying mechanisms shape the adoption of a 'Design for Supply Chain' behaviour in NPD projects?", and 2) "How to facilitate the practical incorporation of 'Design for Supply Chain' behaviours within the teams and organisations involved in NPD projects?"

Further, this chapter attempts to make a compelling case for the quality and novelty of the research findings. This study confronts the stated field problem of DfSC embeddedness, utilising a DSR strategy as outlined by Van Aken et al. (2016). The initial phase of this strategy involved identifying the underlying mechanisms for DfSC implementation, presented in Chapter 3 through an analysis of peer-reviewed case studies. This synthesis culminated in the creation of a roadmap that constitutes the initial conceptual framework. Subsequently, the empirical phase of the DSR strategy, concentrated on evaluating functional perception asymmetries in relation to product, process and supply chain design decision within NPD projects to confirm the research problem, as detailed in Chapter 6. Then, Chapter 7 introduced an artefact solution, grounded in boundary object and planned behavioural theories (Carlile, 2002; Ajzen, 1991), designed to tackle the identified field problem. The insights gained from these research findings are instrumental in understanding DfSC behaviours in NPD projects and are particularly critical for broadening mindsets that are conducive to improved NPD outcomes, both throughout the product lifecycle and across various organisations.

8.2 Research Project Evaluation

The discussion in this subsection embarks on delineating two pivotal arguments: firstly, underscoring the important role of design science in forging theoretical concepts with practical applicability, secondly, scrutinising the research strategy's quality and contribution to reinforce confidence in the project's findings, outputs, and conclusions. These arguments are pivotal in articulating the value and robustness of the research undertaken.

This research project offered a significant contribution towards addressing the practical challenges associated with incorporating the supply chain dimension into complex manufacturing NPD projects. Corley and Gioia (2011) assert that the value of theoretical contributions in organisation and management studies hinges on originality and utility. Positioned within their matrix, this project's contribution is marked by incremental originality and pronounced practical utility. Specifically, it identified a gap in the existing theoretical frameworks concerning the behavioural aspects of integrating supply chain trade-offs within NPD projects. In the pursuit of filling that gap, this research builds on existing knowledge around the concept of 3-DCE, but rather extending these insights to facilitate the practical understanding and implementation of DfSC behaviours. Additionally, the adoption of a design-science methodological approach was instrumental in devising original solutions that enrich the theoretical discourse in this domain.

Design-Science Research (DSR) is inherently characterised by its practical utility, facilitating the application of theory to real-world managerial and organisational challenges, as Corley and Gioia (2011) elucidate. This research directly addresses the emergent friction mechanisms that hinder the implementation of theoretical constructs aimed at harmonising the supply chain with other design decisions within complex product development endeavours. Hence, by enabling stakeholders to discuss and understand the implications of diverse design interventions on project goals across the product lifecycle and supply chain, this study aids managerial decision-making. Ultimately, the overarching aim of the research strategy is to contribute to the enhancement of managerial and organisational capabilities in NPD contexts, while generating knowledge that is not only theoretically robust but practically applicable.

As elucidated in Chapter 5, the essence of design science lies in its capacity to generate generic solutions or design propositions that are both academically rigorous and pragmatically relevant. These propositions are guided by the pragmatic CIMO-logic, as outlined by Denyer et al. (2008), which state that "for this problem-in Context, it is useful to use this Intervention, which will produce, through these Mechanisms, this Outcome". The abductive nature of design science, championed by Oliva (2019) and Chandrasekaran et al. (2020), is especially pertinent in O&SCM research, provided the theoretical contributions are substantial. For this research project, the design science approach involved the extraction and comparison of theoretical insights from scholarly articles with empirical evidence from a vignette-based experiment and focus group workshops, yielding critical insights for addressing the research problem. Such an abductive approach, as depicted in Figure 8.1, ensures that the generated knowledge is both relevant and actionable.

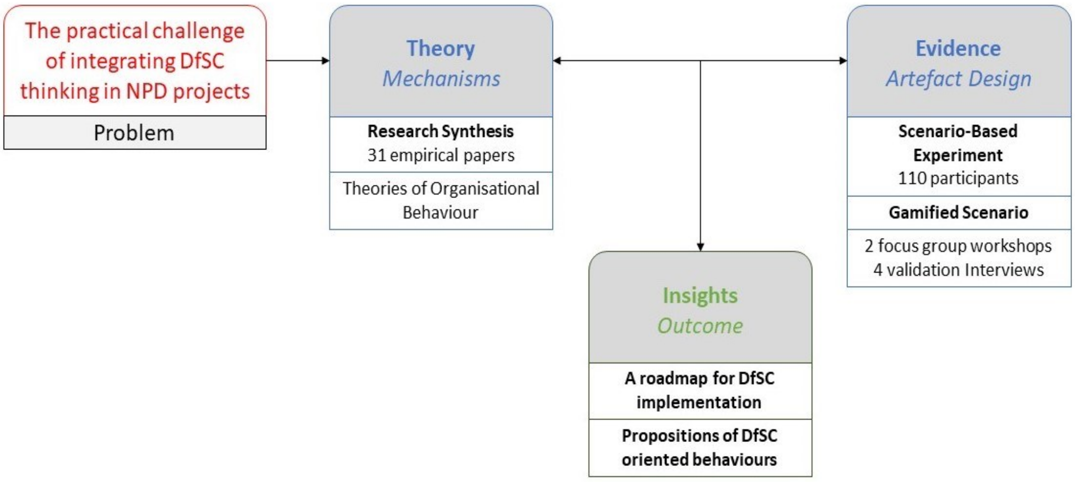


Figure 8.1 – Research Cycle of this Thesis

This design science effort has facilitated the development of an artefact targeted to address the relevant real-world problem at the intersection between O&SCM and NPD. The complexity inherent in DSR, as identified by Groop et al. (2017), is particularly evident in the unstructured nature of the problem at hand, which lacks a definitive formulation. For instance, reflecting on the synthesis in Chapter 3, such as the works Ateş et al. (2015), Tuli and Shankar (2015), Mikkelsen and Johnsen (2019) or DeCampos et al. (2022), it becomes clear that although all these studies intervene to support the involvement of supply chain functions in NPD projects, they view the problem through different lenses. Consequently, the effectiveness of emergent solutions and mechanisms are contingent upon their unique perspective. Thus, this research underscores that interventions aimed at fostering DfSC behaviours across the product's supply chain are profoundly context sensitive.

Addressing the framed problem requires a nuanced approach in which the artefact solution captures the critical and often overlooked importance of individual and organisational behaviour. Central to this approach is the engagement with industry stakeholders to design solutions that not only offer viable practical interventions but also contribute to the refinement of existing theoretical frameworks, as exemplified by Groop et al. (2017) and Akkermans et al. (2019). Initial findings from a scenario-based experiment detailed in Chapter 6 confirmed the existence of functional perception asymmetries concerning the 3-DCE concepts. Subsequently, based on feedback from a workshop setting, the scenario was transformed into a gamified artefact solution tailored to the problem. This revised approach underwent further evaluation in another workshop session and received validation from four industry experts, as presented in Chapter 7. On that note, this study continues to embrace an abductive logic that takes the empirical evidence with the emergent theoretical paradigms, thereby generating insights that contribute to a revised roadmap for DfSC and proposals for DfSC-oriented behaviours.

8.3 A revised roadmap for "Design for Supply Chain" implementation

In the initial roadmap, introduced in Chapter 3, employing a soft-systems approach from Clegg and Shaw (2008) was instrumental to structure and connect the broad, critical and creative analysis that resulted in the underlying mechanisms for DfSC implementation. This foundation guided the research path towards the complex behavioural aspects of interacting SC in NPD project to enhance performance, which was further explored through a scenario-based experiment. This experiment was designed to uncover functional perception asymmetries in product, manufacturing process, and supply chain design. These misalignments were indeed confirmed and identified as crucial elements influencing DfSC behaviour at the individual level. The experimental findings presented in Chapter 6 not only address an initial investigative question (RQ1.1) but paved the way for the exploration of the impact of behaviour on DfSC implementation.

Enhanced by the empirical insights garnered from two focus group workshops and four validation interviews, this research is now equipped to answer the first overarching research question.

RQ1 – How do key underlying mechanisms influence the successful implementation of "Design for Supply Chain" in NPD projects within discrete manufacturing industries?

The revised roadmap continues to use the holonic template, serving as a visual representation of these insights, effectively encapsulating the answer to RQ1, illustrating the dynamic between organisational and individual behaviours in the pursuit of DfSC implementation.

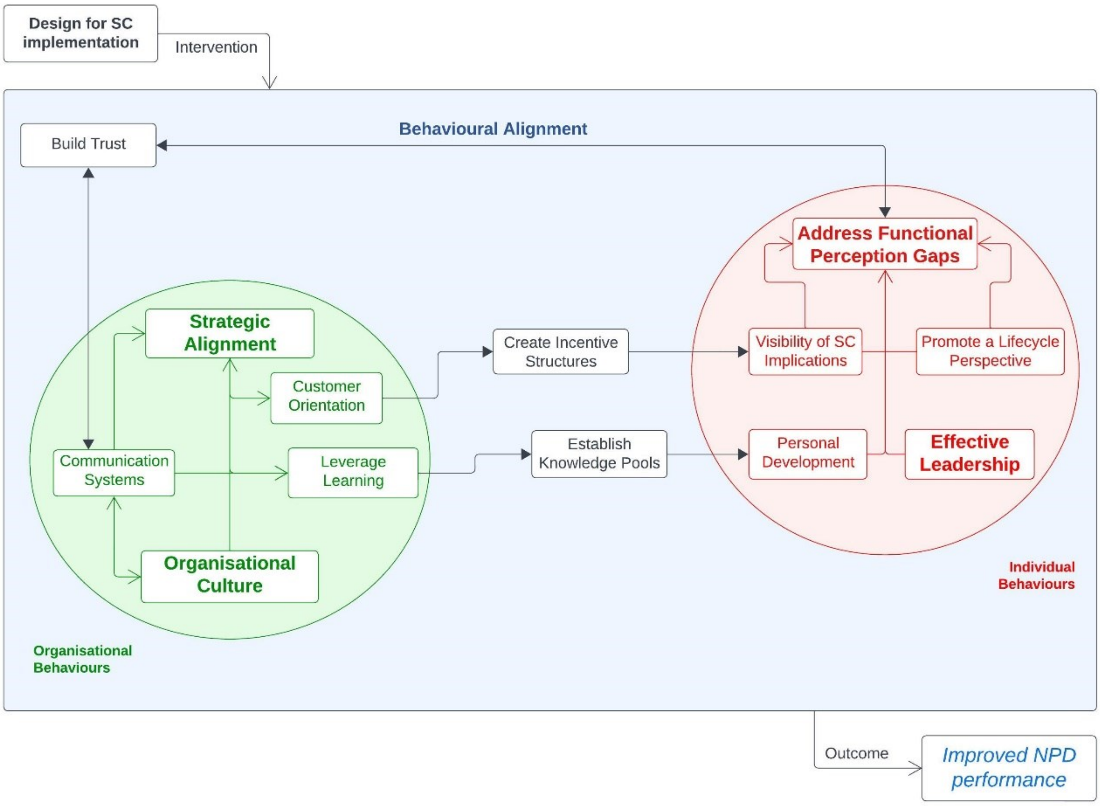


Figure 8.2 – Revised Roadmap for DfSC implementation

The workshop sessions reveal that the underlying mechanisms triggered by DfSC implementation are structured within two higher levels of behavioural systems: organisational and individual. The template's "pick-up" point, as in the initial roadmap (refer to Figure 3.6), focuses on strategic behavioural aspects necessary for DfSC implementation to enhance NPD performance, rather than specific decisions, processes, or activities related to the NPD project. As such, these behavioural mechanisms are fundamental to creating an environment that enables cross-functional integration, encourages a holistic view of the product lifecycle, and eventually leads to a shared understanding of 3-DCE.

The research synthesis identified, within the individual mode, functional perception asymmetries as the primary behavioural mechanism that impacts the goal of enhancing performance through DfSC. The experiment in Chapter 6 demonstrates that managers recognise the importance of supply chain design but only integrate concurrent engineering (product and process design) into their judgments and behaviours. Consequently, the performance will be affected if managers do not accurately perceive the relationship between the supply chain and other dimensions in NPD projects. For instance, their motivation for sharing information may decrease, as decision-makers may not recognise the advantages of enhanced visibility, in contrast to the benefits evidenced in academic literature (Somapa et al., 2018). Likewise, the struggle to incorporate supply chain factors into manufacturing process decisions could affect the supply chain's flexibility during the product lifecycle, as Kumar et al. (2020) reported. Therefore, it is critical to bridge these gaps in managerial perception to fully leverage the potential of DfSC for improving NPD performance.

The findings from this experiment offered two possible explanations for this behavioural misalignment. One plausible interpretation is that decision-makers perceive the supply chain dimension as strategic, whereas they view product and process decision as more tactical or operational. In the revised roadmap, strategic alignment assumes a critical role in connecting organisational and individual behaviours. Another interpretation is that differences in terminology between supply chain and process dimensions might lead to inconsistent understanding of both dimension, a position supported by Khan (2018, p. 105). In fact, PV's input in the validation interview confirms the importance of a common understanding, suggesting that the presentation of certain topics to different NPD teams can impact their behaviours. Hence, another crucial element of the revised roadmap is the "communication systems" mechanism, which now encompasses not just IT systems but also standardising terminologies or concepts.

The necessity for strategic alignment brought attention to a new mechanism that was not included in the initial roadmap: customer orientation. The mechanism originated during WORK_AUTO's workshop session while discussing the responses of their global logistics team to the Powertrain Game. The post-game conversation revealed that despite the logistics department's primary focus on cost effectiveness, they follow WORK_AUTO's path towards DfSC which prioritises product quality to meet customer needs. In fact, the participants' in-game selections reflect and emphasis on product quality. This discovery emphasises that including customer orientation, understanding consumers' demands within NPD teams can help integrate strategic objectives with functional goals and operational activities, assisting in the adoption of DfSC practices.

In both levels of behavioural systems, learning is a key component of the revised roadmap, which while present in the original roadmap, strongly resurfaced during both workshop sessions. WORK_AEROD's journey towards DfSC involves overcoming perception asymmetries by developing cross-functional talent. Actually, it might be the most critical factor for them, as individuals are incentivised to remain curious, learn fast, and improve themselves and others, fostering a culture of learning with world-class capabilities within the company. Talent development is also evident in WORK_AUTO's path towards DfSC, as they promote functional rotation schemes that increase curiosity and learning opportunities. Overall, the learning mechanism, as depicted in the revised roadmap, emphasises collaborative learning and the creation of accessible knowledge pools, enabling both individuals and organisations to leverage these resources to the benefit of improved NPD performance.

Incentive structures that encourage alignment between organisational and individual behavioural alignment are critical for the successful implementation of DfSC. The organisation must effectively convey strategic goals across functional dimensions. Individually, they are equally important to ensure that the supply chain implications are visible throughout various functions and stages of the product lifecycle. This research project proposes an incentive structure that utilises gamification to adopt and integrate DfSC practices by leveraging their existing knowledge. This is an inventive structure of direct involvement, as defined by Benton et al. (2020), which incorporates training and educational strategies to establish enduring relationships instead of focusing on immediate rewards or penalties. Validation interviews in section 7.4 endorse a gamified approach to encourage behavioural change, if supported by the leadership role in broadening of their teams' perspectives.

Effective leadership significantly influences the successful incorporation of DfSC behaviours into NPD teams. PV1 and PV3 highlight the crucial roles of project leaders in coordinating team efforts in handling behavioural dynamics and resolving trade-off disputes. The emphasis on traditional engineering leadership in NPD project in PV4's sector often compromises the organisation's ability to integrate the "supply chain voice" into managerial decision-making. These insights collectively demonstrate the indispensable role of leadership that traditionally hinders DfSC adoption, also acknowledged by PV2. Therefore, effective leadership was a mechanism added to the original framework.

Table 8-A presents a concise overview of the interconnections between the emerging mechanisms. Building upon the empirical analysis, the roadmap shifts from abstract mechanisms to tangible organisational and individual behaviours that must be aligned. This revision provides a more actionable framework that enhances the understanding of the behavioural dynamics in NPD decision-making. Thus, the empirical findings allowed not only the validation of the underlying mechanisms introduced in Chapter 3 but also strengthened its applicability in guiding organisations towards DfSC implementation.

Table 8-A: Summary of the Thematic Analysis

Aggregate Dimensions	Underlying Mechanisms	Selected Statement	From	Connected to
Organisational Behaviours	Strategic Alignment	Seeking to understand the broader context and having an enterprise mindset	• WORK_AUTO • PV1 • PV3	Customer Orientation and Effective Leadership
	Organisational Culture	A culture where we accelerate the most valuable learning and are open to the chance of failure along the way	• WORK_AEROD • PV2 • PV4	Collaborative Orientation and Organisational Behaviours
	Communication Systems	Communication is about being understood and understanding others	• WORK_AEROD • PV3	Build Trust, Effective Leadership and Strategic Alignment
	Leverage Learning	Develop world-class capabilities	• WORK_AEROD • WORK_AUTO	Knowledge Pool and Personal Development
	Customer Orientation	Focus on customer and 'voice of the client', directly influencing project direction	• WORK_AUTO • PV2	Strategic Alignment and Organisational Behaviours
Individual Behaviours	Functional Perception Gaps	Showing awareness and sympathy to other roles and departments reduces friction and promotes teamwork	• WORK_AEROD • WORK_AUTO	Individual and Organisational Behavioural Alignment
	Visibility of SC implications	Awareness of different risks and provision of feedback mechanisms. Management of trade-offs	• WORK_AUTO • WORK_AEROD • PV3 • PV4	Functional Perception Gaps
	Lifecycle Perspective	Define accountability for the product at each stage and long-term implications of the project	• WORK_AEROD • PV1	Functional Perception Gaps
	Personal Development	It includes developing yourself, developing others, and	• WORK_AEROD • WORK_AUTO	Leverage Learning, Strategic Alignment,

		considering how current actions and plans will assist the future for all		Organisational Culture
	Effective Leadership	Top leader's role is critical in guiding team efforts towards customer expectations and organisational goals	• PV1 • PV2 • PV3 • PV4	Strategic Alignment and Individual Behaviours

8.4 Promoting "Design for Supply Chain" Oriented Behaviours

This thesis addresses the critical challenges of promoting and sustaining the implementation of DfSC practices in NPD projects. The "Powertrain game", a key element in the research strategy, is designed a learning tool, as explained in Chapter 7, and included in the Appendix. This game is carefully crafted to facilitate behavioural changes, encouraging managers to move beyond narrow, individualistic, or functional-focused perspectives and adopt a cooperative, holistic approach to decision-making. Precisely, this approach emphasises the importance of considering the implications of decision decisions across the product lifecycle and along the supply chain. Ultimately, this gamified solution seeks to act as an incentive tool that promotes the alignment between organisational and individual behaviours towards supply chain design.

The empirical work from the combined workshops and validation interviews, using Ajzen's (1991) Theory of Planned Behaviour (TPB) as theoretical underpinning, offers insights to address the second overarching research question.

> **RQ2 –** How can teams and organisations incorporate "Design for Supply Chain" behaviours in NPD projects within discrete manufacturing industries?

As extensively discussed by now, the intricate relationship between perceptions and behaviours plays a crucial role in the commitment of organisations to adopt DfSC principles in NPD projects. Drawing parallels with the findings of Januszek et al. (2024), which examine managerial commitment to lean programmes, a significant challenge emerges in linking local improvements to overall performance. Wemmerlöv (2021) highlights how often practitioners struggle to perceive the benefits of process improvements due to confounding variables that obscure the relationship between such approaches and financial outcomes. This issue is particularly pronounced among top managers, who are instrumental in championing these initiatives but often find it difficult to discern their direct impact on financial indicators. The disconnect, as elucidated by both Wemmerlöv (2021) and Januszek et al. (2024), stems from top management's distance from the day-to-day implementation of these strategies, in contrast to middle managers who directly observe the benefits, such as enhanced employee training or increased process stability. Therefore, the efficacy of leadership in advocating and implementing process improvement strategies is paramount.

In the context of embedding DfSC principles to enhance NPD performance, the empirical findings of this study reveal that leadership in decision-making traditionally resides within the Engineering or Marketing departments. As best put by PV4 statement: "*I am the first leader in the long history of this organisation at this level of seniority with a background on Supply Chain and only been in this position for over a year*". Echoing the arguments made by Januszek et al. (2024), this top leadership disconnect to supply chain design may lead top managers overseeing NPD projects to overlook the advantages of DfSC implementation discussed in Chapter 2, failing to connect them with tangible improvements in NPD performance. Further, Ateş et al. (2020) suggest that visionary leaders across different functions, due to their unique boundary-spanning positions (Floyd and Wooldridge, 1997) and varying interactions with top management, may have disparate perceptions of strategy. Hence, the necessity of closing functional perception gaps through effective leadership by linking strategic alignment with DfSc initiatives becomes evident.

At an individual level, the TPB informs about the critical link between belief and behaviours, essential for the effective implementation of organisational actions (Fishbein and Ajzen, 2011). Emiliani (2003) explores how leaders' beliefs shape their behaviours and competencies required for the successful deployment of lean programmes, emphasising that for a fundamental change of individual beliefs across the business, supported by top management participation and commitment. This transformative processes is underpinned by action learning or double loop learning, which involves questioning and correcting defence mechanisms that maintain current beliefs (Oliva, 2019; Anand et al., 2009; Argyris, 1977, 2002). Argyris (2002) highlights the inevitability of individuals to recognise their skilled incompetencies or lack of areas of unawareness towards certain areas to adopt new behaviours effectively. Yet, as PV1 notes in the validation interview, this is a common shortfall in organisations trying to embed DfSC behaviours: "*Typically, people are not very good at documenting their failures, so lessons learned is not really a thing…You will have the database, but you will rarely look at it*". Moreover, through double loop learning, behavioural changes towards DfSC cannot be fully realised by sporadic workshops alone (Argyris, 1977, p. 123). Proactive engagement is required to broaden individual's mental models beyond their functional biases and daily routines, ensuring a more integrated and effective approach to DfSC implementation.

The proposed gamified solution, grounded in boundary object theory (Carlile, 2002), offers a learning platform for enhanced inter-functional and organisational exchange, bespoke to the relevant stakeholders, where different perspectives are not only accepted but internalised. Ultimately, fostering a comprehensive understanding of the multifaceted nature of NPD projects through the product lifecycle. Thus, this approach underscores the critical need for top leadership to participate and promote a culture of double loop learning and strategic awareness, enabling the successful incorporation of DfSC behaviours into NPD processes.

All in all, to answer RQ2, a key finding of this Thesis tells that "An organization aiming to foster DfSC oriented behaviours must actively bridge functional perception gaps through effective leadership, strategic alignment and enhanced inter-functional collaboration. This can be facilitated by innovative educational tools, such as gamified solutions, which create an action learning environment conducive to individual awareness of the comprehensive benefits of DfSC practices, leading towards organisational behavioural changes".

9 CONCLUSION

9.1 Overview

The final chapter offers a summary of the research work conducted in this thesis, reviewing the research aim and highlighting the main findings. Afterwards, there is a reflection on the contributions to the existing body of knowledge as well as the practical and managerial implications. Moreover, this chapter addresses the research limitations and sets the direction for future research opportunities. A conducting statement reflecting on the research project is provided.

9.2 Research Summary

New Product Development (NPD) projects within discrete manufacturing industries are confronted with increasingly dynamic and rapidly changing conditions. Technological advancements are now occurring at an unprecedented pace, especially in critical systems responsible for securing competitive advantages. Notably, the push towards electrification in the automotive industry exemplifies this transformation. Furthermore, the growing imperative for social and environmental sustainability compels organisations to extend their perspective and actions beyond internal operations and ensure long-term viability. The post-COVID business environment, compounded by political and economic tensions, adds an extra layer of uncertainty and volatility to these projects. Consequently, the need for an integrated NPD approach has never been more pressing. However, organisations often find themselves in deeply entrenched practices, struggling to go beyond traditional boundaries and adopt such approaches.

This study focused on the challenges of incorporating supply chain considerations into NPD projects, despite the availability of important frameworks, such as 3-DCE. The examination of the body of knowledge, in Chapter 2, highlights the concrete advantages of concurrent design of products, processes and supply chains in NPD projects. However, it also highlighted the lack of a behavioural dimension, such as adoption behaviours or perception asymmetries, in investigating these practices. Therefore, this research sets out to explore the underlying mechanisms that drive the deployment of Design for Supply Chain (DfSC) behaviours that enhance NPD performance. The notion of DfSC is understood, in this study, as the principle of concurrently accounting for multifaceted functional and supply chain decisions in NPD projects across multiple organisations, seeking mutually beneficial outcomes throughout the product lifecycle.

This thesis, adopting a Design Science Research (DSR) strategy, systematically took on the challenge of proposing a solution to the stated problem. The aim is to improve generic actions that facilitate the adoption of DfSC principles. DSR is both a strategy for producing solution-oriented knowledge and a pragmatic approach for problem-solving, based on a CIMO logic where interventions happen in a context, triggering mechanisms to achieve desired or unexpected outcomes. After defining NPD projects in discrete manufacturing industries as the unit of analysis, the first step of this strategy was to identify and comprehend the underlying mechanisms that are required or hinder the successful implementation of DfSC interventions. Here, a research review was conducted from 31 peer-reviewed empirical studies on interventions similar to the DfSC principles, following a synthesis by interpretation (Rousseau et al., 2008; Pawson et al., 2006).

The underlying mechanisms that emerged from the research synthesis were articulated and structured using a soft-systems approach. This structured model, as delineated by Checkland and Scholes (1999), enhances critical observations around the problem, allowing actions to be taken. Essentially, this structured approach constitutes the conceptual framework that guided the research on DfSC acceptance. The proposed framework clearly establishes decision-making behaviours at the centre of the debate, encouraging organisations to identify and address the diverse perspectives in NPD project decisions. Consequently, organisational behavioural theories serve as the theoretical foundation of this research, not only supporting the elucidation of the problem but also underscoring the framework's utility in justifying this study's findings, thereby enhancing the understanding of the adoption behaviours of DfSC principles in complex NPD projects.

In the first part of Chapter 6, this research progressed detailing a vignette-based experiment conducted to answer the investigative question RQ1.1. The findings are supported by the responses from 110 participants, all of whom with managerial decision-making responsibilities in NPD, to manipulations on 3-DCE decisions in the hypothetical development of a new powertrain project.

> **RQ1.1** – “*How do decision-makers perceive changes in product, process, and supply chain design in NPD projects?*”.

The findings reveal several key findings: 3-DCE is not fully embraced in managerial decision-making processes (Finding A). Product and process design decisions, traditional concurrent engineering, are firmly ingrained in managerial practices, with participants reacting to manipulations in these areas (Finding B). Decisions concerning the supply chain are perceived as strategic but may not be aligned with the other design aspects (Finding C). The data indicates that participants may struggle to distinguish between processes and supply chain designs, which complicates their understanding and implementation of 3-DCE (Finding D).

Further, the scenario was discussed in a workshop format including, key elements from a leading organisation in the aerospace and defence sector, which greatly influenced the research direction, especially by proposing to turn the scenario into a game. This section of the research is extensively detailed in Chapter 7, explaining the gamification process. The game was then employed in a workshop session, this time engaging participants of a prominent UK-based OEM in the automotive industry. The combination of insights from the two workshops, along with data from four validation interviews, helped to comprehensively revisit the initial conceptual framework. These enhanced insights were instrumental in addressing the first overarching research question:

> **RQ1** – “*How do key underlying mechanisms influence the successful implementation of “Design for Supply Chain” in NPD projects in discrete manufacturing industries?”*

The research analysis categorises the underlying mechanisms that impact the adoption of DfSC principles into two behavioural systems: individual and organisational (Finding E).

Five key mechanisms for implementing DfSC emerged within the organisational behavioural system: <u>strategic alignment</u>, emphasising the importance of communicating and understanding the project’s broader context and fostering an enterprise mindset (Finding F); <u>customer orientation</u>, which should drive the focus of the strategic alignment (Finding G); an <u>organisational culture</u> that is open to change, collaboration (Finding H), and values <u>learning</u> to develop and leverage capabilities across the supply chain (Finding I). Additionally, <u>communication systems</u> that promote behavioural alignment between organisations and individuals by building trust among stakeholders (Finding J).

From the individual behavioural system, an additional five main mechanisms emerged: <u>functional perception asymmetries</u> significantly contribute to the challenge of embedding DfSC behaviours, as confirmed in the scenario experiment (Findings A to D). To bridge these gaps, the discussions suggested increasing individual awareness of supply chain implications throughout the product lifecycle (Finding K). Linked to a culture of learning, individual stakeholders should invest in behaviours related to personal development, maintaining curiosity that extends beyond their functional responsibilities (Finding L). Finally, effective leadership is crucial for successfully capitalising on DfSC implementation (Finding M), since the commitment of top management is strongly linked to the effectiveness of adoption (Januszek et al., 2024; Emiliani, 2003).

Finally, in the context of DSR, the gamified solution functions as an artefact for problem-solving. This artefact, operating within the theoretical lens of Carlile's (2004) boundary object framework, facilitates the transfer of knowledge across disciplinary boundaries. When combined with Ajzen's (1991) TPB and Argyris's (1977) concept of double loop learning, the gamified solution incentivises behavioural changes by transferring individuals' current beliefs into new domain-specific knowledge embedded with DfSC principles. The outcomes of these interactions contribute to addressing the second overarching research question, indicating the solution's capacity to bridge theoretical principles and practical implementation.

> **RQ2 –** How can teams and organisations incorporate "Design for Supply Chain" behaviours in NPD projects within discrete manufacturing industries?

This research question can be effectively answered with the following key finding: an organisation aiming to foster DfSC oriented behaviours must actively bridge functional perception gaps through effective leadership, strategic alignment, and enhanced inter-functional collaboration. This can be facilitated by innovative educational tools, such as gamified solutions, which create an action learning environment conducive to individual awareness of the comprehensive benefits of DfSC practices, leading towards organisational behavioural changes (Finding N).

9.3 Research Contributions

9.3.1 Theoretical Contributions

This study contributes significantly to the existing knowledge on integrating the supply chain into NPD projects. It does this by looking more closely at the behavioural implications of Fine's (2000) 3-DCE concept. Overall, this study stands out for its systematic efforts to address the gaps in the practical implementation of DfSC concepts. This issue has not been sufficiently tackled in prior empirical research (Pashaei and Olhager, 2015). Notably, this thesis utilises a DSR strategy as its guiding approach to answer the call for a hybrid mode of knowledge generation that explains the functioning of the key relational dynamics (Fawcett and Waller, 2011). Through a scenario-based experiment, this study brings perception asymmetries in O&SCM to the centre of the debate, an area with limited contributions. Finally, by fulfilling its aim of facilitating the adoption of DfSC behaviours, this research demonstrates how a gamified solution can be used as boundary objects to create a tool for solving real-world problems.

Despite Ellram et al.'s (2007) significant contribution by using Fine's (1998) 3-DCE as a theoretical lens to enhance NPD performance, there is still a lack of studies that empirically investigate the outcomes of these powerful ideas (Reitsma et al., 2023). Chapter 3 of this research offers a systematic synthesis that locates, selects, and interprets empirical studies with similar common themes to identify key contexts, interventions, mechanisms, and outcomes. This adds to the academic discourse. Moreover, this thesis cleverly applies Clegg's (2007) PrOH template using soft-systems principles to develop a roadmap for DfSC implementation, which aims to direct future research efforts.

Additionally, this work contributes to filling the notable research gap on perception asymmetries in O&SCM that Slot et al. (2020) recognised. It does so in Chapter 6 by examining managerial perception gaps in product, process, and supply chain design using a scenario-based experiment. Previous studies have mostly focused on how perception influences the relationship between buyers and suppliers, highlighting the possibility of disagreements causing disruptions in collaboration (Villena and Craighead, 2017; Oosterhuis et al., 2013). Recent work by Creazza et al. (2022) demonstrates that by aligning perceptions in the supply chain, organisations can develop more effective risk strategies and mitigation initiatives. Thus, existing literature, though scarce, highlights the impact of perception asymmetries in the context of collaborative business operations, such as those in NPD projects that are the unit of analysis of this study.

The empirical contributions of this thesis shed light on the significance of behavioural considerations in the adoption of DfSC principles, a previously unexplored topic with only recent studies delving into the adoption behaviours of lean practices (Januszek et al., 2024; Arellano et al., 2021). By deploying a DSR strategy to develop and test an artefact solution, this study not only aids practitioners in implementing DfSC practices but also extends the theoretical foundations by integrating behavioural theories, such as TPB, boundary objects, and double loop learning, into the design effort. The insights gathered from the workshop sessions and validation interviews in Chapter 7 further elucidate the interplay between organisational and individual behaviours in the successful implementation of DfSC practices.

Lastly, this thesis advances methodological approaches in O&SCM by operationalising a DSR strategy, in accordance with Akkermans et al.'s (2019) recommendation for DSR contribution to existing research methodologies in the field. This research conducted a systematic review in Chapter 5 to offer an operational framework for DSR, aiming to provide a structured approach, despite the absence of a fixed methodology, as outlined by Van Aken et al. (2016). This framework, based on abductive reasoning and empirical engagement with the industry (see Figure 8.1), offers a comprehensive plan for implementing an intervention and derives insights that have an impact on both theory and practice.

9.3.2 Practical, Managerial Implications

This research is primarily motivated by the practical challenge of committing to supply chain implications within the context of NPD projects in discrete manufacturing industries. In essence, the fundamental aim of this thesis is to help organisations leverage the concrete benefits these approaches offer while also assisting individuals to broaden their current knowledge and beliefs regarding DfSC. Therefore, this study provides practical insights for professionals at both strategic and operational levels and diverse functions (e.g., engineering, product design, manufacturing, logistics, and procurement) to enhance supply chain integration and thereby boost project performance.

One of the key practical contributions of this research is its focus on overcoming friction mechanisms in the adoption of DfSC behaviours. Through the detailed examination of case studies and industry engagement, this research developed a roadmap for DfSC implementation at both organisational and individual levels. The roadmap indicates that to successfully capitalise on the adoption of DfSC, organisations require strategic alignment driven by customer focus and a culture that incentivises learning and personal development to tackle perception gaps. These key mechanisms can be incorporated into the projects' strategic planning, highlighting the areas that must be monitored for NPD success.

The results from the scenario-based experiment are also beneficial to managerial action. Particularly, this experiment shed light on the real beliefs and behaviours that managers involved in NPD go through. It is not unusual for managers to believe that they are already adopting DfSC principles in their decision-making processes. However, the results in Chapter 6 reflect a concealed bias in their responses to design manipulations (e.g., product architecture, manufacturing process changes, or supply chain visibility level). By addressing these misalignments, individuals can reflect on their hidden beliefs and improve decision-making by devising strategies that incorporate them into their own decision-making processes. This may involve targeted training sessions and enhanced communication systems to provide an integrated view of the design consequences across the supply chain and product lifecycle.

Through the development of the gamified solution, this thesis offers a tool that can be employed by organisations to seriously debate the importance of promoting DfSC behaviours. Furthermore, by combining the gamification elements with the theoretical concepts of TPB, both organisations and individuals can identify their own belief configurations, thus facilitating the development of bespoke strategies for double loop learning (i.e., the transformation of decision-making behaviours based on experience). Crucially, this research discovered that the commitment of top management to the learning tool is vital for engaging employees and initiating genuine cross-boundary discussions that can alter rooted behaviours.

In summary, this research provides valuable practical insights for industry professionals, addressing a pressing issue in NPD projects. The potential of learning solutions for facilitating DfSC adoption, rooted in the alignment of functional perceptions through the visualisation of supply chain implications over the product lifecycle, offers a comprehensive blueprint for organisations aiming to improve their NPD performance. The research will help practitioners navigate modern supply chain complexities, leading to more resilient and competitive supply chains and sustainable products in constantly changing environments.

9.4 Limitations and Future Research opportunities

This research, like any scholarly work, is subject to certain limitations, which are duly recognised in this subsection. One significant issue is the possibility of reporting bias due to the author's active participation in different research stages. This bias may appear in various aspects: in the selection and interpretation of the reviewed case studied in Chapter 3; in the target selection of participants for the scenario-based experiment in Chapter 6; and in the active development of the artefact solution in Chapter 7. To mitigate potential bias, the research synthesis adhered to the methodological guidelines set forth by Tranfield et al. (2003) as well as Rousseau et al.'s (2008) recommendations for evidence synthesis, including purposive sampling and validating the coding system, to reduce potential biases. The necessity of meticulously selecting participants for the experiments was precisely laid out to correspond with the specifications of the research problem. For the development of the artefact solution, a pilot test was performed with an independent supply chain and procurement leader, initially presented to six professionals (see Table 7-D), and later, validation interviews were conducted with four industry experts from varied sectors to discuss the merits of the solution. Despite these measures, studying the artefact solution and roadmap in other DSR studies remains important for its wider validation and acceptance, emphasising the significance of ongoing testing and improvement in design-science research.

The artefact solution proposed in this thesis does not represent a final product ready for immediate implementation within New Product Development (NPD) teams to foster Design for Supply Chain (DfSC) behaviours. This limitation, namely the inability to generalise the artefact for universal application, might appear significant. However, within the realm of Design Science Research (DSR), the iterative process of problem analysis, solution design, and continuous refinement through testing cycles is foundational, as outlined by Van Aken et al. (2016). This approach acknowledges the complexity of real-world interventions, particularly those involving social systems and human agency, where the process of redesign is crucial for the artefact's success in management practices (Van Aken and Berends, 2018).

Importantly, the role of leadership commitment is pivotal for the effective implementation of DfSC practices. Thus, the gamified solution proposed should not be seen as a static tool but rather as one that requires continuous redesign in close collaboration with top management. This collaborative approach ensures that the solution is tailored to address specific organisational contexts and challenges, adhering to the design principles laid out in this thesis. Such a bespoke adaptation process enhances the solution's relevance and efficacy, aligning it more closely with the unique supply chain needs and dynamics of each organisation and stakeholder it seeks to benefit.

Further exploring the limitations, this research focus on managers with NPD responsibilities inherently raises the issue of a small sample size, which constrains the validity and generalisability of its findings. Additionally, while the examination of DfSC practices in workshop sessions with members of the aerospace and automotive industries strengthens internal validity, it limits the opportunities to generalise beyond the context of discrete manufacturing industries. In an effort to mitigate these limitations, the research incorporated additional evidence at various stages to bolster its conclusions. For instance, the scenario experiment was conducted with 110 members of multiple organisations and field-tested in the aerospace industry, and the gamified solution was field-tested with elements of the automotive industry and validated with extensive interviews. Extending the study to include other industries beyond discrete manufacturing, such as process or service industries, could enhance the generalisability of the findings and explore the applicability of DfSC behaviours in various contexts.

Moreover, analysing behavioural considerations presents its own set of challenges, particularly in controlling for potential variables such as the impact of new regulations or organisational restructuring. This concern is echoed by Arellano et al. (2021), who highlighted the difficulty in isolating these effects completely. To navigate this complexity, the study opted to select mechanisms at a higher level in both the development of the DfSC roadmap and the decision-making mechanisms within the game, consciously avoiding the inclusion of excessively context-specific factors. This decision seeks to find a middle ground between relevance and generalisability, enabling insights that, while informed by particular industry practices, are not overly constrained by them.

Building on the acknowledgement of existing limitations, this research opens several avenues for future investigations that could enhance the understanding of the dynamics at play in DfSC implementation. Firstly, the experiment detailed in Chapter 6 presents an opportunity for deeper exploration through its potential execution across three distinct functional groups: engineering, logistics, and procurement. Such segmentation would not only shed light on the effects of the manipulation within the 3-DCE concept but also reveal how sensitivities to these design dimensions may vary across different functions. For example, it raises the question of whether engineering roles might react to product design manipulations in a significantly different manner compared to procurement roles.

Additionally, the integration of the TPB with game elements, encapsulated in the scoring rules, offers fertile ground for empirical enhancement. Future research could employ fQCA techniques to evaluate whether the beliefs outlined in Table 7-C accurately and comprehensively mirror managerial attitudes towards DfSC. Although potential endogeneity concerns and the complexity of this technique, as highlighted by Arellano et al. (2021), suggest caution. Nonetheless, despite these investigations exceeding the primary objective of this thesis, they propel an exciting new path for emerging deeper in the examination of the behavioural aspects of DfSC practices.

In conclusion, future research would benefit from focusing on carefully examining how organisations adopt DfSC principles. Fundamentally, this thesis has provided an opportunity to investigate the behavioural aspects of DfSC adoption. Future research could concentrate on explaining these phenomena. One promising approach is to conduct a detailed longitudinal case study that carefully follows the redesign and adoption of the proposed artefact solution to meet the specific needs of the supply chain. This investigation should not only examine the initial adoption but also analyse to what extent the artefact promoted changes in the organisation’s behaviours, carefully considering and separating any variables that could affect the results to fully comprehend the artefact’s influence.

Notably, future research could gratly benefit from integration of the behavioural mechanisms identified in this study with modelling methodologies such as the Design Structure Matrix (DSM) and Set-Based Concurrent Engineering (SBCE). While this Thesis primarily focused on identifying behavioural mechanisms through a design-science approach, incorporating DSM and SBCE methodologies could enhance decision-making in individual NPD projects by systematically mapping dependencies and exploring multiple design alternatives concurrently, thereby realigning the contributions of this Thesis with Fine’s original work.

The DSM is a valuable tool for representing and analysing the dependencies within complex systems, facilitating improved coordination and communication among teams (Browning, 2015). Yang et al. (2015) demonstrated how DSM and Multi-Domain Matrix (MDM) models can identify coordination drivers and barriers in global product development projects, leading to optimised team structures and reduced coordination costs. Similarly, by modelling the organisational and individual behaviours in the revised DfSC roadmap, organisations could, for instance, more effectively visualise the interdependencies arising from functional perception gaps, supply chain visibility, and lifecycle considerations identified in this research. Thus, an extension of this research based on this approach would assist organisations in modelling behavioural mechanisms and enhancing decision-making processes in individual NPD projects.

Additionally, SBCE or Set-Based design offers a supplementary approach that encourages the exploration of various design alternatives and postponement of decision commitments to gain better insights (Toche et al., 2020). The redesign of the artefact solution with set-based design principles could facilitate a more consistent approach to the adoption of DfSC principles. For example, by modifying the game mechanics into realistic design solutions and gradually narrowing down options based on the intersection of feasible sets, as suggested by Sobek et al. (1999), participants could more effectively determine whether their individual behaviours align with those of the organisation and its strategic objectives. This approach could maximise the potential of the Powertrain game and enhance the adoption of DfSC practices.

Consequently, extending this research to include DSM and SBCE methodologies presents a promising path for improving decision-making in NPD projects. By combining the gamified solution with robust modelling techniques, future studies can provide a more comprehensive framework for organisations aiming to improve supply chain integration and NPD performance.

9.5 Concluding Statement

This research work in this thesis was supported by an amalgamation of simple but powerful ideas. Starting from the philosophical approach to research that should be focused on solving a research problem, as encapsulated by the design science perspective. The identified problem was the alignment of product, process, and supply chain decisions, brilliantly depicted in the 3-DCE. The core of the question is, given the excellent research around the topic as well as the demonstrated benefits, why do multiple organisations still struggle to get the alignment right in NPD operations? From extensive research, the behavioural aspects of practice adoption came to light. Through a synthesis of evidence from empirical research and experimental design, a roadmap for DfSC was proposed. Not enough, this thesis offered an artefact solution in the form of a gamified tool that promotes learning of supply chain implications across the product lifecycle. Hopefully, this research added to the existing knowledge and contributed to the adoption of such powerful principles for the development of better-performing products in real-world contexts.

10 REFERENCES

Abdalla, H. S. (1999) ‘Concurrent engineering for global manufacturing’, *International Journal of Production Economics*, Elsevier, vol. 60, pp. 251–260.

Ajzen, I. (1985) ‘From intentions to actions: A theory of planned behavior’, in *Action control: From cognition to behavior*, Springer, pp. 11–39.

Ajzen, I. (1991) ‘The theory of planned behavior’, *Organizational behavior and human decision processes*, Elsevier, vol. 50, no. 2, pp. 179–211.

van Aken, J. E. and Romme, G. (2009) ‘Reinventing the future: adding design science to the repertoire of organization and management studies’, *Organization Management Journal*, Routledge, vol. 6, no. 1, pp. 5–12 [Online]. DOI: 10.1057/omj.2009.1.

Akkermans, H., Van Oppen, W., Wynstra, F. and Voss, C. (2019) ‘Contracting outsourced services with collaborative key performance indicators’, *Journal of Operations Management*, vol. 65, no. 1, pp. 22–47 [Online]. DOI: 10.1002/joom.1002.

Ali, A., Mahfouz, A. and Arisha, A. (2017) ‘Analysing supply chain resilience: integrating the constructs in a concept mapping framework via a systematic literature review’, *Supply Chain Management: An International Journal*, vol. 22, no. 1, pp. 16–39 [Online]. DOI: 10.1108/SCM-06-2016-0197 (Accessed 9 August 2022).

Anand, G., Ward, P. T., Tatikonda, M. V. and Schilling, D. A. (2009) ‘Dynamic capabilities through continuous improvement infrastructure’, *Journal of operations management*, Elsevier, vol. 27, no. 6, pp. 444–461.

Ancona, D. G. and Caldwell, D. F. (1992) ‘Demography and design: Predictors of new product team performance’, *Organization science*, INFORMS, vol. 3, no. 3, pp. 321–341.

Anderson, D. M. (2003) *Design for manufacturability & concurrent engineering: how to design for low cost, design in high quality, design for lean manufacture, and design quickly for fast production*, CIM press.

Angelis, J., Conti, R., Cooper, C. and Gill, C. (2011) ‘Building a high-commitment lean culture’, *Journal of Manufacturing Technology Management*, Emerald Group Publishing Limited, vol. 22, no. 5, pp. 569–586.

Appelqvist, P., Lehtonen, J. M. and Kokkonen, J. (2004) ‘Modelling in product and supply chain design: Literature survey and case study’, *Journal of Manufacturing Technology Management*, vol. 15, no. 7, pp. 675–685 [Online]. DOI: 10.1108/17410380410555916.

Arellano, M. C., Meuer, J. and Netland, T. H. (2021) ‘Commitment follows beliefs: A configurational perspective on operations managers’ commitment to practice adoption’, *Journal of Operations Management*, vol. 67, no. 4, pp. 450–475 [Online]. DOI: 10.1002/joom.1130 (Accessed 30 June 2023).

Argyris, C. (1977) ‘Double loop learning in organizations’, *Harvard business review*, Boston, vol. 55, no. 5, pp. 115–125.

Argyris, C. (2002) ‘Double-loop learning, teaching, and research’, *Academy of management learning & education*, Academy of Management Briarcliff Manor, NY 10510, vol. 1, no. 2, pp. 206–218.

Ateş, M. A., Van den Ende, J. and Ianniello, G. (2015) ‘Inter-organizational coordination patterns in buyer-supplier-design agency triads in NPD projects’, *International Journal of Operations and Production Management*, vol. 35, no. 11, pp. 1512–1545 [Online]. DOI: 10.1108/IJOPM-01-2013-0036.

Ateş, N. Y., Tarakci, M., Porck, J. P., Van Knippenberg, D. and Groenen, P. J. F. (2020) ‘The Dark Side of Visionary Leadership in Strategy Implementation: Strategic Alignment, Strategic Consensus, and Commitment’, *Journal of Management*, vol. 46, no. 5, pp. 637–665 [Online]. DOI: 10.1177/0149206318811567 (Accessed 20 February 2024).

Autio, E. and Thomas, L. (2014) *Innovation ecosystems*, The Oxford handbook of innovation management.

Bagozzi, R. P. and Yi, Y. (1988) ‘On the evaluation of structural equation models’, *Journal of the academy of marketing science*, Springer, vol. 16, pp. 74–94.

Bahr, W., Mavrogenis, V. and Sweeney, E. (2022) ‘Gamification of warehousing: exploring perspectives of warehouse managers in the UK’, *International Journal of Logistics Research and Applications*, vol. 25, no. 3, pp. 247–259 [Online]. DOI: 10.1080/13675567.2021.1892042 (Accessed 15 September 2022).

Bai, T., Kirshner, S. N. and Wu, M. (2021) ‘Managing overconfident newsvendors: a target-setting approach’, *Production and Operations Management*, Wiley Online Library, vol. 30, no. 11, pp. 3967–3986.

Baldwin, C. Y. and Clark, K. B. (2003) ‘Managing in an age of modularity’, *Managing in the modular age: Architectures, networks, and organizations*, Blackwell Publishing Oxford, vol. 149, pp. 84–93.

Baskerville, R., Baiyere, A., Gregor, S., Hevner, A. and Rossi, M. (2018) ‘Design science research contributions: Finding a balance between artifact and theory’, *Journal of the Association for Information Systems*, vol. 19, no. 5, p. 3.

Belzile, J. A. and Öberg, G. (2012) ‘Where to begin? Grappling with how to use participant interaction in focus group design’, *Qualitative Research*, Sage Publications Sage UK: London, England, vol. 12, no. 4, pp. 459–472.

Bendoly, E. (2016) ‘Fit, bias, and enacted sensemaking in data visualization: frameworks for continuous development in operations and supply chain management analytics’, *Journal of Business Logistics*, Wiley Online Library, vol. 37, no. 1, pp. 6–17.

Benton, W. C., Prahinski, C. and Fan, Y. (2020) ‘The influence of supplier development programs on supplier performance’, *International Journal of Production Economics*, vol. 230, p. 107793 [Online]. DOI: 10.1016/j.ijpe.2020.107793 (Accessed 15 February 2024).

Bevilacqua, M., Ciarapica, F. E. and Giacchetta, G. (2007) ‘Development of a sustainable product lifecycle in manufacturing firms: a case study’, *International Journal of*

Production Research, vol. 45, no. 18–19, pp. 4073–4098 [Online]. DOI: 10.1080/00207540701439941 (Accessed 21 August 2022).

Binder, M. and Clegg, B. (2008) 'The importance of collaborative frontloading in automotive supply networks', *Journal of Manufacturing Technology Management*, vol. 19, no. 3, pp. 315–331 [Online]. DOI: 10.1108/17410380810853759.

Boardman, J. T. (1995) 'Wholes and parts-a systems approach', *IEEE Transactions on Systems, Man, and Cybernetics*, IEEE, vol. 25, no. 7, pp. 1150–1161.

Boardman, J. T. and Clegg, B. T. (2001) 'Structured engagement in the extended enterprise', *International Journal of Operations and Production Management*, vol. 21, no. 5–6, pp. 795–811 [Online]. DOI: 10.1108/01443570110390471.

Boaz, A., Ashby, D., Denyer, D., Egan, M., Harden, A., Jones, D. R., Pawson, R. and Tranfield, D. (2006) 'A multitude of syntheses: a comparison of five approaches from diverse policy fields', *Evidence & Policy*, vol. 2, no. 4, pp. 479–502 [Online]. DOI: 10.1332/174426406778881755 (Accessed 5 March 2023).

Boothroyd, G., Dewhurst, P. and Knight, W. (2002) *Product design for manufacture and assembly*, Second Edition., Marcel Dekker, Inc.

Bozdogan, K. (2010) 'Evolution of the Lean Enterprise System: A Critical Synthesis and Agenda for the Future', in *Encyclopedia of Aerospace Engineering*, Part 31.

Brown, S. L. and Eisenhardt, K. M. (1995) 'Product Development: Past Research, Present Findings, and Future Directions', *Academy of Management Review*, vol. 20, no. 2, pp. 343–378 [Online]. Available at https://jstor.org/stable/258850.

Browning, T. R. (2015) 'Design structure matrix extensions and innovations: a survey and new opportunities', *IEEE Transactions on engineering management*, IEEE, vol. 63, no. 1, pp. 27–52.

Buchanan, D. A. and Huczynski, A. A. (2019) *Organizational behaviour*, Pearson UK.

Burnes, B. and Bargal, D. (2017) 'Kurt Lewin: 70 years on', *Journal of Change Management*, Taylor & Francis, vol. 17, no. 2, pp. 91–100.

Busse, C., Schleper, M. C., Weilenmann, J. and Wagner, S. M. (2017) 'Extending the supply chain visibility boundary: Utilizing stakeholders for identifying supply chain sustainability risks', *International Journal of Physical Distribution and Logistics Management*, vol. 47, no. 1, pp. 18–40 [Online]. DOI: 10.1108/IJPDLM-02-2015-0043.

Cadden, T., Marshall, D. and Cao, G. (2013) 'Opposites attract: organisational culture and supply chain performance', *Supply Chain Management: an international journal*, Emerald Group Publishing Limited, vol. 18, no. 1, pp. 86–103.

Cai, X. T. and Wang, S. (2021) 'Design gene based secure mechanism for collaborative product development', *Advanced Engineering Informatics*, vol. 47 [Online]. DOI: 10.1016/j.aei.2020.101228.

Campagnolo, D. and Camuffo, A. (2010) 'The concept of modularity in management studies: A literature review', *International Journal of Management Reviews*, vol. 12, no. 3, pp. 259–283 [Online]. DOI: 10.1111/j.1468-2370.2009.00260.x (Accessed 6 September 2022).

Campbell, R., Pound, P., Pope, C., Britten, N., Pill, R., Morgan, M. and Donovan, J. (2003) 'Evaluating meta-ethnography: a synthesis of qualitative research on lay experiences of diabetes and diabetes care', *Social Science & Medicine*, vol. 56, no. 4, pp. 671–684 [Online]. DOI: 10.1016/S0277-9536(02)00064-3 (Accessed 4 March 2023).

Cao, H. and Folan, P. (2012) 'Product life cycle: the evolution of a paradigm and literature review from 1950–2009', *Production Planning & Control*, Taylor & Francis, vol. 23, no. 8, pp. 641–662.

van Capelleveen, G., Wieren, J. V., Amrit, C. and Murat, D. (2021) 'Exploring recommendations for circular supply chain management through interactive visualisation', *Decision Support Systems*, Elsevier B.V., vol. 140, no. 113431, pp. 1–12 [Online]. DOI: 10.1016/j.dss.2020.113431.

Caputo, M. and Zirpoli, F. (2001) 'A new organisation for supplier involvement in vehicle design: the Italian automotive industry case', *International Journal of Automotive Technology and Management*, vol. 1, no. 2/3, p. 301 [Online]. DOI: 10.1504/IJATM.2001.000041 (Accessed 26 May 2022).

Caridi, M., Pero, M. and Sianesi, A. (2017) 'Design chain visibility: How much information should you share with your partners during new product development projects?', *Benchmarking: An International Journal*, Emerald Publishing Limited, vol. 24, no. 5, pp. 1337–1363 [Online]. DOI: 10.1108/BIJ-04-2016-0059 (Accessed 4 September 2022).

Carlile, P. R. (2002) 'A pragmatic view of knowledge and boundaries: Boundary objects in new product development', *Organization Science*, vol. 13, no. 4 [Online]. DOI: 10.1287/orsc.13.4.442.2953.

Carlile, P. R. (2004) 'Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries', *Organization science*, INFORMS, vol. 15, no. 5, pp. 555–568.

Cavalieri, S. and Pezzotta, G. (2012) 'Product–Service Systems Engineering: State of the art and research challenges', *Computers in industry*, Elsevier, vol. 63, no. 4, pp. 278–288.

Chandrasekaran, A., de Treville, S. and Browning, T. (2020) 'Intervention-based research (IBR)—What, where, and how to use it in operations management', *Journal of Operations Management*, Wiley Online Library, vol. 66, no. 4, pp. 370–378.

Chaudhuri, A., Mohanty, B. K. and Singh, K. N. (2013) 'Supply chain risk assessment during new product development: a group decision making approach using numeric and linguistic data', *International Journal of Production Research*, vol. 51, no. 10, pp. 2790–2804 [Online]. DOI: 10.1080/00207543.2012.654922 (Accessed 28 July 2023).

Chaudhuri, A., Naseraldin, H., Søberg, P. V., Kroll, E. and Librus, M. (2020) 'Should hospitals invest in customised on-demand 3D printing for surgeries?', *International Journal of Operations and Production Management*, vol. 41, no. 1, pp. 55–62 [Online]. DOI: 10.1108/IJOPM-05-2020-0277.

Checkland, P. (2000) 'Soft systems methodology: a thirty year retrospective', *Systems research and behavioral science*, John Wiley & Sons, Ltd. Chichester, UK, vol. 17, no. S1, pp. S11–S58.

Checkland, P. and Poulter, J. (2020) 'Soft systems methodology', *Systems approaches to making change: A practical guide*, Springer, pp. 201–253.

Checkland, P. and Scholes, J. (1999) *Soft systems methodology in action*, John Wiley & Sons.

Chen, C. C., Chen, X.-P. and Meindl, J. R. (1998) 'How can cooperation be fostered? The cultural effects of individualism-collectivism', *Academy of management review*, Academy of Management Briarcliff Manor, NY 10510, vol. 23, no. 2, pp. 285–304.

Chen, J., Zhao, X. and Lewis, M. (2022) 'Supplier motivation to share knowledge: an experimental investigation of a social exchange perspective', *International Journal of Operations & Production Management* [Online]. DOI: 10.1108/IJOPM-03-2022-0186 (Accessed 9 March 2023).

Chen, Y.-S., Su, H.-C. and Ro, Y. K. (2016) 'Can I read your mind? Perception gaps in supply chain relationships', *Journal of Purchasing and Supply Management*, vol. 22, no. 4, pp. 311–324 [Online]. DOI: 10.1016/j.pursup.2016.06.006 (Accessed 8 May 2023).

Cherryholmes, C. H. (1992) 'Notes on pragmatism and scientific realism', *Educational researcher*, Sage Publications Sage CA: Thousand Oaks, CA, vol. 21, no. 6, pp. 13–17.

Child, P., Diederichs, R., Sanders, F.-H. and Wisniowski, S. (1991) 'SMR forum: the management of complexity', *MIT Sloan Management Review*, Massachusetts Institute of Technology, Cambridge, MA, vol. 33, no. 1, p. 73.

Choi, T. Y., Dooley, K. J. and Rungtusanatham, M. (2001) 'Supply networks and complex adaptive systems: control versus emergence', *Journal of Operations Management*, vol. 19, no. 3, pp. 351–366 [Online]. DOI: 10.1016/S0272-6963(00)00068-1.

Choi, T. Y. and Hong, Y. (2002) 'Unveiling the structure of supply networks: case studies in Honda, Acura, and DaimlerChrysler', *Journal of Operations Management*, Wiley Online Library, vol. 20, no. 5, pp. 469–493.

Christopher, M. (2016) *Logistics & Supply Chain Management*, Pearson Education Ltd.

Christopher, M. and Towill, D. (2001) 'An integrated model for the design of agile supply chains', *International Journal of Physical Distribution & Logistics Management*, vol. 31, no. 4, pp. 235–246 [Online]. DOI: 10.1108/09600030110394914.

Clegg, B. and Shaw, D. (2008) 'Using process-oriented holonic (PrOH) modelling to increase understanding of information systems', *Information Systems Journal*, Wiley Online Library, vol. 18, no. 5, pp. 447–477.

Clegg, B. T. (2007) 'Building a Holarchy Using Business Process-Oriented Holonic (PrOH) Modeling', *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, vol. 37, no. 1, pp. 23–40 [Online]. DOI: 10.1109/TSMCA.2006.886343 (Accessed 30 November 2023).

Clegg, B. T. and Boardman, J. T. (1996) 'Process integration and improvement using systemic diagrams and a human-centred approach', *Concurrent Engineering Research and Applications*, vol. 4, no. 2, pp. 119–135 [Online]. DOI: 10.1177/1063293x9600400203.

Clottey, T. and Benton Jr, W. (2020) 'Recommendations for assessing unit nonresponse bias in dyadic focused empirical supply chain management research', *Decision Sciences*, Wiley Online Library, vol. 51, no. 2, pp. 423–447.

Cohen, J. (2013) *Statistical power analysis for the behavioral sciences*, Academic press.

Cohen, M. D. (2007) 'Administrative Behavior: Laying the Foundations for Cyert and March', *Organization Science*, vol. 18, no. 3, pp. 503–506 [Online]. DOI: 10.1287/orsc.1070.0275 (Accessed 20 November 2023).

Colicchia, C. and Strozzi, F. (2012) 'Supply chain risk management: a new methodology for a systematic literature review', Wilding, R. (ed), *Supply Chain Management: An International Journal*, vol. 17, no. 4, pp. 403–418 [Online]. DOI: 10.1108/13598541211246558 (Accessed 9 August 2022).

Collins, S. T. and Browning, T. R. (2019) 'Eckerd', *Journal of Operations Management*, Wiley Online Library, vol. 65, no. 3, pp. 216–241.

Colman, A. M. (2015) *A dictionary of psychology*, Oxford quick reference.

Comes, T., Van de Walle, B. and Van Wassenhove, L. (2020) 'The coordination-information bubble in humanitarian response: theoretical foundations and empirical investigations', *Production and Operations Management*, Wiley Online Library, vol. 29, no. 11, pp. 2484–2507.

Cooper, R. G. (2008) 'Perspective: The stage-gate® idea-to-launch process—update, what's new, and nexgen systems', *Journal of product innovation management*, Wiley Online Library, vol. 25, no. 3, pp. 213–232.

Cooper, R. G., Edgett, S. J. and Kleinschmidt, E. J. (2004a) 'Benchmarking Best NPD Practices—I', *Research-Technology Management*, Routledge, vol. 47, no. 1, pp. 31–43 [Online]. DOI: 10.1080/08956308.2004.11671606.

Cooper, R. G., Edgett, S. J. and Kleinschmidt, E. J. (2004b) 'Benchmarking Best NPD Practices—II', *Research-Technology Management*, Routledge, vol. 47, no. 3, pp. 50–59 [Online]. DOI: 10.1080/08956308.2004.11671630.

Cooper, R. G., Edgett, S. J. and Kleinschmidt, E. J. (2004c) 'Benchmarking Best NPD Practices—III', *Research-Technology Management*, Routledge, vol. 47, no. 6, pp. 43–55 [Online]. DOI: 10.1080/08956308.2004.11671662.

Cordano, M. and Frieze, I. H. (2000) 'Pollution reduction preferences of US environmental managers: Applying Ajzen's theory of planned behavior', *Academy of Management journal*, Academy of Management Briarcliff Manor, NY 10510, vol. 43, no. 4, pp. 627–641.

Corley, K. G. and Gioia, D. A. (2004) 'Identity ambiguity and change in the wake of a corporate spin-off', *Administrative science quarterly*, SAGE Publications Sage CA: Los Angeles, CA, vol. 49, no. 2, pp. 173–208.

Corley, K. G. and Gioia, D. A. (2011) 'Building theory about theory building: what constitutes a theoretical contribution?', *Academy of management review*, Academy of Management Briarcliff Manor, NY, vol. 36, no. 1, pp. 12–32.

Cornelissen, J., Höllerer, M. A. and Seidl, D. (2021) 'What theory is and can be: Forms of theorizing in organizational scholarship', *Organization Theory*, Sage Publications Sage UK: London, England, vol. 2, no. 3, p. 26317877211020328.

Cornelissen, J., Stephens, V. and Matthews, L. (2024) 'Unlocking the power of diversity for supply chain knowledge: Is pluralism in theorizing styles the key?', *Journal of Supply Chain Management*, Wiley Online Library, vol. 60, no. 3, pp. 3–17.

Cotter, J., Forster, G. and Sweeney, E. (2009) ‘Supply Chain Learning:the Role of Games’, *Supply Chain Perspectives, the Journal of National Institute for Trransport and Logistics*, vol. 10, no. 3, pp. 32–36.

Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J. and Handfield, R. B. (2007) ‘The severity of supply chain disruptions: design characteristics and mitigation capabilities’, *Decision sciences*, Wiley Online Library, vol. 38, no. 1, pp. 131–156.

Craighead, C. W., Ketchen Jr, D. J. and Darby, J. L. (2020) ‘Pandemics and supply chain management research: toward a theoretical toolbox’, *Decision Sciences*, Wiley Online Library, vol. 51, no. 4, pp. 838–866.

Creazza, A., Colicchia, C., Spiezia, S. and Dallari, F. (2022) ‘Who cares? Supply chain managers’ perceptions regarding cyber supply chain risk management in the digital transformation era’, *Supply Chain Management: An International Journal*, vol. 27, no. 1, pp. 30–53 [Online]. DOI: 10.1108/SCM-02-2020-0073 (Accessed 6 May 2023).

Creswell, J. W. and Poth, C. N. (2016) *Qualitative inquiry and research design: Choosing among five approaches*, Sage publications.

Crippa, R., Larghi, L., Pero, M. and Sianesi, A. (2010) ‘The impact of new product introduction on supply chain ability to match supply and demand’, *International Journal of Engineering, Science and Technology*, vol. 2, no. 9, pp. 83–93.

Cutherell, D. (1996) ‘Chapter 16: product architecture’, in *The PDMA handbook of new product development*, John Wiley and Sons.

Cyert, R. M. and March, J. G. (1963) ‘A behavioral theory of the firm’, *Englewood Cliffs, NJ*, vol. 2, no. 4, pp. 169–187.

Dabholkar, P. A. (1994) ‘Incorporating choice into an attitudinal framework: analyzing models of mental comparison processes’, *Journal of consumer research*, The University of Chicago Press, vol. 21, no. 1, pp. 100–118.

Dadzie, C., Winston, E. M. and Dadzie, K. (2017) ‘How Organizational Culture Shapes Baseline Supply Chain Integration in China’, Academy of Management Briarcliff Manor, NY 10510, vol. 2017, no. 1, p. 17096.

Daspit, J., Justice Tillman, C., Boyd, N. G. and Mckee, V. (2013) ‘Cross-functional team effectiveness: An examination of internal team environment, shared leadership, and cohesion influences’, *Team Performance Management: An International Journal*, Emerald Group Publishing Limited, vol. 19, no. 1/2, pp. 34–56.

Davis, E. W. and Spekman, R. E. (2004) *The Extended Enterprise: Gaining Competitive advantage through collaborative supply chains*, FT press.

DeCampos, H. A., Fawcett, S. E. and Melnyk, S. A. (2022) ‘Collaboration expectation gaps, transparency and integrated NPD performance: A multi-case study’, *Journal of Purchasing and Supply Management*, vol. 28, no. 4, p. 100789 [Online]. DOI: 10.1016/j.pursup.2022.100789 (Accessed 26 September 2022).

Dekoninck, E. A., Domingo, L., O’Hare, J. A., Pigosso, D. C. A., Reyes, T. and Troussier, N. (2016) ‘Defining the challenges for ecodesign implementation in companies: Development and consolidation of a framework’, *Journal of Cleaner Production*, vol. 135, pp. 410–425 [Online]. DOI: 10.1016/j.jclepro.2016.06.045.

Deng, X. and Marsillac, E. (2019) ‘Achieving automotive suppliers ’ mass customization through modularity responsibility of information sharing’, *Journal of Manufacturing Technology Management*, vol. 31, no. 2, pp. 306–329 [Online]. DOI: 10.1108/JMTM-12-2018-0459.

Denyer, D. and Tranfield, D. (2009) ‘Producing a systematic review’, in *The Sage Handbook of Organizational Research Methods*, Chapter 39, Sage Publications, pp. 671–689.

Denyer, D., Tranfield, D. and Van Aken, J. E. (2008) ‘Developing design propositions through research synthesis’, *Organization Studies*, vol. 29, no. 3, pp. 393–413 [Online]. DOI: 10.1177/0170840607088020.

Deterding, S. (2015) ‘The lens of intrinsic skill atoms: A method for gameful design’, *Human–Computer Interaction*, Taylor & Francis, vol. 30, no. 3–4, pp. 294–335.

Dhalla, N. K. and Yuspeh, S. (1976) ‘Forget the product life cycle concept’,.

Doran, D. (2003) ‘Supply chain implications of modularization’, *International Journal of Operations & Production Management*, vol. 23, no. 3, pp. 316–326 [Online]. DOI: 10.1108/01443570310462785.

Doran, D., Hill, A., Hwang, K. S. and Jacob, G. (2007) ‘Supply chain modularisation: Cases from the French automobile industry’, *International Journal of Production Economics*, vol. 106, no. 1, pp. 2–11 [Online]. DOI: 10.1016/j.ijpe.2006.04.006.

Dougherty, D. (1992) ‘Interpretive barriers to successful product innovation in large firms’, *Organization science*, INFORMS, vol. 3, no. 2, pp. 179–202.

DuBrin, A. J. (2013) *Fundamentals of organizational behavior: An applied perspective*, Elsevier.

Dyer, J. H. (2000) *Collaborative advantage: Winning through extended enterprise supplier networks.*, Oxford University Press, Inc.

Eckerd, S. (2016) ‘Experiments in purchasing and supply management research’, *Journal of Purchasing and Supply Management*, Elsevier, vol. 22, no. 4, pp. 258–261 [Online]. DOI: 10.1016/j.pursup.2016.08.002.

Eckerd, S., DuHadway, S., Bendoly, E., Carter, C. and Kaufmann, L. (2020) ‘On making experimental design choices: Discussions on the use and challenges of demand effects, incentives, deception, samples, and vignettes’, *Journal of Operations Management*, no. May 2019, pp. 261–275 [Online]. DOI: 10.1002/joom.1128.

Eden, C. and Huxham, C. (1996) ‘Action Research for Management Research’, *British Journal of Management*, vol. 7, pp. 75–86.

Eisenhardt, K. M. and Tabrizi, B. N. (1995) ‘Accelerating adaptive processes: Product innovation in the global computer industry’, *Administrative science quarterly*, JSTOR, pp. 84–110.

Eisto, T., Hölttä, V., Mahlamäki, K., Kollanus, J. and Nieminen, M. (2010) ‘Early supplier involvement in new product development: A Casting-Network Collaboration Model’, *World Academy of Science, Engineering and Technology*, vol. 62, pp. 856–866 [Online]. Available at https://www.scopus.com/inward/record.uri?eid=2-s2.0-78651591726&partnerID=40&md5=1d8ea2253eb83293cf3ab148b5a8c60c.

Elkjaer, B. and Simpson, B. (2011) 'Pragmatism: A lived and living philosophy. What can it offer to contemporary organization theory?', in *Philosophy and organization theory*, Emerald Group Publishing Limited, pp. 55–84.

Ellram, L. M. and Stanley, L. L. (2008) 'Integrating strategic cost management with a 3DCE environment: Strategies, practices, and benefits', *Journal of Purchasing and Supply Management*, vol. 14, no. 3, pp. 180–191 [Online]. DOI: 10.1016/j.pursup.2008.05.003.

Ellram, L. M., Tate, W. and Carter, C. R. (2008) 'Applying 3DCE to environmentally responsible manufacturing practices', *Journal of Cleaner Production*, vol. 16, no. 15, pp. 1620–1631 [Online]. DOI: 10.1016/j.jclepro.2008.04.017.

Ellram, L. M., Tate, W. L. and Carter, C. R. (2007) 'Product-process-supply chain: An integrative approach to three-dimensional concurrent engineering', *International Journal of Physical Distribution and Logistics Management*, vol. 37, no. 4, pp. 305–330 [Online]. DOI: 10.1108/09600030710752523.

Ellram, L. M., Tate, W. L. and Choi, T. Y. (2020) 'The Conflicted Role of Purchasing in New Product Development Costing', *Journal of Supply Chain Management*, vol. 56, no. 1, pp. 3–32 [Online]. DOI: 10.1111/jscm.12217.

Emiliani, M. (2003) 'Linking leaders' beliefs to their behaviors and competencies', *Management Decision*, MCB UP Ltd, vol. 41, no. 9, pp. 893–910.

Eng, T. (2005) 'The influence of a firm's cross-functional orientation on supply chain performance', *Journal of Supply Chain Management*, Wiley Online Library, vol. 41, no. 4, pp. 4–16.

Ernst, H. (2002) 'Success factors of new product development: A review of the empirical literature', *International Journal of Management Reviews*, vol. 4, no. 1, pp. 1–40 [Online]. DOI: 10.1111/1468-2370.00075.

Eslami, M. H. and Melander, L. (2019) 'Exploring uncertainties in collaborative product development: Managing customer-supplier collaborations', *Journal of Engineering and Technology Management - JET-M*, vol. 53, pp. 49–62 [Online]. DOI: 10.1016/j.jengtecman.2019.05.003.

Fabbe-Costes, N., Lechaptois, L. and Spring, M. (2020) '"The map is not the territory": a boundary objects perspective on supply chain mapping', *International Journal of Operations and Production Management*, vol. 40, no. 9, pp. 1475–1497 [Online]. DOI: 10.1108/IJOPM-12-2019-0828.

Fawcett, S. E., Jones, S. L. and Fawcett, A. M. (2012) 'Supply chain trust: The catalyst for collaborative innovation', *Business Horizons*, 'Kelley School of Business, Indiana University', vol. 55, no. 2, pp. 163–178 [Online]. DOI: 10.1016/j.bushor.2011.11.004.

Fawcett, S. E. and Waller, M. A. (2011) 'Making Sense Out of Chaos : Why Theory is Relevant to Supply Chain Research', *Journal of Business Logistics*, vol. 32, no. 1, pp. 1–5.

Fine, C. H. (1998) *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*, Reading, Massachusetts, Perseus Books.

Fine, C. H. (2000) 'Clockspeed-Basead Strategies for Supply Chain Design', *Production and Operations Management*, vol. 9, no. 3, pp. 213–221 [Online]. Available at http://onlinelibrary.wiley.com/doi/10.1111/j.1937-5956.2000.tb00134.x/abstract.

Fine, C. H., Golany, B. and Naseraldin, H. (2005) 'Modeling tradeoffs in three-dimensional concurrent engineering: A goal programming approach', *Journal of Operations Management*, vol. 23, no. 3–4, pp. 389–403 [Online]. DOI: 10.1016/j.jom.2004.09.005.

Fine, C. H. and Li, L. (1987) 'Technology Choice, Product Life Cycles, And Flexible Automation', *Massachusetts Institute of Technology*, p. 45.

Finne, M. and Holmström, J. (2013) 'A manufacturer moving upstream: Triadic collaboration for service delivery', *Supply Chain Management: An International Journal*, vol. 18, no. 1, pp. 21–33 [Online]. DOI: 10.1108/13598541311293159.

Fishbein, M. and Ajzen, I. (1977) 'Belief, attitude, intention, and behavior: An introduction to theory and research',.

Fishbein, M. and Ajzen, I. (2011) *Predicting and changing behavior: The reasoned action approach*, Taylor & Francis.

Fisher, M. (1997) 'What is the right SC for your product?', *Harvard business review*.

Fixson, S. K. (2005) 'Product architecture assessment: A tool to link product, process, and supply chain design decisions', *Journal of Operations Management*, vol. 23, no. 3–4, pp. 345–369 [Online]. DOI: 10.1016/j.jom.2004.08.006.

Fixson, S. K. (2007) 'Modularity and commonality research: past developments and future opportunities', *Concurrent Engineering*, Sage Publications Sage UK: London, England, vol. 15, no. 2, pp. 85–111.

Fixson, S. K. and Park, J. K. (2008) 'The power of integrality: Linkages between product architecture, innovation, and industry structure', *Research Policy*, vol. 37, no. 8, pp. 1296–1316 [Online]. DOI: 10.1016/j.respol.2008.04.026.

Floyd, S. W. and Wooldridge, B. (1997) 'Middle management's strategic influence and organizational performance', *Journal of Management studies*, Wiley Online Library, vol. 34, no. 3, pp. 465–485.

Fornell, C. and Larcker, D. F. (1981) 'Evaluating structural equation models with unobservable variables and measurement error', *Journal of marketing research*, Sage Publications Sage CA: Los Angeles, CA, vol. 18, no. 1, pp. 39–50.

Forrester, J. W. (1965) 'A new corporate design', *IMR; Industrial Management Review (pre-1986)*, Massachusetts Institute of Technology, Cambridge, MA, vol. 7, no. 1, p. 5.

Forza, C. (2002) 'Survey research in operations management: a process-based perspective', *International journal of operations & production management*, MCB UP Ltd, vol. 22, no. 2, pp. 152–194.

Forza, C. and Salvador, F. (2001) 'Information flows for high-performance manufacturing', *International Journal of Production Economics*, Elsevier, vol. 70, no. 1, pp. 21–36.

Found, P. A., Mogale, D., Xu, Z. and Yang, J. (2024) 'Food supply chain resilience in major disruptions', *Journal of Manufacturing Technology Management*, Emerald Publishing Limited.

Francis, V. (2008) 'Supply chain visibility: lost in translation?', *Supply chain management: An international journal*, Emerald Group Publishing Limited, vol. 13, no. 3, pp. 180–184.

Frandsen, T. (2017) 'Evolution of modularity literature: a 25-year bibliometric analysis', *International Journal of Operations & Production Management*, Emerald Publishing Limited, vol. 37, no. 6, pp. 703–747 [Online]. DOI: 10.1108/IJOPM-06-2015-0366 (Accessed 4 September 2022).

Fujimoto, T. (1999) *The evolution of a manufacturing system at Toyota*, Oxford university press.

Gan, T. S. (2023) 'Concurrent Product and Supply Chain Design: Framework, Process, Methods and Application', Technische Universität München.

Gan, T. S., Steffan, M., Grunow, M. and Akkerman, R. (2021) 'Concurrent design of product and supply chain architectures for modularity and flexibility: process, methods, and application', *International Journal of Production Research*, Taylor & Francis, vol. 0, no. 0, pp. 1–20 [Online]. DOI: 10.1080/00207543.2021.1886370.

Ganbold, O., Phan, A. and Matsui, Y. (2017) 'Organizational Culture and Supply Chain Integration: Empirical Study on Japanese Manufacturers', Academy of Management Briarcliff Manor, NY 10510, vol. 2017, no. 1, p. 17580.

Gerwin, D. (1993) 'Manufacturing Flexibility : A Strategic Perspective', *Management Science*, vol. 39, no. 4, pp. 395–410.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M. (1994) *The new production of knowledge: The dynamics of science and research in contemporary societies*, Sage Publications, Inc.

Gioia, D. A., Corley, K. G. and Hamilton, A. L. (2013) 'Seeking qualitative rigor in inductive research: Notes on the Gioia methodology', *Organizational research methods*, Sage Publications Sage CA: Los Angeles, CA, vol. 16, no. 1, pp. 15–31.

Gmelin, H. and Seuring, S. (2014) 'Achieving sustainable new product development by integrating product life-cycle management capabilities', *International Journal of Production Economics*, vol. 154, pp. 166–177 [Online]. DOI: 10.1016/j.ijpe.2014.04.023.

Godin, B. (1998) 'Writing performative history: the new new Atlantis?', *Social Studies of Science*, vol. 28, no. 3, pp. 465–483.

Gokpinar, B., Hopp, W. J. and Iravani, S. M. (2010) 'The impact of misalignment of organizational structure and product architecture on quality in complex product development', *Management science*, INFORMS, vol. 56, no. 3, pp. 468–484.

Gold, G. J. (2011) 'Review of Predicting and Changing Behavior: The Reasoned Action Approach', *The Journal of Social Psychology*, vol. 151, no. 3, pp. 382–385 [Online]. DOI: 10.1080/00224545.2011.563209.

Golrizgashti, S., Zhu, Q. and Sarkis, J. (2022) 'Formalizing the strategic product deletion decision: incorporating multiple stakeholder views', *Industrial Management & Data Systems*, Emerald Publishing Limited, vol. 122, no. 4, pp. 887–919 [Online]. DOI: 10.1108/IMDS-07-2021-0435 (Accessed 4 September 2022).

Gralla, E., Goentzel, J. and Fine, C. (2016) 'Problem formulation and solution mechanisms: a behavioral study of humanitarian transportation planning', *Production and operations management*, Wiley Online Library, vol. 25, no. 1, pp. 22–35.

Granstrand, O. and Holgersson, M. (2020) 'Innovation ecosystems: A conceptual review and a new definition', *Technovation*, Elsevier, vol. 90, p. 102098.

Gregor, S. and Hevner, A. R. (2013) 'Positioning and presenting design science research for maximum impact', *MIS quarterly*, JSTOR, pp. 337–355.

Groop, J., Ketokivi, M., Gupta, M. and Holmström, J. (2017) 'Improving home care: Knowledge creation through engagement and design', *Journal of Operations Management*, Elsevier, vol. 53–56, no. August, pp. 9–22 [Online]. DOI: 10.1016/j.jom.2017.11.001.

Hackl, J., Krause, D., Otto, K., Windheim, M., Moon, S. K., Bursac, N. and Lachmayer, R. (2020) 'Impact of modularity decisions on a firm's economic objectives', *Journal of Mechanical Design*, American Society of Mechanical Engineers, vol. 142, no. 4, p. 041403.

Hald, K. S. and Nordio, C. (2021) 'Ambidexterity in collaborative new product development processes', *Business Process Management Journal*, Emerald Publishing Limited, vol. 27, no. 3, pp. 987–1008 [Online]. DOI: 10.1108/BPMJ-05-2020-0220 (Accessed 4 September 2022).

Hamari, J., Koivisto, J. and Sarsa, H. (2014) 'Does Gamification Work? -- A Literature Review of Empirical Studies on Gamification', *2014 47th Hawaii International Conference on System Sciences*, Waikoloa, HI, IEEE, pp. 3025–3034 [Online]. DOI: 10.1109/HICSS.2014.377 (Accessed 25 September 2023).

Hambrick, D. C., MacMillan, I. C. and Day, D. L. (1982) 'Strategic attributes and performance in the BCG matrix—A PIMS-based analysis of industrial product businesses', *Academy of Management Journal*, Academy of Management Briarcliff Manor, NY 10510, vol. 25, no. 3, pp. 510–531.

Hansen, Z. N. L. and Ahmed-Kristensen, S. (2011) 'Global product development: the impact on the product development process and how companies deal with it', *International Journal of Product Development*, Inderscience Publishers, vol. 15, no. 4, pp. 205–226.

Haque, B., Pawar, K. and Barson, R. (2003) 'The application of business process modelling to organisational analysis of concurrent engineering environments', *Technovation*, Elsevier, vol. 23, no. 2, pp. 147–162.

Hasle, P. and Vang, J. (2021) 'Designing Better Interventions: Insights from Research on Decent Work', *Journal of Supply Chain Management*, vol. 57, no. 2, pp. 58–70 [Online]. DOI: 10.1111/jscm.12261.

Hatch, M. and Badinelli, R. D. (1999) 'A concurrent optimization methodology for concurrent engineering', *IEEE Transactions on Engineering Management*, IEEE, vol. 46, no. 1, pp. 72–86.

Hauser, J. R. and Clausing, D. (1988) 'The house of quality', *Harvard Business Review*, Harvard Business Review Vol. 66, May-June 1988, vol. 66, no. 3, pp. 63–73.

Hayes, R. H. and Wheelwright, S. C. (1979a) 'Link manufacturing process and product life cycles', *Harvard Business Review*, vol. 57, no. 1, pp. 133–140.

Hayes, R. H. and Wheelwright, S. C. (1979b) 'The Dynamics of Process-Product Life Cycles', *Harvard Business Review*, vol. 57, no. 2, pp. 127–136.

Hedenstierna, C. P. T., Disney, S. M., Eyers, D. R., Holmstrom, J., Syntetos, A. A. and Wang, X. (2019) 'Economies of collaboration in build-to-model operations', *Journal of Operations Management*, pp. 753–773 [Online]. DOI: 10.1002/joom.1014.

Helmuth, C. A., Craighead, C. W., Connelly, B. L., Collier, D. Y. and Hanna, J. B. (2015) 'Supply chain management research: Key elements of study design and statistical testing', *Journal of Operations Management*, vol. 36, no. 1, pp. 178–186 [Online]. DOI: 10.1016/j.jom.2014.12.001 (Accessed 28 June 2022).

Hessels, L. K. and van Lente, H. (2008) 'Re-thinking new knowledge production: A literature review and a research agenda', *Research Policy*, vol. 37, no. 4, pp. 740–760 [Online]. DOI: 10.1016/j.respol.2008.01.008.

Hevner, A. R., March, S. T., Park, J. and Ram, S. (2004) 'Two Paradigms on Research Essay Design Science in Information Systems Research', *MIS Quarterly*, vol. 28, no. 1, pp. 75–79.

Hilletofth, P. and Eriksson, D. (2011) 'Coordinating new product development with supply chain management', *Industrial Management and Data Systems*, vol. 111, no. 2, pp. 264–281 [Online]. DOI: 10.1108/02635571111115173.

Hobday, M. (1998) 'Product complexity, innovation and industrial organisation', *Research Policy*, vol. 26, no. 6, pp. 689–710 [Online]. DOI: 10.1016/S0048-7333(97)00044-9 (Accessed 3 May 2022).

Hodgkinson, G. P. and Rousseau, D. M. (2009) 'Bridging the rigour-relevance gap in management research: It's already happening!', *Journal of Management Studies*, vol. 46, no. 3, pp. 534–546 [Online]. DOI: 10.1111/j.1467-6486.2009.00832.x.

Hoffman, D. R. (1998) 'An overview of concurrent engineering', IEEE, pp. 1–7.

Holmström, J., Ketokivi, M. and Hameri, A. P. (2009) 'Bridging practice and theory: A design science approach', *Decision Sciences*, vol. 40, no. 1, pp. 65–87 [Online]. DOI: 10.1111/j.1540-5915.2008.00221.x.

Hölttä-Otto, K. and De Weck, O. (2007) 'Degree of modularity in engineering systems and products with technical and business constraints', *Concurrent Engineering*, Sage Publications Sage UK: London, England, vol. 15, no. 2, pp. 113–126.

Hong, P. and Roh, J. (2009) 'Internationalization, product development and performance outcomes: A comparative study of 10 countries', *Research in International Business and Finance*, Elsevier, vol. 23, no. 2, pp. 169–180.

Hoskisson, R. E., Chirico, F., Zyung, J. and Gambeta, E. (2017) 'Managerial risk taking: A multitheoretical review and future research agenda', *Journal of management*, Sage Publications Sage CA: Los Angeles, CA, vol. 43, no. 1, pp. 137–169.

Howard, M. and Squire, B. (2007) 'Modularization and the impact on supply relationships', Gunasekaran, A. (ed), *International Journal of Operations & Production Management*, vol. 27, no. 11, pp. 1192–1212 [Online]. DOI: 10.1108/01443570710830593 (Accessed 6 June 2023).

Huang, G. Q. and Eastman, C. M. (eds.) (1996) *Design for X: Concurrent engineering imperatives*, 1st Edition., London, UK, Chapman & Hall.

Huang, G. Q., Zhang, X. Y. and Liang, L. (2005) 'Towards integrated optimal configuration of platform products, manufacturing processes, and supply chains', *Journal of Operations Management*, vol. 23, no. 3–4, pp. 267–290 [Online]. DOI: 10.1016/j.jom.2004.10.014.

Huff, A. S. (2000a) '1999 Presidential Address: Changes in Organizational Knoweldge Production', *Academy of Management Review*, vol. 25, no. 2, pp. 288–293.

Huff, A. S. (2000b) 'Citigroup's John Reed and Stanford's James March on management research and practice', *Academy of Management Executive*, vol. 14, no. 1, pp. 52–64 [Online]. DOI: 10.5465/AME.2000.2909839.

Huff, A. S. (2009) *Designing research for publication*, Sage.

Ilyas, I. M., Kammerlander, N., Turturea, R. and van Essen, M. (2024) 'When business model innovation creates value for companies: A meta-analysis on institutional contingencies', *Journal of Management Studies*, Wiley Online Library, vol. 61, no. 5, pp. 1825–1883.

Ireland, R. D. and Webb, J. W. (2007) 'A multi-theoretic perspective on trust and power in strategic supply chains', *Journal of Operations management*, Elsevier, vol. 25, no. 2, pp. 482–497.

Jacob, J., Stankovic, M., Spuerck, I. and Shokraneh, F. (2022) 'Goal setting with young people for anxiety and depression: What works for whom in therapeutic relationships? A literature review and insight analysis', *BMC Psychology*, vol. 10, no. 1, p. 171 [Online]. DOI: 10.1186/s40359-022-00879-5 (Accessed 24 February 2023).

Januszek, S., Netland, T. H. and Furlan, A. (2024) 'The role of managerial perceptions and behaviors across hierarchical levels during lean implementation', *International Journal of Operations & Production Management*, vol. 44, no. 1, pp. 54–74 [Online]. DOI: 10.1108/IJOPM-07-2022-0417 (Accessed 20 December 2023).

Jaruzelski, Barry, Chwalik, R. and Goehle, B. (2018) *What the top innovators get right*, Winter 2018/ Issue 93, PWC [Online]. Available at https://www.strategy-business.com/feature/What-the-Top-Innovators-Get-Right (Accessed 20 July 2023).

Jayaram, J. and Pathak, S. (2013) 'A holistic view of knowledge integration in collaborative supply chains', *International Journal of Production Research*, Taylor & Francis, vol. 51, no. 7, pp. 1958–1972.

Jiao, J., Simpson, T. W. and Siddique, Z. (2007) 'Product family design and platform-based product development: a state-of-the-art review', *Journal of Intelligent Manufacturing*, vol. 18, no. 1, pp. 5–29 [Online]. DOI: 10.1007/s10845-007-0003-2 (Accessed 5 September 2022).

Johansson, E. and Johansson, M. I. (2006) 'Materials supply systems design in product development projects', *International Journal of Operations & Production Management*, Emerald Group Publishing Limited, vol. 26, no. 4, pp. 371–393 [Online]. DOI: 10.1108/01443570610650549 (Accessed 4 September 2022).

Johnsen, T. E., Mikkelsen, O. S. and Wong, C. Y. (2019) 'Strategies for complex supply networks: findings from the offshore wind power industry', *Supply Chain Management: An International Journal*, Emerald Publishing Limited, vol. 24, no. 6, pp. 872–886.

Johnson, M., Burgess, N. and Sethi, S. (2019) ‘Temporal pacing of outcomes for improving patient flow : Design science research in a National Health Service hospital’, *Journal of Operations Management*, vol. 66, pp. 35–53 [Online]. DOI: 10.1002/joom.1077.

Johnson, M. E. (2010) ‘Product/Service Design Collaboration: Managing the Product Life Cycle’, *Wiley Encyclopedia of Operations Research and Management Science*, Wiley Online Library.

Kahn, K. B., Barczak, G., Nicholas, J., Ledwith, A. and Perks, H. (2012) ‘An examination of new product development best practice’, *Journal of product innovation management*, Wiley Online Library, vol. 29, no. 2, pp. 180–192.

Kahneman, D. and Tversky, A. (1979) ‘Prospect Theory: An Analysis of Decision under Risk’, *Econometrica*, vol. 47, no. 2, pp. 263–292.

Kaipia, R., Holmström, J., Småros, J. and Rajala, R. (2017) ‘Information sharing for sales and operations planning: Contextualized solutions and mechanisms’, *Journal of Operations Management*, vol. 52, pp. 15–29 [Online]. DOI: 10.1016/j.jom.2017.04.001.

Kelemen, M. L. and Rumens, N. (2008) *An introduction to critical management research*, Sage.

Ketokivi, M., Turkulainen, V., Seppälä, T., Rouvinen, P. and Ali-Yrkkö, J. (2017) ‘Why locate manufacturing in a high-cost country? A case study of 35 production location decisions’, *Journal of Operations Management*, John Wiley & Sons, Ltd, vol. 49–51, no. 1, pp. 20–30 [Online]. DOI: 10.1016/j.jom.2016.12.005 (Accessed 4 September 2022).

Keys, L. K. (1990) ‘System life cycle engineering and DF’X’’, *IEEE Transactions on Components, Hybrids, and Manufacturing Technology*, IEEE, vol. 13, no. 1, pp. 83–93.

Khan, F. I., Sadiq, R. and Veitch, B. (2004) ‘Life cycle iNdeX (LInX): a new indexing procedure for process and product design and decision-making’, *Journal of Cleaner Production*, vol. 12, no. 1, pp. 59–76 [Online]. DOI: 10.1016/S0959-6526(02)00194-4 (Accessed 21 August 2022).

Khan, O. (2018) *Product Design and the Supply Chain: competing through design*, Kogan Page Publishers.

Khan, O., Christopher, M. and Burnes, B. (2008) ‘The impact of product design on supply chain risk: A case study’, *International Journal of Physical Distribution and Logistics Management*, vol. 38, no. 5, pp. 412–432 [Online]. DOI: 10.1108/09600030810882834.

Khan, O., Christopher, M. and Creazza, A. (2012) ‘Aligning product design with the supply chain: A case study’, *Supply Chain Management*, vol. 17, no. 3, pp. 323–336 [Online]. DOI: 10.1108/13598541211227144.

Khan, O. and Creazza, A. (2009) ‘Managing the product design-supply chain interface: Towards a roadmap to the “design centric business”’, *International Journal of Physical Distribution & Logistics Management*, Emerald Group Publishing Limited, vol. 39, no. 4, pp. 301–319 [Online]. DOI: 10.1108/09600030910962258 (Accessed 4 September 2022).

Khire, R., Becz, S., Reeve, H. and Zeidner, L. (2010) ‘Assessing Performance Uncertainty in Complex Hybrid Systems’, *10th AIAA Aviation Technology, Integration, and Operations*

(ATIO) Conference, Fort Worth, Texas, American Institute of Aeronautics and Astronautics [Online]. DOI: 10.2514/6.2010-9225 (Accessed 23 July 2022).

Kieser, A. and Leiner, L. (2009) 'Why the Rigour – Relevance Gap in Management Alfred Kieser and Lars Leiner', *Journal of Management Studies*, vol. 46, no. May, pp. 516–533 [Online]. Available at http://www.mendeley.com/research/rigour-relevance-gap-management-alfred-kieser-lars-leiner/.

Kim, S., Chae, S., Wagner, S. M. and Miller, J. W. (2022) 'Buyer abusive behavior and supplier welfare: An empirical study of truck owner–operators', *Journal of Supply Chain Management*, Wiley Online Library, vol. 58, no. 4, pp. 90–111.

Kinra, A., Hald, K. S., Mukkamala, R. R. and Vatrapu, R. (2020) 'An unstructured big data approach for country logistics performance assessment in global supply chains', *International Journal of Operations and Production Management*, vol. 40, no. 4, pp. 439–458 [Online]. DOI: 10.1108/IJOPM-07-2019-0544.

Knight, L., Tate, W., Carnovale, S., Di Mauro, C., Bals, L., Caniato, F., Gualandris, J., Johnsen, T., Matopoulos, A., Meehan, J., Miemczyk, J., Patrucco, A. S., Schoenherr, T., Selviaridis, K., Touboulic, A. and Wagner, S. M. (2022) 'Future business and the role of purchasing and supply management: Opportunities for "business-not-as-usual" PSM research', *Journal of Purchasing and Supply Management*, vol. 28, no. 1, p. 100753 [Online]. DOI: 10.1016/j.pursup.2022.100753 (Accessed 6 June 2022).

Kobayashi, H. (2005) 'Strategic evolution of eco-products : a product life cycle planning methodology', *Research in Engineering Design (2005)*, vol. 16, pp. 1–16 [Online]. DOI: 10.1007/s00163-005-0001-3.

Koivisto, J. and Hamari, J. (2019) 'The rise of motivational information systems: A review of gamification research', *International Journal of Information Management*, vol. 45, pp. 191–210 [Online]. DOI: 10.1016/j.ijinfomgt.2018.10.013 (Accessed 16 September 2022).

Kott, A., Cederquist, A. and Kollar, C. (1990) 'Product modelling as a foundation for a concurrent engineering system', *Proceedings of the Twenty-First Annual Pittsburgh Conference*, Pittsburgh, PA, USA, Modeling and Simulation, p. Vol. 21, 3, 1289-1295.

Koufteros, X. A., Rawski, G. E. and Rupak, R. (2010) 'Organizational integration for product development: the effects on glitches, on-time execution of engineering change orders, and market success', *Decision Sciences*, Wiley Online Library, vol. 41, no. 1, pp. 49–80.

Koufteros, X. A., Vonderembse, M. A. and Doll, W. J. (2002) 'Integrated product development practices and competitive capabilities: The effects of uncertainty, equivocality, and platform strategy', *Journal of Operations Management*, vol. 20, no. 4, pp. 331–355 [Online]. DOI: 10.1016/S0272-6963(02)00018-9.

Koufteros, X., Vonderembse, M. and Doll, W. (2001) 'Concurrent engineering and its consequences', *Journal of operations management*, Elsevier, vol. 19, no. 1, pp. 97–115.

Koufteros, X., Vonderembse, M. and Jayaram, J. (2005) 'Internal and External Integration for Product Development : The Contingency Ef ...', *Integration The Vlsi Journal*, vol. 36, no. 1, pp. 97–134 [Online]. DOI: 10.1111/j.1540-5915.2005.00067.x.

Kovács, G. and Spens, K. M. (2005) 'Abductive reasoning in logistics research', Van Hoek, R. (ed), *International Journal of Physical Distribution & Logistics Management*, vol. 35, no.

2, pp. 132–144 [Online]. DOI: 10.1108/09600030510590318 (Accessed 14 September 2023).

Kreipl, S. and Pinedo, M. (2004) 'Planning and scheduling in supply chains: an overview of issues in practice', *Production and Operations management*, SAGE Publications Sage CA: Los Angeles, CA, vol. 13, no. 1, pp. 77–92.

Krishnan, V. and Ulrich, K. T. (2001) 'Product development decisions: A review of the literature', *Management Science*, vol. 47, no. 1, pp. 1–21 [Online]. DOI: 10.1287/mnsc.47.1.1.10668.

Kriwet, A., Zussman, E. and Seliger, G. (1995) 'Systematic integration of design-for-recycling into product design', *International journal of production economics*, Elsevier, vol. 38, no. 1, pp. 15–22.

Kumar, M., Tsolakis, N., Agarwal, A. and Srai, J. S. (2020) 'Developing distributed manufacturing strategies from the perspective of a product-process matrix', *International Journal of Production Economics*, Elsevier, vol. 219, pp. 1–17.

Kunz, N. and Van Wassenhove, L. N. (2019) 'Fleet sizing for UNHCR country offices', *Journal of Operations Management*, vol. 65, no. 3, pp. 282–307 [Online]. DOI: 10.1002/joom.1013.

Kunz, N., Van Wassenhove, L. N., McConnell, R. and Hov, K. (2015) 'Centralized vehicle leasing in humanitarian fleet management: the UNHCR case', *Journal of Humanitarian Logistics and Supply Chain Management*, vol. 5, no. 3, pp. 387–404 [Online]. DOI: 10.1108/JHLSCM-07-2015-0034.

Lau, A. K. W., A.K.W. Lau, Yam, R.C.M., R.C.M. Yam and Yam, Richard C.M. (2005) 'A case study of product modularization on supply chain design and coordination in Hong Kong and China', *Journal of Manufacturing Technology Management*, vol. 16, no. 4, pp. 432–446 [Online]. DOI: 10.1108/17410380510594516.

Lee, D. M. (1992) 'Management of concurrent engineering: organizational concepts and a framework of analysis', *Engineering Management Journal*, Taylor & Francis, vol. 4, no. 2, pp. 15–25.

Lee, H. L. (2002) 'Aligning Supply Chain Strategies with Product Uncertainties', *California Management Review*, vol. 44, no. 3, pp. 105–119.

Lee, H. L., Padmanabhan, V. and Whang, S. (1997) 'The bullwhip effect in supply chains', *Sloan Management Review*, vol. 38, no. 3, pp. 93–102.

Lee, K.-H. and Kim, J.-W. (2011) 'Integrating Suppliers into Green Product Innovation Development: an Empirical Case Study in the Semiconductor Industry', *Business Strategy and the Environment*, John Wiley & Sons, Ltd, vol. 20, no. 8, pp. 527–538 [Online]. DOI: 10.1002/bse.714 (Accessed 4 September 2022).

Lester, D. L., Parnell, J. A. and Carraher, S. (2003) 'Organizational life cycle: A five-stage empirical scale', *The international journal of organizational analysis*, MCB UP Ltd, vol. 11, no. 4, pp. 339–354.

Levitt, T. (1965) 'Exploit the product life cycle', *Harvard business review*, vol. 43, no. 6, pp. 81–94.

Lewin, K. (1951) ‘Field theory in social science: selected theoretical papers (Edited by Dorwin Cartwright.).’, Harpers.

Lindlöf, L. (2014) *Visual management-on communication in product development organizations*, Chalmers Tekniska Hogskola (Sweden).

Liu, H., Ke, W., Wei, K. K., Gu, J. and Chen, H. (2010) ‘The role of institutional pressures and organizational culture in the firm’s intention to adopt internet-enabled supply chain management systems’, *Journal of Operations Management*, vol. 28, no. 5, pp. 372–384 [Online]. DOI: 10.1016/j.jom.2009.11.010 (Accessed 23 June 2023).

Liu, W., Beltagui, A., Ye, S. and Williamson, P. (2022) ‘Harnessing exaptation and ecosystem strategy for accelerated innovation: Lessons From the VentilatorChallengeUK’, *California Management Review*, SAGE Publications Sage CA: Los Angeles, CA, vol. 64, no. 3, pp. 78–98.

Lonati, S., Quiroga, B. F., Zehnder, C. and Antonakis, J. (2018) *On doing relevant and rigorous experiments: Review and recommendations*, *Journal of Operations Management*.

Lu, Q. and Wood, L. (2006) ‘The refinement of design for manufacture: Inclusion of process design’, *International Journal of Operations and Production Management*, vol. 26, no. 10, pp. 1123–1145 [Online]. DOI: 10.1108/01443570610691102.

Macnagthen, P. and Myers, G. (2007) ‘Focus groups’, in *Qualitative Research Practice*, Chapter 4, London: SAGE.

Maitlis, S. and Christianson, M. (2014) ‘Sensemaking in Organizations: Taking Stock and Moving Forward’, *Academy of Management Annals*, vol. 8, no. 1, pp. 57–125 [Online]. DOI: 10.1080/19416520.2014.873177.

Mancha, R. M. and Yoder, C. Y. (2015) ‘Cultural antecedents of green behavioral intent: An environmental theory of planned behavior’, *Journal of environmental psychology*, Elsevier, vol. 43, pp. 145–154.

Marczewski, A. (2013) *Gamification: a simple introduction*, Andrzej Marczewski.

Markham, S. K. and Kingon, A. I. (2004) ‘Turning Technical Advantage into Product Advantage’, in *PDMA New Product Development Toolbook II*, John Wiley & Sons, Inc., pp. 71–92.

Marsillac, E. and Roh, J. J. (2014) ‘Connecting product design, process and supply chain decisions to strengthen global supply chain capabilities’, *International Journal of Production Economics*, vol. 147, pp. 317–329 [Online]. DOI: 10.1016/j.ijpe.2013.04.011.

Matopoulos, A., Barros, A. C. and van der Vorst, J. G. A. J. (2015) ‘Resource-efficient supply chains: A research framework, literature review and research agenda’, *Supply Chain Management*, vol. 20, no. 2, pp. 218–236 [Online]. DOI: 10.1108/SCM-03-2014-0090.

Matopoulos, A., Tate, W. L. and Price, B. J. (2015) ‘Improving resource efficiency through the adoption of 3DCE throughout the product life cycle’, *In 19th Cambridge international manufacturing symposium.*, pp. 1–13.

Matthews, R. and Al-Saadi, R. (2021) ‘Organisational Complexity of the Eurofighter Typhoon Collaborative Supply Chain’, *Defence and Peace Economics*, Taylor & Francis, pp. 1–16.

May, A., Carter, C. and Joyner, S. (2000) ‘Virtual team working in the european automotive industry: User requirements and a case study approach’, *Human Factors and Ergonomics in Manufacturing & Service Industries*, John Wiley & Sons, Ltd, vol. 10, no. 3, pp. 273–289 [Online]. DOI: 10.1002/1520-6564(200022)10:3<273::AID-HFM4>3.0.CO;2-F (Accessed 4 September 2022).

McCabe, D. L. and Dutton, J. E. (1993) ‘Making Sense of the Environment: The Role of Perceived Effectiveness’, *Human Relations*, SAGE Publications Ltd, vol. 46, no. 5, pp. 623–643 [Online]. DOI: 10.1177/001872679304600503 (Accessed 19 April 2023).

McCarthy, D., Matopoulos, A. and Davies, P. (2015) ‘Life cycle assessment in the food supply chain: a case study’, *International Journal of Logistics Research and Applications*, Taylor & Francis, vol. 18, no. 2, pp. 140–154.

McDermott, C. and Handfield, R. (2000) ‘Concurrent Development and Strategic Outsourcing: Do the rules change in breakthrough innovation?’, *The Journal of High Technology Management Research*, vol. 11, no. 1, pp. 35–57.

McDonough III, E. F. (2000) ‘Investigation of factors contributing to the success of cross-functional teams’, *Journal of Product Innovation Management: An International Publication of the Product Development & Management Association*, Wiley Online Library, vol. 17, no. 3, pp. 221–235.

Mello, M. H., Gosling, J., Naim, M. M., Strandhagen, J. O. and Brett, P. O. (2017) ‘Improving coordination in an engineer-to-order supply chain using a soft systems approach’, *Production Planning & Control*, vol. 28, no. 2, pp. 89–107 [Online]. DOI: 10.1080/09537287.2016.1233471.

Mena, C., Melnyk, S. A., Baghersad, M. and Zobel, C. W. (2020) ‘Sourcing Decisions under Conditions of Risk and Resilience: A Behavioral Study’, *Decision Sciences*, vol. 51, no. 4, pp. 985–1014 [Online]. DOI: 10.1111/deci.12403.

Mentzer, J. T. and Flint, D. J. (1997) ‘Validity in logistics research’, *Journal of business logistics*, Blackwell Publishing Ltd., vol. 18, no. 1, p. 199.

Messina, D., Barros, A. C., Soares, A. L. and Matopoulos, A. (2020) ‘An information management approach for supply chain disruption recovery’, *International Journal of Logistics Management*, vol. 41, no. 3, pp. 489–519 [Online]. DOI: https://doi.org/10.1108/IJLM-11-2018-0294.

Mikkelsen, O. S. and Johnsen, T. E. (2019) ‘Purchasing involvement in technologically uncertain new product development projects: Challenges and implications’, *Journal of Purchasing and Supply Management*, vol. 25, no. 3 [Online]. DOI: 10.1016/j.pursup.2018.03.003.

Miles, M. B. and Huberman, A. M. (1994) *Qualitative data analysis: An expanded sourcebook*, sage.

Miner, J. B. (2006) *Organizational behavior 2. Essential theories of process and structure*, New edition., Armonk, NY, M.E. Sharpe.

Miner, J. B. (2015) ‘Organizational Learning Concepts: James March’, in *Organizational Behavior 2*, Routledge, pp. 96–107.

Mintzberg, H., Raisinghani, D. and Theoret, A. (1976) ‘The Structure of “Unstructured” Decision Processes’, *Administrative Science Quarterly*, vol. 21, no. June, pp. 246–275.

Mir, S., Blessley, M., Zacharia, Z. and Aloysius, J. (2022) ‘Mending fences in a buyer–supplier relationship: The role of justice in relationship restoration’, *Journal of Supply Chain Management*, vol. 58, no. 3, pp. 23–46 [Online]. DOI: 10.1111/jscm.12272 (Accessed 29 November 2023).

Mirzabeiki, V., Holmström, J. and Främling, K. (2014) ‘Collaborative tracking and tracing: The value of a composite design’, *International Journal of Logistics Management*, vol. 25, no. 3, pp. 522–536 [Online]. DOI: 10.1108/IJLM-07-2012-0056.

Mombeshora, I. M. (2016) ‘Investigating the Potential of a Three Dimensional Concurrent Engineering Based Approach to Environmental New Product Development’, University of Bath.

Moon, K. L. and Ngai, E. W. T. (2010) ‘R&D framework for an intelligent fabric sample management system: A design science approach’, *International Journal of Operations and Production Management*, vol. 30, no. 7, pp. 721–743 [Online]. DOI: 10.1108/01443571011057317.

Morita, M., Machuca, J. A. D. and de los Ríos, J. L. P. D. (2018) ‘Integration of product development capability and supply chain capability: The driver for high performance adaptation’, *International Journal of Production Economics*, vol. 200, pp. 68–82 [Online]. DOI: 10.1016/j.ijpe.2018.03.016.

Mottonen, M., Harkonen, J., Belt, P., Haapasalo, H. and Simila, J. (2009) ‘Managerial view on design for manufacturing’, *Industrial Management & Data Systems*, Emerald Group Publishing Limited, vol. 109, no. 6, pp. 859–872 [Online]. DOI: 10.1108/02635570910968081 (Accessed 4 September 2022).

Murfield, M. L. U., Esper, T. L., Tate, W. L. and Petersen, K. J. (2016) ‘Supplier Role Conflict: An Investigation of Its Relational Implications and Impact on Supplier Accommodation’, *Journal of Business Logistics*, vol. 37, no. 2, pp. 168–184 [Online]. DOI: 10.1111/jbl.12123.

Nagel, D. M., Giunipero, L., Jung, H., Salas, J. and Hochstein, B. (2021) ‘Purchaser perceptions of early phase supplier relationships: The role of similarity and likeability’, *Journal of Business Research*, vol. 128, pp. 174–186 [Online]. DOI: 10.1016/j.jbusres.2021.01.026 (Accessed 9 March 2023).

Naim, M. M. and Gosling, J. (2022) ‘Revisiting the whole systems approach: designing supply chains in a turbulent world’, *The International Journal of Logistics Management*, Emerald Publishing Limited, vol. ahead-of-print, no. ahead-of-print [Online]. DOI: 10.1108/IJLM-02-2021-0121 (Accessed 16 September 2022).

Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Rocha-Lona, L. and Tortorella, G. (2019) ‘Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal’, *Journal of Manufacturing Technology Management*, Emerald Publishing Limited, vol. 30, no. 3, pp. 607–627.

Nepal, B., Monplaisir, L. and Famuyiwa, O. (2011) ‘A multi-objective supply chain configuration model for new products’, *International Journal of Production Research*, vol. 49, no. 23, pp. 7107–7134 [Online]. DOI: 10.1080/00207543.2010.511294.

Netland, T., Arellano, M. and Meuer, J. (2021) ‘Change Only Happens When Managers Believe What They’re Saying’, *California Management Review Insights*.

Noblit, G. W. and Hare, R. D. (1999) ‘Chapter 5: Meta-Ethnography: Synthesizing Qualitative Studies’, in *Particularities: Collected Essays on Ethnography and Education*, vol. 44, pp. 93–123.

Norrman, A. and Prataviera, L. B. (2023) ‘Revisiting postponement: The importance of cross-functional integration to understand tax implications in global supply chains’, *Journal of Business Logistics*, Wiley Online Library.

Olhager, J. and Rudberg, M. (2002) ‘Linking manufacturing strategy decisions on process choice with manufacturing planning and control systems’, *International Journal of production research*, Taylor & Francis, vol. 40, no. 10, pp. 2335–2351.

Oliva, R. (2019) ‘Intervention as a research strategy’, *Journal of Operations Management*, Wiley Online Library, vol. 65, no. 7, pp. 710–724.

Oosterhuis, M., Molleman, E. and van der Vaart, T. (2013) ‘Differences in buyers’ and suppliers’ perceptions of supply chain attributes’, *International Journal of Production Economics*, vol. 142, no. 1, pp. 158–171 [Online]. DOI: 10.1016/j.ijpe.2012.11.001.

Oswick, C. and Robertson, M. (2009) ‘Boundary objects reconsidered: From bridges and anchors to barricades and mazes’, *Journal of Change Management*, Taylor & Francis, vol. 9, no. 2, pp. 179–193.

Pagani, M. and Fine, C. H. (2008) ‘Value network dynamics in 3G–4G wireless communications: A systems thinking approach to strategic value assessment’, *Journal of Business Research*, Elsevier, vol. 61, no. 11, pp. 1102–1112.

Pal, R. and Torstensson, H. (2011) ‘Aligning critical success factors to organizational design: A study of Swedish textile and clothing firms’, *Business Process Management Journal*, vol. 17, no. 3, pp. 403–436 [Online]. DOI: 10.1108/14637151111136351.

Parmigiani, A., Irwin, J. and Lahneman, B. (2022) ‘Building greener motorhomes: How dualpurpose technical and relational capabilities affect component and full product innovation’, *Strategic Management Journal*, vol. 43, pp. 1110–1140 [Online]. DOI: 10.1002/smj.3356.

Pashaei, S. and Olhager, J. (2015) ‘Product architecture and supply chain design: A systematic review and research agenda’, *Supply Chain Management*, vol. 20, no. 1, pp. 98–112 [Online]. DOI: 10.1108/SCM-12-2013-0487.

Patel, P. C., Azadegan, A. and Ellram, L. M. (2013) ‘The Effects of Strategic and Structural Supply Chain Orientation on Operational and Customer-Focused Performance: Effects of Strategic and Structural Supply Chain Orientation’, *Decision Sciences*, vol. 44, no. 4, pp. 713–753 [Online]. DOI: 10.1111/deci.12034 (Accessed 3 June 2023).

Pawson, R. (2002) ‘Evidence and policy and naming and shaming’, *Policy studies*, Taylor & Francis, vol. 23, no. 3, pp. 211–230.

Pawson, R. (2013) *The Science of Evaluation - A realist Manifesto*, London, Sage Publications, Ltd.

Pawson, R., Greenhalgh, T., Harvey, G. and Walshe, K. (2006) ‘Realist synthesis: an introduction’, *an introduction*, p. 56.

Pawson, R. and Tilley, N. (1997) *Realistic Evaluation*, London, Sage Publications, Ltd.

Peffers, K., Tuunanen, T., Rothenberger, M. A. and Chatterjee, S. (2014) ‘A Design Science Research Methodology for Information Systems Research A Design Science Research Methodology for Information Systems Research’, vol. 1222 [Online]. DOI: 10.2753/MIS0742-1222240302.

Pero, M., Abdelkafi, N., Sianesi, A. and Blecker, T. (2010) ‘A framework for the alignment of new product development and supply chains’, *Supply Chain Management: An International Journal*, Emerald Group Publishing Limited, vol. 15, no. 2, pp. 115–128 [Online]. DOI: 10.1108/13598541011028723 (Accessed 4 September 2022).

Petersen, K. J., Handfield, R. B. and Ragatz, G. L. (2005) ‘Supplier integration into new product development: Coordinating product, process and supply chain design’, *Journal of Operations Management*, vol. 23, no. 3–4, pp. 371–388 [Online]. DOI: 10.1016/j.jom.2004.07.009.

Pil, F. K. and Fujimoto, T. (2007) ‘Lean and reflective production: the dynamic nature of production models’, *International journal of production research*, Taylor & Francis, vol. 45, no. 16, pp. 3741–3761.

Pilbeam, C., Alvarez, G. and Wilson, H. (2012) ‘The governance of supply networks: a systematic literature review’, Wilding, R. (ed), *Supply Chain Management: An International Journal*, vol. 17, no. 4, pp. 358–376 [Online]. DOI: 10.1108/13598541211246512 (Accessed 8 August 2022).

Pullan, T. T., Bhasi, M. and Madhu, G. (2013) ‘Decision support tool for lean product and process development’, *Production Planning & Control*, Taylor & Francis, vol. 24, no. 6, pp. 449–464.

Pulles, N. J., Veldman, J., Schiele, H. and Sierksma, H. (2014) ‘Pressure or pamper? The effects of power and trust dimensions on supplier resource allocation’, *Journal of supply chain management*, Wiley Online Library, vol. 50, no. 3, pp. 16–36.

Ramdas, K., Fisher, M. and Ulrich, K. (2003) ‘Managing Variety for Assembled Products: Modeling Component Systems Sharing’, *Manufacturing & Service Operations Management*, vol. 5, no. 2, pp. 142–156 [Online]. DOI: 10.1287/msom.5.2.142.16073 (Accessed 5 September 2022).

Rauniar, R. and Rawski, G. (2012) ‘Organizational structuring and project team structuring in integrated product development project’, *International Journal of Production Economics*, Elsevier, vol. 135, no. 2, pp. 939–952.

Rawboon, K., Yamazaki, A. K., Klomklieng, W. and Thanomsub, W. (2021) ‘Future competencies for three demanding careers of industry 4.0: Robotics engineers, data scientists, and food designers’, *The Journal of Competency-Based Education*, Wiley Online Library, vol. 6, no. 2, p. e01253.

Reich, J., Kinra, A., Kotzab, H. and Brusset, X. (2021) ‘Strategic global supply chain network design–how decision analysis combining MILP and AHP on a Pareto front can improve decision-making’, *International Journal of Production Research*, Taylor & Francis, vol. 59, no. 5, pp. 1557–1572 [Online]. DOI: 10.1080/00207543.2020.1847341.

Reitsma, E., Hilletofth, P. and Johansson, E. (2023) ‘Supply chain design during product development: a systematic literature review’, *Production Planning & Control*, Taylor & Francis, vol. 34, no. 1, pp. 1–18.

Riar, M., Morschheuser, B., Zarnekow, R. and Hamari, J. (2022) ‘Gamification of cooperation: A framework, literature review and future research agenda’, *International Journal of Information Management*, Elsevier, vol. 67, p. 102549.

Ro, Y. K., Su, H.-C. and Chen, Y.-S. (2016) ‘A Tale of Two Perspectives on an Impending Supply Disruption’, *Journal of Supply Chain Management*, vol. 52, no. 1, pp. 3–20 [Online]. DOI: 10.1111/jscm.12100 (Accessed 8 May 2023).

Robson, K., Plangger, K., Kietzmann, J. H., McCarthy, I. and Pitt, L. (2015) ‘Is it all a game? Understanding the principles of gamification’, *Business Horizons*, vol. 58, no. 4, pp. 411–420 [Online]. DOI: 10.1016/j.bushor.2015.03.006 (Accessed 14 September 2022).

Roscoe, S., Eckstein, D., Blome, C. and Goellner, M. (2020) ‘Determining how internal and external process connectivity affect supply chain agility: a life-cycle theory perspective’, *Production planning & control*, Taylor & Francis, vol. 31, no. 1, pp. 78–91.

Rousseau, D. M., Manning, J. and Denyer, D. (2008) ‘Evidence in Management and Organizational Science: Assembling the Field’s Full Weight of Scientific Knowledge Through Syntheses’, *Academy of Management Annals*, vol. 2, no. 1, pp. 475–515 [Online]. DOI: 10.5465/19416520802211651 (Accessed 8 August 2022).

Rudolph, J. W., Morrison, J. B. and Carroll, J. S. (2009) ‘The Dynamics of Action-Oriented Problem Solving: Linking Interpretation and Choice’, *Academy of Management Review*, vol. 34, no. 4, pp. 733–756.

Rungtusanatham, M. and Forza, C. (2005) ‘Coordinating product design, process design, and supply chain design decisions: Part A: Topic motivation, performance implications, and article review process’, *Journal of Operations Management*, Elsevier, vol. 23, no. 3–4, pp. 257–265.

Rungtusanatham, M., Wallin, C. and Eckerd, S. (2011) ‘The vignette in a scenario-based role-playing experiment’, *Journal of Supply Chain Management*, vol. 47, no. 3, pp. 9–16 [Online]. DOI: 10.1111/j.1745-493X.2011.03232.x.

Russo, I., Pellathy, D. and Omar, A. (2021) ‘Managing Outsourced Reverse Supply Chain Operations: Middle-Range Theory Development’, *Journal of Supply Chain Management*, pp. 1–23 [Online]. DOI: 10.1111/jscm.12244.

Sako, M. (2003) ‘Modularity and Outsourcing’, in Prencipe, A., Davies, A., and Hobday, M. (eds), *The Business of Systems Integration*, Oxford University Press, Inc., pp. 299–253.

Salvador, F. and Villena, V. H. (2013) ‘Supplier Integration and NPD Outcomes: Conditional Moderation Effects of Modular Design Competence’, *Journal of Supply Chain Management*, vol. 49, no. 1, pp. 87–113 [Online]. DOI: 10.1111/j.1745-493x.2012.03275.x.

Sandberg, J. and Tsoukas, H. (2015) ‘Making sense of the sensemaking perspective: Its constituents, limitations, and opportunities for further development’, *Journal of organizational behavior*, Wiley Online Library, vol. 36, no. S1, pp. S6–S32.

Sarasvathy, S. D. (2003) ‘Entrepreneurship as a science of the artificial’, *Journal of Economic Psychology*, vol. 24, no. 2, pp. 203–220 [Online]. DOI: 10.1016/S0167-4870(02)00203-9.

Saunders, M. N. K., Lewis, P. and Thornhill, A. (2023) *Research Methods for Business Students*, Ninth Edition., Harlow, Pearson.

Sawyerr, E. and Harrison, C. (2019) ‘Developing resilient supply chains: lessons from high-reliability organisations’, *Supply Chain Management: An International Journal*, vol. 25, no. 1, pp. 77–100 [Online]. DOI: 10.1108/SCM-09-2018-0329 (Accessed 9 August 2022).

Schoenherr, T., Ellram, L. M. and Tate, W. L. (2015) ‘A note on the use of survey research firms to enable empirical data collection’, *Journal of Business Logistics*, Wiley Online Library, vol. 36, no. 3, pp. 288–300.

Schultz, K. L., Robinson, L. W., Thomas, L. J., Schultz, J. and McClain, J. O. (2018) ‘The use of framing in inventory decisions’, *Production and Operations Management*, Wiley Online Library, vol. 27, no. 1, pp. 49–57.

Selldin, E. and Olhager, J. (2007) ‘Linking products with supply chains: testing Fisher’s model’, *Supply Chain Management: An International Journal*, Emerald Group Publishing Limited, vol. 12, no. 1, pp. 42–51.

Seuring, S. and Müller, M. (2008) ‘From a literature review to a conceptual framework for sustainable supply chain management’, *Journal of Cleaner Production*, vol. 16, no. 15, pp. 1699–1710 [Online]. DOI: 10.1016/j.jclepro.2008.04.020 (Accessed 19 May 2022).

Sharifi, H., Ismail, H. S., Qiu, J. and Najafi Tavani, S. (2013) ‘Supply chain strategy and its impacts on product and market growth strategies: A case study of SMEs’, *International Journal of Production Economics*, vol. 145, no. 1, pp. 397–408 [Online]. DOI: 10.1016/j.ijpe.2013.05.005.

Sharifi, H., Ismail, H. S. and Reid, I. (2006) ‘Achieving agility in supply chain through simultaneous “design of” and “design for” supply chain’, *Journal of Manufacturing Technology Management*, vol. 17, no. 8, pp. 1078–1098 [Online]. DOI: 10.1108/17410380610707393.

Sharma, R., Gulati, S., Kaur, A., Sinhababu, A. and Chakravarty, R. (2022) ‘Research discovery and visualization using ResearchRabbit: A use case of AI in libraries’, *COLLNET Journal of Scientometrics and Information Management*, vol. 16, no. 2, pp. 215–237 [Online]. DOI: 10.1080/09737766.2022.2106167 (Accessed 24 February 2023).

Shekarian, M., Nooraie, S. V. R. and Parast, M. M. (2020) ‘An examination of the impact of flexibility and agility on mitigating supply chain disruptions’, *International Journal of Production Economics*, Elsevier, vol. 220, p. 107438.

Shenas, D. and Derakhshan, S. (1992) ‘Technological interdependence and company organization: the case of simultaneous engineering in the car industry’, *International Journal of Vehicle Design*, Inderscience Publishers, vol. 13, no. 5–6, pp. 533–541.

Shimizu, K. (2007) ‘Prospect theory, behavioral theory, and the threat-rigidity thesis: Combinative effects on organizational decisions to divest formerly acquired units’, *Academy of Management Journal*, Academy of Management Briarcliff Manor, NY 10510, vol. 50, no. 6, pp. 1495–1514.

Sieber, J. E. (1998) ‘Planning ethically responsible research’, *Handbook of applied social research methods*, pp. 127–156.

Simon, H. A. (1969) *The Sciences of the Artificial*, London, MIT Press.

Simon, H. and March, J. (2015) ‘Administrative behavior and organizations’, in *Organizational Behavior 2*, Routledge, pp. 41–59.

Skowronski, K., Benton Jr, W. and Hill, J. A. (2020) ‘Perceived supplier opportunism in outsourcing relationships in emerging economies’, *Journal of Operations Management*, Wiley Online Library, vol. 66, no. 7–8, pp. 989–1023.

Slack, N. (1983) ‘Flexibility as a manufacturing objective’, *International Journal of Operations & Production Management*, MCB UP Ltd, vol. 3, no. 3, pp. 4–13.

Slot, J. H., Wuyts, S. and Geyskens, I. (2020) ‘Buyer participation in outsourced new product development projects: The role of relationship multiplexity’, *Journal of Operations Management*, vol. 66, no. 5, pp. 578–612 [Online]. DOI: 10.1002/joom.1085 (Accessed 11 June 2023).

Smith, R. P. (1997) ‘The historical roots of concurrent engineering fundamentals’, *IEEE Transactions on Engineering Management*, IEEE, vol. 44, no. 1, pp. 67–78.

Sobek II, D. K., Ward, A. C. and Liker, J. K. (1999) ‘Toyota’s principles of set-based concurrent engineering’, *MIT Sloan Management Review*.

Somapa, S., Cools, M. and Dullaert, W. (2018) ‘Characterizing supply chain visibility–a literature review’, *The International Journal of Logistics Management*, Emerald Publishing Limited, vol. 29, no. 1, pp. 308–339.

Sommer, S. C., Bendoly, E. and Kavadias, S. (2020) ‘How do you search for the best alternative? Experimental evidence on search strategies to solve complex problems’, *Management Science*, vol. 66, no. 3, pp. 1395–1420 [Online]. DOI: 10.1287/mnsc.2018.3247.

Song, M. and Montoya-Weiss, M. M. (2001) ‘The effect of perceived technological uncertainty on Japanese new product development’, *Academy of Management journal*, Academy of Management Briarcliff Manor, NY 10510, vol. 44, no. 1, pp. 61–80.

Sosa, M. E., Eppinger, S. D. and Rowles, C. M. (2003) ‘Identifying modular and integrative systems and their impact on design team interactions’, *J. Mech. Des.*, vol. 125, no. 2, pp. 240–252.

Sosa, M. E., Eppinger, S. D. and Rowles, C. M. (2004) ‘The Misalignment of Product Architecture and Organizational Structure in Complex Product Development’, *Management Science*, vol. 50, no. 12, pp. 1674–1689 [Online]. DOI: 10.1287/mnsc.1040.0289 (Accessed 18 July 2023).

Sosa, M. E., Eppinger, S. D. and Rowles, C. M. (2007) *Are Your Engineers Talking to One Another When They Should?* [Online]. Available at https://hbr.org/2007/11/are-your-engineers-talking-to-one-another-when-they-should (Accessed 21 July 2023).

Speier, C., Whipple, J. M., Closs, D. J. and Voss, M. D. (2011) ‘Global supply chain design considerations: Mitigating product safety and security risks’, *Journal of Operations Management*, vol. 29, no. 7–8, pp. 721–736 [Online]. DOI: 10.1016/j.jom.2011.06.003 (Accessed 19 April 2023).

Spekman, R. and Davis, E. W. (2016) ‘The extended enterprise: a decade later’, *International Journal of Physical Distribution & Logistics Management*, Emerald Group Publishing Limited, vol. 46, no. 1, pp. 43–61.

Spencer, M. and Cox, J. (1995) ‘An analysis of the product-process matrix and repetitive manufacturing’, *The International Journal Of Production Research*, Taylor & Francis, vol. 33, no. 5, pp. 1275–1294.

Stank, T. P., Pellathy, D., In, J., Mollenkopf, D. A. and Bell, J. E. (2017) ‘New Frontiers in Logistics Research: Theorizing at the Middle Range’, *Journal of Business Logistics*, vol. 38, pp. 6–17 [Online]. DOI: https://doi.org/10.1111/jbl.12151.

Star, S. L. (1989) ‘The structure of ill-structured solutions: Boundary objects and heterogeneous distributed problem solving’, in *Distributed artificial intelligence*, Elsevier, pp. 37–54.

Star, S. L. (2010) ‘This is not a boundary object: Reflections on the origin of a concept’, *Science, technology, & human values*, Sage Publications Sage CA: Los Angeles, CA, vol. 35, no. 5, pp. 601–617.

Star, S. L. and Griesemer, J. R. (1989) ‘Institutional ecology,translations’ and boundary objects: Amateurs and professionals in Berkeley’s Museum of Vertebrate Zoology, 1907-39’, *Social studies of science*, Sage Publications London, vol. 19, no. 3, pp. 387–420.

Sterman, J. (2002) ‘System Dynamics: systems thinking and modeling for a complex world’, Massachusetts Institute of Technology. Engineering Systems Division.

Sternberg, H., Linan, I., Prockl, G. and Norrman, A. (2022) ‘Tragedy of the facilitated commons: A multiple-case study of failure in systematic horizontal logistics collaboration’, *Journal of Supply Chain Management*, Wiley Online Library, vol. 58, no. 4, pp. 30–57.

Stevens, R. (1998) *Systems engineering: coping with complexity*, Pearson Education.

Stock, R. M. (2014) ‘How should customers be integrated for effective interorganizational NPD teams? An input–process–output perspective’, *Journal of Product Innovation Management*, Wiley Online Library, vol. 31, no. 3, pp. 535–551.

Straatmann, T., Rothenhöfer, L. M., Meier, A. and Mueller, K. (2018) ‘A configurational perspective on the theory of planned behaviour to understand employees’ change-supportive intentions’, *Applied Psychology*, Wiley Online Library, vol. 67, no. 1, pp. 91–135.

Sun, H. and Lau, A. (2020) ‘The impact of modular design and innovation on new product performance’, *Journal of Manufacturing Technology Management*, Emerald Publishing Limited, vol. 31, no. 2, pp. 370–391 [Online]. DOI: 10.1108/JMTM-09-2018-0319 (Accessed 4 September 2022).

Sutton, R. I. and Staw, B. M. (1995) ‘What theory is not’, *Administrative science quarterly*, JSTOR, pp. 371–384.

Suurmond, R., Wynstra, F. and Dul, J. (2020) ‘Unraveling the Dimensions of Supplier Involvement and their Effects on NPD Performance: A Meta-Analysis’, *Journal of Supply Chain Management*, vol. 56, no. 3, pp. 26–46 [Online]. DOI: 10.1111/jscm.12221 (Accessed 9 June 2023).

Sydelko, P., Espinosa, A. and Midgley, G. (2023) ‘Designing interagency responses to wicked problems: A viable system model board game’, *European Journal of Operational Research*, Elsevier.

Tang, C. S., Zimmerman, J. D. and Nelson, J. I. (2009) ‘Managing New Product Development and Supply Chain Risks: The Boeing 787 Case’, *Supply Chain Forum: An International Journal*, vol. 10, no. 2, pp. 74–86 [Online]. DOI: 10.1080/16258312.2009.11517219 (Accessed 29 September 2023).

Terwiesch, C., Loch, C. H. and Meyer, A. D. (2002) ‘Exchanging Preliminary Information in Concurrent Engineering’, *Organization Science*, vol. 13, no. 4, pp. 402–419.

Thomas, L. D. W., Autio, E. and Gann, D. M. (2014) ‘Architectural Leverage: Putting Platforms in Context’, *Academy of Management Perspectives*, vol. 28, no. 2, pp. 198–219 [Online]. DOI: 10.5465/amp.2011.0105 (Accessed 6 September 2022).

Thomas, R. J. (1995) *New product success stories: Lessons from leading innovators*, John Wiley & Sons.

Toche, B., Pellerin, R. and Fortin, C. (2020) ‘Set-based design: a review and new directions’, *Design Science*, Cambridge University Press, vol. 6, p. e18.

Tranfield, D., Denyer, D. and Smart, P. (2003) ‘Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review’, *British Journal of Management*, vol. 14, no. 3, pp. 207–222 [Online]. DOI: 10.1111/1467-8551.00375.

Tuli, P. and Shankar, R. (2015) ‘Collaborative and lean new product development approach: A case study in the automotive product design’, *International Journal of Production Research*, vol. 53, no. 8, pp. 2457–2471 [Online]. DOI: 10.1080/00207543.2014.974849.

Ulrich, K. (1995) ‘The role of product architecture in the manufacturing firm’, *Research Policy*, vol. 24, no. 3, pp. 419–440 [Online]. DOI: 10.1016/0048-7333(94)00775-3.

Ulrich, K. T., Eppinger, S. D. and Yang, M. C. (2020) *Product design and development [electronic resource]*, McGraw-Hill Education [Online]. Available at https://search.ebscohost.com/login.aspx?direct=true&db=cat00594a&AN=aston.b1911763&site=eds-live.

Valle, S. and Vázquez-Bustelo, D. (2009) ‘Concurrent engineering performance: Incremental versus radical innovation’, *International Journal of Production Economics*, Elsevier, vol. 119, no. 1, pp. 136–148.

Van Aken, J. E. (2004) ‘Management Research Based on the Paradigm of the Design Sciences: The Quest for Field-Tested and Grounded Technological Rules’, *Journal of*

Management Studies, vol. 41, no. 2, pp. 219–246 [Online]. DOI: 10.1111/j.1467-6486.2004.00430.x.

Van Aken, J. E. (2005) 'Management research as a design science: Articulating the research products of mode 2 knowledge production in management', *British Journal of Management*, vol. 16, no. 1, pp. 19–36 [Online]. DOI: 10.1111/j.1467-8551.2005.00437.x.

Van Aken, J. E. and Berends, H. (2018) *Problem solving in organizations*, Third Edition., Cambridge University Press.

Van Aken, J. E., Chandrasekaran, A. and Halman, J. (2016) 'Conducting and publishing design science research: Inaugural essay of the design science department of the Journal of Operations Management', *Journal of Operations Management*, vol. 47–48, pp. 1–8 [Online]. DOI: 10.1016/j.jom.2016.06.004.

Van Echtelt, F. E. A., Wynstra, F., Van Weele, A. J. and Duysters, G. (2008) 'Managing Supplier Involvement in New Product Development: A Multiple-Case Study', *Journal of Product Innovation Management*, John Wiley & Sons, Ltd, vol. 25, no. 2, pp. 180–201 [Online]. DOI: 10.1111/j.1540-5885.2008.00293.x (Accessed 4 September 2022).

Van Hoek, R. and Chapman, P. (2006) 'From tinkering around the edge to enhancing revenue growth: supply chain-new product development', *Supply Chain Management: an international journal*, Emerald Group Publishing Limited, vol. 11, no. 5, pp. 385–389.

Van Hoek, R. and Chapman, P. (2007) 'How to move supply chain beyond cleaning up after new product development', *Supply Chain Management: an international journal*, Emerald Group Publishing Limited, vol. 12, no. 4, pp. 239–244.

Van Hootegem, G., Huys, R. and Delarue, A. (2004) 'The sustainability of teamwork under changing circumstances: The case of Volvo-Ghent', *International Journal of Operations & Production Management*, Emerald Group Publishing Limited, vol. 24, no. 8, pp. 773–786.

Van Pelt, S., Haasnoot, M., Arts, B., Ludwig, F., Swart, R. and Biesbroek, R. (2015) 'Communicating climate (change) uncertainties: Simulation games as boundary objects', *Environmental science & policy*, Elsevier, vol. 45, pp. 41–52.

Váncza, J., Monostori, L., Lutters, D., Kumara, S., Tseng, M., Valckenaers, P. and Van Brussel, H. (2011) 'Cooperative and responsive manufacturing enterprises', *CIRP annals*, Elsevier, vol. 60, no. 2, pp. 797–820.

Vayvay, Ö. and Cruz-Cunha, M. M. (2016) 'Supplier involvement in new product development: A case study from the semiconductor industry', *E a M: Ekonomie a Management*, vol. 19, no. 3, pp. 123–141 [Online]. DOI: 10.15240/tul/001/2016-3-009.

Venkatesh, V., Morris, M. G., Davis, G. B. and Davis, F. D. (2003) 'User Acceptance of Information Technology: Toward a Unified View', *MIS Quarterly*, vol. 27, no. 3, pp. 425–478.

Venkatesh, V., Thong, J. Y. L. and Xu, X. (2012) 'Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology', *MIS Quarterly*, vol. 36, no. 1, pp. 157–178 [Online]. Available at https://www.jstor.org/stable/41410412 Accessed:

Verma, R. and Goodale, J. C. (1995) ‘Statistical power in operations management research’, *Journal of Operations Management*, Elsevier, vol. 13, no. 2, pp. 139–152.

Viles, E., Bultó, R., Mateo, R. and Jurburg, D. (2021) ‘Production ramp-up in European automotive production systems: a performance analysis’, *Production Planning & Control*, vol. 32, no. 1, pp. 34–51 [Online]. DOI: 10.1080/09537287.2020.1711980 (Accessed 28 July 2023).

Villena, V. H. and Craighead, C. W. (2017) ‘On the Same Page? How Asymmetric Buyer-Supplier Relationships Affect Opportunism and Performance’, *Production and Operations Management*, vol. 26, no. 3, pp. 491–508 [Online]. DOI: 10.1111/poms.12648 (Accessed 16 June 2023).

Voordijk, H., Meijboom, B. and De Haan, J. (2006) ‘Modularity in supply chains: A multiple case study in the construction industry’, *International Journal of Operations and Production Management*, vol. 26, no. 6, pp. 600–618 [Online]. DOI: 10.1108/01443570610666966.

Wagner, S. M. and Thakur-Weigold, B. (2018) ‘Supporting collaboration in humanitarian supply chains–insights from a design science project’, *Production Planning and Control*, Taylor & Francis, vol. 29, no. 14, pp. 1130–1144 [Online]. DOI: 10.1080/09537287.2018.1542175.

Wang, Y., Chen, C. H. and Zghari-Sales, A. (2021) ‘Designing a blockchain enabled supply chain’, *International Journal of Production Research*, Taylor & Francis, vol. 59, no. 5, pp. 1450–1475 [Online]. DOI: 10.1080/00207543.2020.1824086.

Wang, Y. and Hazen, B. T. (2016) ‘Consumer product knowledge and intention to purchase remanufactured products’, *International Journal of Production Economics*, Elsevier, vol. 181, pp. 460–469.

Wang, Y., Singgih, M., Wang, J. and Rit, M. (2019) ‘Making sense of blockchain technology: How will it transform supply chains?’, *International Journal of Production Economics*, Elsevier B.V., vol. 211, no. April 2018, pp. 221–236 [Online]. DOI: 10.1016/j.ijpe.2019.02.002.

Warmelink, H., Koivisto, J., Mayer, I., Vesa, M. and Hamari, J. (2020) ‘Gamification of production and logistics operations: Status quo and future directions’, *Journal of business research*, Elsevier, vol. 106, pp. 331–340.

Weick, K. E. (1995a) ‘What theory is not, theorizing is’, *Administrative science quarterly*, JSTOR, vol. 40, no. 3, pp. 385–390.

Weick, K. E. (1995b) *Sensemaking in organizations*, Sage, vol. 3.

Weick, K. E., Sutcliffe, K. M. and Obstfeld, D. (2005) ‘Organizing and the process of sensemaking’, *Organization science*, Informs, vol. 16, no. 4, pp. 409–421.

Wemmerlöv, U. (2021) ‘The retrospective determination of process improvement’s economic value at the individual manufacturing firm level: Literature review and proposed measurement framework’, *Journal of Operations Management*, vol. 67, no. 2, pp. 182–211 [Online]. DOI: 10.1002/joom.1112 (Accessed 18 February 2024).

Westkämper, E., Alting, L. and Arndt, G. (2001) ‘Life cycle management and assessment: approaches and visions towards sustainable manufacturing’, *Proceedings of the*

Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, Sage Publications Sage UK: London, England, vol. 215, no. 5, pp. 599–626.

Whalen, K. A., Berlin, C., Ekberg, J., Barletta, I. and Hammersberg, P. (2018) '"All they do is win": Lessons learned from use of a serious game for Circular Economy education', *Resources, Conservation and Recycling*, Elsevier, vol. 135, pp. 335–345.

Wheelwright, S. C. and Clark, K. (1992) 'Creating project plans to focus product development', *Harvard business review*, vol. March-Apri, pp. 70–82.

Whetten, D. A. (1989) 'What constitutes a theoretical contribution?', *Academy of management review*, Academy of Management Briarcliff Manor, NY 10510, vol. 14, no. 4, pp. 490–495.

Whipple, J. M. and Frankel, R. (2000) 'Strategic alliance success factors', *Journal of supply chain management*, Wiley Online Library, vol. 36, no. 2, pp. 21–28.

Wiedmer, R., Whipple, J. M., Griffis, S. E. and Voorhees, C. M. (2020) 'Resource Scarcity Perceptions in Supply Chains: The Effect of Buyer Altruism on the Propensity for Collaboration', *Journal of Supply Chain Management*, vol. 56, no. 4, pp. 45–64 [Online].

Wiegmann, P. M., Talmar, M. and de Nijs, S. B. (2023) 'Forging a sharper blade: A design science research approach for transition studies', *Environmental Innovation and Societal Transitions*, vol. 48, p. 100760 [Online].

Williams, B. D., Roh, J., Tokar, T. and Swink, M. (2013) 'Leveraging supply chain visibility for responsiveness: The moderating role of internal integration', *Journal of operations management*, Elsevier, vol. 31, no. 7–8, pp. 543–554.

Williamson, O. E. (2008) 'Outsourcing: Transaction Cost Economics and Supply Chain Management', *Journal of Supply Chain Management*, vol. 44, no. 2, pp. 5–16 [Online].

Winner, R. I., Pennell, J. P., Bertrand, H. E. and Slusarczuk, M. M. (1988) 'The role of concurrent engineering in weapons system acquisition', *IDA Report R*, vol. 338.

Wood, L. C. and Reiners, T. (2012) 'Gamification in Logistics and Supply Chain Education: Extending active learning', p. 8.

Woodward, J. (1994) 'Industrial organization: theory and practice', Oxford.

Xu, H. (2020) 'Minimizing the ripple effect caused by operational risks in a make-to-order supply chain', *International Journal of Physical Distribution and Logistics Management*, vol. 50, no. 4, pp. 381–402 [Online].

Yadav, S. R., Mishra, N., Kumar, V. and Tiwari, M. K. (2011) 'A framework for designing robust supply chains considering product development issues', *International Journal of Production Research*, vol. 49, no. 20, pp. 6065–6088 [Online].

Yang, C., Ye, H. J. and Feng, Y. (2021) 'Using gamification elements for competitive crowdsourcing: exploring the underlying mechanism', *Behaviour & Information Technology*, Taylor & Francis, vol. 40, no. 9, pp. 837–854.

Yang, D. (2011) 'Optimisation of product change process and demand-supply chain in high tech environment'.

Yang, Q., Kherbachi, S., Hong, Y. S. and Shan, C. (2015) 'Identifying and managing coordination complexity in global product development project', *International Journal of Project Management*, Elsevier, vol. 33, no. 7, pp. 1464–1475.

Yao, X. R. and Askin, R. (2019) 'Review of supply chain configuration and design decision-making for new product', *International Journal of Production Research*, vol. 57, no. 7, pp. 2226–2246 [Online].

Yassine, A. A. and Wissmann, L. A. (2007) 'The implications of product architecture on the firm', *Systems Engineering*, Wiley Online Library, vol. 10, no. 2, pp. 118–137.

Yin, Y., Kaku, I. and Liu, C. (2014) 'Product architecture, product development process, system integrator and product global performance', *Production Planning & Control*, Taylor & Francis, vol. 25, no. 3, pp. 203–219.

Yousafzai, S. Y., Foxall, G. R. and Pallister, J. G. (2010) 'Explaining internet banking behavior: theory of reasoned action, theory of planned behavior, or technology acceptance model?', *Journal of applied social psychology*, Wiley Online Library, vol. 40, no. 5, pp. 1172–1202.

Zhang, Q. and Anwar, M. A. (2023) 'Leveraging gamification technology to motivate environmentally responsible behavior: An empirical examination of Ant Forest', *Decision Sciences*, Wiley Online Library.

Zizzo, D. J. (2010) 'Experimenter demand effects in economic experiments', no. October 2009, pp. 75–98 [Online].

Zsidisin, G. A. and Smith, M. E. (2005) 'Managing Supply Risk with Early Supplier Involvement: A Case Study and Research Propositions', *Journal of Supply Chain Management*, vol. 41, no. 4, pp. 44–57 [Online].

11 APPENDIX

11.1 Essential Definitions

Three-Dimensional Concurrent Engineering (3-DCE): "…When firms do not explicitly acknowledge and manage supply chain design and engineering as a concurrent activity to product and process design and engineering, they often encounter problems late in product development, or with manufacturing launch, logistical support, quality control, and production costs…" (Fine, 1998, p. 133)

Design for Supply Chain (DfSC): "The design principle of concurrently account for the multifaceted functional (design, engineering, manufacturing, logistics, procurement) and supply chain decisions in NPD projects. These decisions, taken by multiple teams and organisations, should aim to ensure mutual beneficial outcomes throughout the product lifecycle". Here, "mutual beneficial outcomes" are those where product and manufacturing performance gains from the design decisions outweigh the end-to-end costs for the different stakeholders across the products' supply chain.

CIMO Logic: "For this problem-in Context, it is useful to use this Intervention, which will produce, through these Mechanisms, this Outcome" Denyer et al. (2008). The task is to "sift through the mixed fortunes" of the intervention and "discover those contexts (C+) that have produced solid and successful outcomes (O+) from those contexts (C-) that induce failure (O-)" (Pawson, 2002, p. 345)

Product Architecture: The scheme by which the function of a product is allocated to physical components. Ulrich (1995). Fundamentally dictated by the function-component interfaces. Fixson (2005)

Supply Chain Visibility: The "access to high quality information that describes various factors of demand and supply". (Williams et al., 2013, p. 545)

PrOH template modelling: Aims "to help novice modellers to build defensible process models while resolving complexities, for example, where processes are difficult to define perhaps because of low throughput volumes or high variation; involve a lengthy time to complete; or provide few repeated learning opportunities" (Clegg and Shaw, 2008, p. 449)

Design Science Research: a research strategy aimed at developing knowledge on generic actions, processes, and systems to address field problems or exploit opportunities in various domains. It focuses on creating new and valid solutions that are both practically and academically relevant, offering generic designs that can serve as models for solving similar problems across different contexts. (Van Aken et al., 2016)

Theory of Planned Behaviour: An extended version of a general theory of the relationships between attitudes and behaviours, according to which behaviours is determined by behavioural intentions. It incorporates a construct of perceived behavioural control which isa function of one's beliefs about how likely it is that one has the resources and opportunities required to perform the behaviour. (Ajzen, 1991)

Boundary Objects: They objects "plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star, 1989, p. 46), allowing different groups to work together. (Star, 2010, p. 602)

Gamification: The "application of gaming metaphors to real-life tasks to influence behaviour, improve motivation and enhance engagement". (Marczewski, 2013)

11.2 Thematic categories in the reviewed articles of Research Synthesis

	Appelqvist, Patrik	Ateş, M.A	Boardman & Clegg	Caridi, Maria	DeCampos	Dekoninck, E.A.	Eisto, T	Eltram, Lisa M.	Eslami, Mo.	Golrizgashti, S.	Hald, K.S.	Hilletofth, Per	Johanson, Eva	Ketokivi, Mikko	Khan, Omera	Lau, A.K.W.	Lee, Ki-Hoon	Marsillac, Erika	May, Andrew	Mello, M. H.	Mikkelsen, Ole S.	Motonen, Matti	Parmigiani, Anne	Pero, Margherita	Sharifi, H	Sharifi, H	Tuli, Prashant	Van Echtelt, Ferrie E. A.	Vancza, J.	Vayvay, O	Zsidisin, G.
	2004	2015	2001	2017	2022	2016	2010	2008	2019	2022	2021	2011	2006	2017	2009	2005	2011	2014	2000	2017	2019	2009	2022	2010	2006	2013	2015	2008	2011	2016	2005
Unit of analysis																															
Multiple		x		x	x	x	x	x						x	x		x	x						x	x	x		x	x		
Single	x		x						x	x	x	x	x			x			x	x	x	x	x				x			x	x
Type of Intervention																															
Extended Involvement		x	x		x	x	x		x			x					x								x		x		x	x	x
Framework Adoption	x									x	x				x			x		x				x	x			x			
Process Redesign								x					x	x		x		x	x		x	x									
Strategic Thinking				x		x					x												x			x		x			
Technology Support	x				x					x						x			x		x										
Expected Outcome																															
Downstream										x	x	x						x					x								x
Focal Company	x	x	x					x	x	x	x		x	x	x	x				x	x	x					x	x		x	
Holistic				x	x	x													x					x		x			x		
Upstream							x	x									x					x			x					x	
Outcome of the Intervention																															
NA										x				x																	
Accomplished	x						x	x								x			x		x	x			x				x		x
Not Accomplished				x		x			x			x	x							x				x		x				x	
Partially accomplished		x	x		x						x				x		x	x					x				x	x			

11.3 Articles selected for the SLR on DSR in O&SCM

Authors	SCM Problem / Opportunity	CIMO logic	Research methods
Moon and Ngai (2010)	Sourcing decision-making	○ **C:** Fashion Industry ○ **I:** Design a System Protype (RFID) for sample management ○ **M:** Organisation of fabric swatches, localisation, information when the fabric in a short period ○ **O:** Deeper understanding of their operations in managing fabric samples and wiser decisions in resource allocation	1) In depth interviews with potential system users 2) Design of a system prototype (multi-phase construction) 3) Case Study implementation
Mirzabeiki *et al.* (2014)	Alignment of SC interests	○ **C:** Swedish rail-wagon Supply Chain (3 different organisations) ○ **I:** Combining sensor data with wagon ID, Design a RFID-based tracking system ○ **M:** Infrastructure, services to customers, safety in the transport of dangerous goods, documentation, track and trace systems ○ **O:** Improve the efficiency of rail transport operators' maintenance operations and potentially de- crease wear and tear on rail tracks owned by the government authority	1) Inductive case study: 2) Data Collected for a period of 9 months: 3) Interviews, documentation, and project meeting with elements of the different organisations
Finne and Holmström (2013)	Relationship between subsystem supplier and the end user	○ **C:** Service supply chain ○ **I:** Design a systems integration to lose relationship with end user ○ **M:** Integrator roles, triadic nature of service supply chains, servitization of manufacturing, levels of collaboration ○ **O:** Decision-making process where the supplier provides the product to the partner and manages a service to the end user	1) Preliminary interviews/ External benchmarking/ Literature Review 2) Meetings with key decision-makers/ Design & development of solution/ Workshops 3) Field testing the solution through pilots
Kaipia *et al.* (2017)	Information sharing / management in SCs	○ **C:** Retail Supply Chain: study of 2 supplier companies operating in the grocery sector and delivering the same retailer ○ **I:** Design of a collaborative product introduction process	1) Studying problem in context, with meeting with the companies 2) Intervention design in collaboration with practitioners

		○ **M**: Lead time to change production, lead time to react to realised sales in forecasts, focusing planning efforts ○ **O**: Mixed outcomes: one supplier realised tangible benefits from its access to retailer PoS data, the other did not find it evident having difficulties to scale up the sales information	3) Observing outcomes: interviews, and observation 4) Revisit to observe how solution evolved: open-ended interviews
Busse *et al.* (2017)	Supply Chain Sustainability Risk (SCSR) Assessment / SC Visibility	○ **C:** Swiss Global Food Retailer and elevated stakeholder pressure for sustainability ○ **I:** A framework for SCSR identification process ○ **M:** Wage and social conditions for farm workers, transparency on the origin of raw materials, criminality ○ **O:** Identification of Sustainability risk hotspots	1) Field-testing study in the largest Swiss retail, for a specific food product (tomatoes from Italy) 2) Integration of newspaper articles, NGO reports, union reports, interviews with industry experts
Wagner and Thakur-Weigold (2018)	Dysfunctional operations in humanitarian Supply Chains	○ **C:** International Humanitarian Organisations ○ **I:** Experimental learning approach, based on the 'B*eer game'* ○ **M:** time pressure to react, lack of transparency, distorted information, strategic role of L&SCM, psychological habits, trust, turnover of IHO staff ○ **O:** Commercial L&SCM knowledge is fundamental, being able to 'speak the language' of the IHO's, need for cross-functional collaboration, feedback loop between actors should not be considered as an unnecessary bureaucracy	1) Educational Program for the humanitarian supply chain actors in 10 different localisations (3 years of *field-test)*
Akkermans *et al.* (2019)	Buyer-Supplier Contracting, collaborative KPIs	○ **C1** coproduction of services directly affecting customers' business; **C2** complex operational service process network; **C3** Financially driven contract leading to misaligned incentives; **C4** Burning platform of low operational performance and financial losses. ○ **I1** process interventions to develop collaborative KPIs; **I2** the collaborative KPIs. ○ **M1** willingness to engage in open dialogue to 'unfreeze'; **M2** systemic end-to-end modelling leads to integral understanding; **M3** the collaborative design process fosters consensus and commitment; **M4** alignment of incentives through well-chosen collaborative KPIs	1) Multiple stages of a major research project, with mixed techniques 2) Creation of a "learning workplace" (idea factory) were practitioners and scholars coproduce knowledge 3) A very detailed CIMO logic for design research (Pawson, 2013; Denyer et al., 2008)

		○ **O1** transparency of process performance and its drivers, **O2** improve decision-making; **O3** improved operational performance; **O4** improved relationship quality.	
Hedenstierna et al. (2019)	Exploit and integrate of new technologies (3DP) into SCM decisions	○ **C:** Logistics service provider entering 3DP industry and interaction with leading 3DP company ○ **I:** Dynamic *make-or-buy* artefact from unidirectional to bidirectional outsourcing ○ **M:** Build-to-model, order books as time buffer, production variability strategies, outsource and subcontractor roles, collaboration. ○ **O:** Understanding of the benefits to exploit partial outsourcing on 3DP, and create value-added activity	1) Case Research on Shapeways-Panalpina partnership 2) Combination of solution design and scenario planning 3) No Implementation or evaluation but analytical assessment of the outcome
Kunz and Van Wassenhove (2019)	Resource (Fleet) management	○ **C:** Humanitarian organisation with limited knowledge about optimal fleet size in country offices ○ **I:** Fleet sizing model to predict required number of vehicles in the new situation ○ **M:** Population of concern, # of Staff, # of locations, # of small partners, # number of large partners, guilt factor, transparency, and accountability ○ **O:** Country office takes appropriate fleet sizing decisions	1) Stepwise Linear Regression Approach to construct the model 2) Case study and evaluation stage was presented on the article Kunz *et al.* (2015)
Johnson et al. (2019)	Improving patient flow through the creation of a set of interconnected, temporally paced routines	○ **C:** Small size hospital ○ **I:** Connect and engage the subjects, creation of routines, reduce input variation ○ **M:** Cultural divisions, alignment of goals, patient flow which impacts patient experience, ability to address complex issues, external and internal communication, collaborative environment, ambulatory emergency care capacity ○ **O:** Sense of camaraderie, improvement in the rate of discharge, improvement of patient flow, staff satisfaction	1) Field journal to capture notes and reflections across the project 2) Weekly project meetings to discuss the success or otherwise of interventions 3) Quantitative data reflecting the outcomes of the project

Xu (2020)	Ripple effect caused by operational risks in make to order SCs (Visualisation)	○ **C:** Customers often not realize problems quickly, therefore the effects can propagate along the SC ○ **I:** Develop a web-based SC system to provide real time visibility and collaborative handling of delivery problems ○ **M:** Material flow, customer orders, negotiation process, reporting ○ **O:** Problems are handled effectively and in near real time, minimising the ripple effect in SC	1) Design of a technological artefact based on (Peffers et al., 2014; Hevner et al., 2004) 2) Development of a theoretical framework based on the CIMO logic 3) Pilot testing the artefact on a three-tier client/server on the automotive industry
Messina *et al.* (2020)	Internal and External information for SC decision makers, when facing SC disruptions	○ **C**: Supply chain disruptions ○ **I1** information organisation integrating internal and external information, **I2** a knowledge base of past disruptions ○ **M1** visibility over the supply chain, **M2** organisational memory supporting structured decision-making ○ **O**: Improved disruption recovery	1) Case research 2) Data collected based on semi-structured interviews (17), from 3 different organisations
Chaudhuri *et al.* (2020)	Make or Buy Decisions, and adoption of New Technologies (3DP)	○ **C1** CT and MRI files not merged, **C2** requirement of additional operations, **C3** long surgery time, **C4** long recovery time ○ **I1** merge CT and MRI files, **I2** 3D printed model for planning **I3** patient-specific 3D printed instruments ○ **M1** understanding of patient anatomy, **M2** complexity of surgical planning, **M3** development of customised surgical guides ○ **O1** reducing flow time ad its variability, **O2** reducing the variability of the clinical outcome	1) Interviews of Experts (12) 2) Solution incubation in 2 different contexts (Israel and India healthcare systems 3) Collaborative research with a 3DP company
Kinra *et al.* (2020)	Logistics performance measurements	○ **C**: Country Logistics Performance ○ **I**: Design an artefact based on textual big data approach for country logistics performance assessment ○ **M**: Logistics Performance Index, textual big data analytic applications, benchmarking, machine learning techniques, Supply Chain flows ○ **O**: Successful design initiation and solution incubation of the artefact, adding to the literature in country logistics performance and possible adoption of the design by the World Bank	1) Performed a world frequency analysis through a text corpus of *Global Perspectives*, the flagship periodical of CSCMP 2) The overall scope of the analysis included 20 different countries/regions and a text corpus of 22 text documents that cover their logistics performance over the period 2006–2014

Reich *et al.* (2021)	Development of a more flexible and easy-to-use decision support systems for Global SCs	○ **C1** low logistics performance of the company, **C2** SCM function not valued, **C3** lack of sophisticated tools ○ **I:** Design, and implement a decision support procedure based on scientific methods that would re-design their distribution network ○ **M1** Managing structural complexity (MILP), **M2** trade-offs between goals (Pareto front), ○ **O1** more transparency and visualisation of the SC, **O2** hire a data analytics specialist to take over the design tool	1) Development of a framework using: quantitative, qualitative and management experience 2) Conduct interviews outside the case company (MedTech Industry) 3) 3 methods for the design: MILP, AHP, and Pareto front
Hasle and Vang (2021)	To integrate measurements of productivity, decent work and OSH activities in the Supply Chain Context	○ **C**: Garment industry in emerging countries, where: OSH seen as a cost, competitiveness is secured by low labour costs ○ **I**: Change of institutionalised logics (integration of OSH and productivity) ○ **M**: OSH to enhance productivity and thereby competitiveness, recruitment phase, ownership of the intervention, embedding the intervention results ○ **O**: Need for redesign the intervention, since the results only lasted for the period of the intervention itself	1) Initial intervention of 6 months 2) Plan for an extended implementation period, with stepwise incremental changes 3) 5S as the basic lean tool, with regular Kaizen events for worker suggestions
Wang et al. (2021)	Relationship and implementation of new technologies (blockchain) to enable Supply Chain transparency	○ **C**: SMEs business in the construction industry ○ **I**: Design (PoC) of a smart contract pilot with blockchain ○ **M**: Liability, Behaviour, Transparency, Track and Tracing, SC Value ○ **O**: Business value mentality shift regarding the relationship with technology in the company case	1) A two-year longitudinal empirical case study 2) Cross-functional company experts: 3) Workshops, co-design of the artefact, interviews 4) Collaborative research

11.4 The Powertrain Scenario

Introduction (Common to all treatments)
Your company is a high-value manufacturing OEM in the UK, traditionally recognised for luxury and high-performance cars. The company's philosophy is "no compromise on the pursuit of being the world's most illustrious high-technology brand". Your company's senior managers pressured by market competition decided to introduce a fully electric sports car. Before starting the project, they asked a prestigious Consultancy firm for a detailed market evaluation. The report stated that the price should be around £95,000 for basic settings with a range of up to 295 miles. You were selected to be the project manager responsible for the Electric Vehicle powertrain (battery, e-motor, power electronics, and thermal-management modules), reporting directly to the Leading Project Manager. Given your experience and previous record of success, you have complete autonomy and your decisions are trusted within the Company. The Consultancy firm also reported that the powertrain would represent 45% to 55% of the total cost of the EV. Your strategy is to ensure a reliable supply and eliminate any potential bottlenecks in the assembly line while keeping the powertrain cost below the 51% mark. You are working with a cross-functional team that you already know well formed by "Product Designers", "Product Engineers", "Process Engineers", "Systems Architect", "Purchasing/ Supply Chain/ Material Flow Analysts" and "Category Buyers". You are also in regular communication with other teams of the firm.

Attention check (Common to all treatments)
Please select the settlement that best summarize the previous information.

- ☐ I am the Leading Project Manager of the project
- ☐ I am the Product Designer responsible for the EV powertrain
- ☐ I am the Project Manager responsible for the EV powertrain

Treatment 1
The Company's vehicles are recognized by a very particular body structure and set of features. After many meetings with the other teams and the project leader, you decided to integrate the battery pack into the existing architecture, allowing for a smoother transition with the high-technology features of the vehicle. You will work closely with a set of existing Suppliers that will allow your company to build an Integration Interface with access to their information systems. Thus, you will have real-time data about the needed components, from the final design to the raw materials. Moreover, difficulties were identified during the process of picking up and placing the battery cells for assembly. It was accepted that the automation levels of the manufacturing process will be reduced when compared with the previous models.

Treatment 2
The Company's vehicles are recognised by a very particular body structure and set of features. After many meetings with the other teams and the project leader, you decided to integrate the battery pack into the existing architecture, allowing for a smoother transition with the high-technology features of the vehicle. You will work closely with a set of existing Suppliers that will allow your company to build an Integration Interface with access to their information systems. Thus, you will have real-time data about the needed components, from the final design to the raw materials. Moreover, difficulties were identified during the process of picking up and placing the battery cells for assembly. You decided to implement a novel process design that significantly simplifies the manufacturing process, reducing the total number of material handling.

Treatment 3
The Company's vehicles are recognized by a very particular body structure and set of features. After many meetings with the other teams and the project leader, you decided to integrate the battery pack into the existing architecture, allowing for a smoother transition with the high technology features of the vehicle. You will work closely with a set of existing Suppliers that promise to timely fill your orders, but

the integration of both your information systems will not be possible at this stage. Thus, you will have to rely on the forecasts on the materials you need. Moreover, difficulties were identified during the process of picking up and placing the battery cells for assembly. It was accepted that the automation levels of the manufacturing process will be reduced when compared with the previous models.

Treatment 4
The Company's vehicles are recognized by a very particular body structure and set of features. After many meetings with the other teams and the project leader, you decided to integrate the battery pack into the existing architecture, allowing for a smoother transition with the high technology features of the vehicle. You will work closely with a set of existing Suppliers that promise to timely fill your orders, but the integration of both your information systems will not be possible at this stage. Thus, you will have to rely on the forecasts on the materials you need. Moreover, difficulties were identified during the process of picking up and placing the battery cells for assembly. You decided to implement a novel process design that significantly simplifies the manufacturing process, reducing the total number of material handling.

Treatment 5
The team decided to not compromise the powertrain for the body architecture and other features allowing for a bigger battery pack. According to the team assessment, this additional freedom will allow for potential advantages such as higher ranges, more power and faster charging. You will work closely with a set of existing Suppliers that will allow your company to build an Integration Interface with access to their information systems. Thus, you will have real-time data about the needed components, from the final design to the raw materials. Moreover, difficulties were identified during the process of picking up and placing the battery cells for assembly. It was accepted that the automation levels of the manufacturing process will be reduced when compared with the previous models.

Treatment 6
The team decided to not compromise the powertrain for the body architecture and other features allowing for a bigger battery pack. According to the team assessment, this additional freedom will allow for potential advantages such as higher ranges, more power and faster charging. You will work closely with a set of existing Suppliers that will allow your company to build an Integration Interface with access to their information systems. Thus, you will have real-time data about the needed components, from the final design to the raw materials. Moreover, difficulties were identified during the process of picking up and placing the battery cells for assembly. You decided to implement a novel process design that significantly simplifies the manufacturing process, reducing the total number of material handling.

Treatment 7
The team decided to not compromise the powertrain for the body architecture and other features allowing for a bigger battery pack. According to the team assessment, this additional freedom will allow for potential advantages such as higher ranges, more power and faster charging. You will work closely with a set of existing Suppliers that promise to timely fill your orders, but the integration of both your information systems will not be possible at this stage. Thus, you will have to rely on the forecasts on the materials you need. Moreover, difficulties were identified during the process of picking up and placing the battery cells for assembly. It was accepted that the automation levels of the manufacturing process will be reduced when compared with the previous models.

Treatment 8
The team decided to not compromise the powertrain for the body architecture and other features allowing for a bigger battery pack. According to the team assessment, this additional freedom will allow for potential advantages such as higher ranges, more power and faster charging. You will work closely with a set of existing Suppliers that promise to timely fill your orders, but the integration of both your information systems will not be possible at this stage. Thus, you will have to rely on the forecasts on

the materials you need. Moreover, difficulties were identified during the process of picking up and placing the battery cells for assembly. You decided to implement a novel process design that significantly simplifies the manufacturing process, reducing the total number of material handling.

Realism Checks (Dabholkar, 1994)

- The situation described in the scenario was realistic.
- I can imagine a project in the described situation.
- I was involved in a similar project.

Supplier Participation (SP) (Salvador & Villena, 2013)

- Suppliers were involved early in the design efforts for this project.
- The team partnered with suppliers for the design of this project
- Suppliers were frequently consulted about the design of this product.

Interface Ease (IE) (Fixson, 2005)

- The architecture of the powertrain will not cause problems in the functionality of the components.
- The interface between the powertrain and the other parts of the EV will be effortless.
- The design decisions of the powertrain will not cause bottlenecks through the manufacturing process.

NPD Performance measures (NPDPerf) (Selldin & Olhager, 2007)

- The team will be able to achieve its goals in terms of cost.
- The team will be able to achieve its goals in terms of quality.
- The team will be able to achieve its goals in terms of delivery speed.

11.4.1 Recruitment Message

Dear <name>,

My name is Filipe Sarmento, and I am currently undertaking my PhD research at Aston University. The aim of my project is to improve manufacturing practices by understanding the alignment between Product, Process and Supply Chain designs.

I am currently running a study to understand the mechanisms that influence the reasoning of experience professionals when making multidimensional decisions in product design. To this end, as someone over 18 years of ag, who is fluent in English, and who is an experienced professional working in the Manufacturing Sector in the UK or Ireland and who is involved in critical product and/or supply chain design decisions, I would like to invite you to complete the following survey: https://sites.google.com/view/powerdfsc/home.

It should take approximately 30 minutes to complete, and your assistance would be greatly appreciated. Should you have any questions about the survey, please don't hesitate to contact me.

Thank you for your time.

Kind Regards,

Filipe D G Sarmento

11.4.2 Scenario-Experiment Calculations

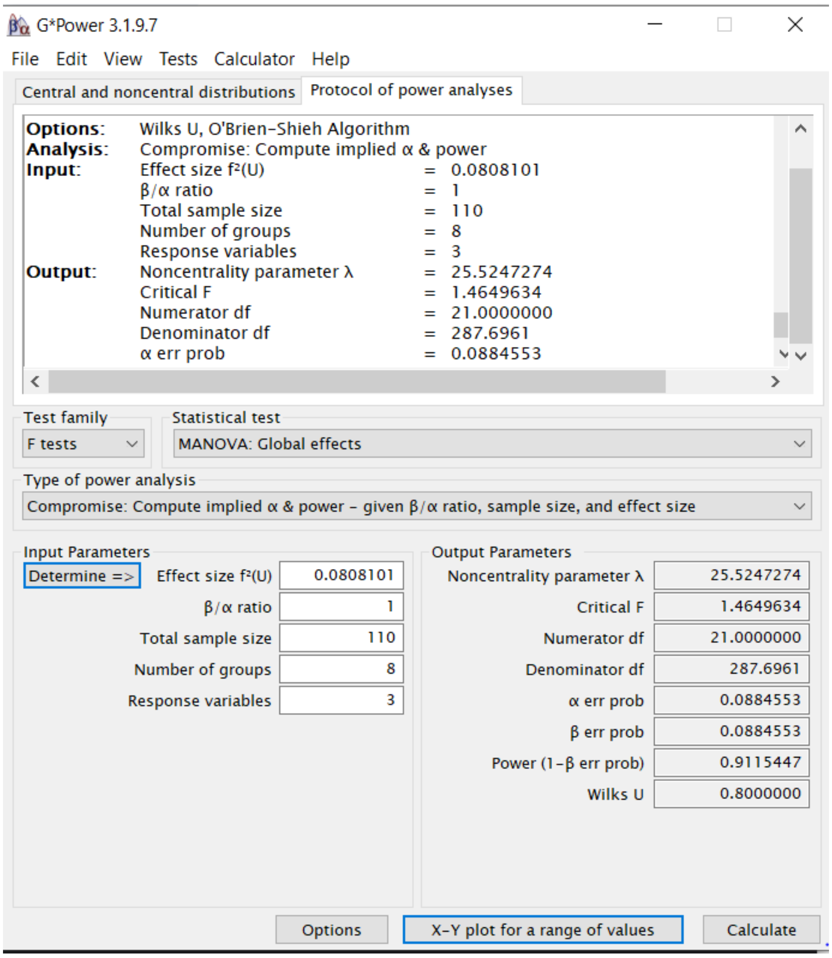


Figure 11.1 - Statistical Power of the Experiment

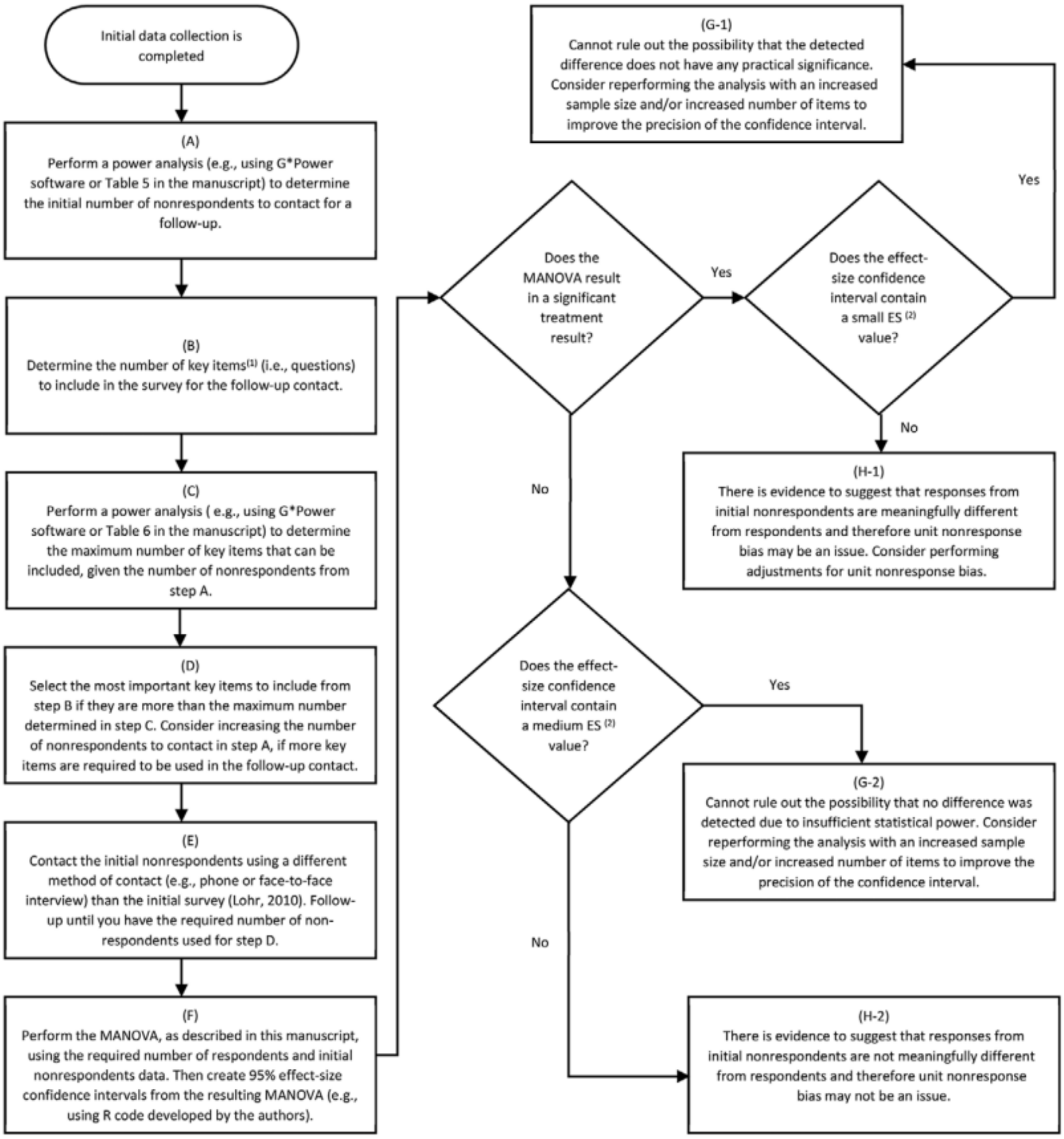


Figure 11.2 – Simplified Procedure for Performing a MANOVA sourced from Cottley and Benton Jr (2020, p. 446)

11.5 Workshop Protocol: WORK_AEROD

First Part: Short presentation about the Design for Supply Chain concept (10min)

Second Part: Views on Cross-Functional teams (40 min)

The aim is to understand the nature of your cross-functional teams: “Is *Design for Supply Chain* at the core of your business”? The following questions will be presented and quickly discussed orally:

I. **What are the internal processes of your cross-functional teams? Please describe with examples.**
   i. In what projects do you work in cross-functional teams? How are people selected to participate in these teams?
   ii. How do you make it work? What actions are put in place? Who is accountable?

iii. Does your company constitute multifunctional teams with the goal of accelerating product development, or is it an organisation wide orientation to promote supply chain integration?

II. What are the results of your cross-functional teams? To what extent are they responsible for the following:

i. Product quality.
ii. Delivery performance.
iii. Speed in reacting to engineering/other problems.
iv. Integration with supply chain partners.
v. Information exchange.
vi. Achieve or maintain short time from product concept to introduction.

III. How do you know that your cross-functional teams are working? (Nominate factors)

i. What measures are used to assess cross-functional team success?
ii. What are the main challenges to implement a cross-functional mindset?
iii. What are the alternatives?

Third Part: Powertrain Scenario Design (40 min)

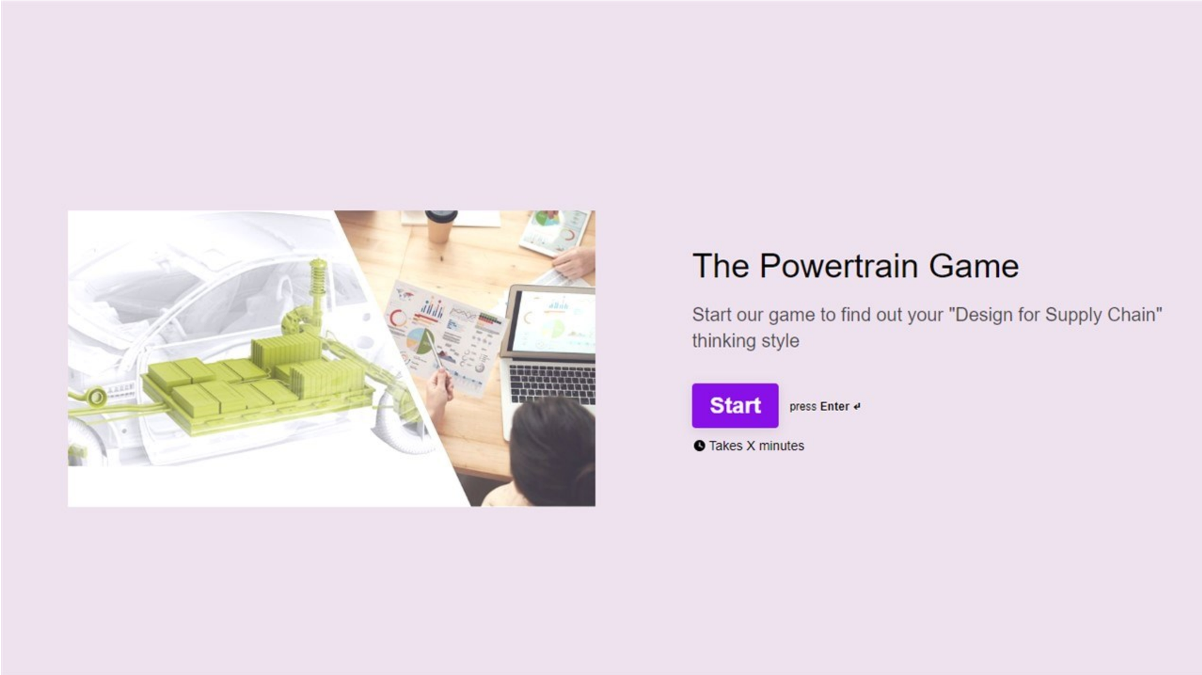
The aim is to understand the behaviour and value that professionals involved in NPD projects put into variables like product design, manufacturing processes and supply chain design. This will be accomplished by manipulating a variable for each dimension: product modularity (high/low), process manufacturing changes (high/low), supply chain visibility (high/low). An online questionnaire will be conducted, we will deliver flyers with the QR code for the scenario.

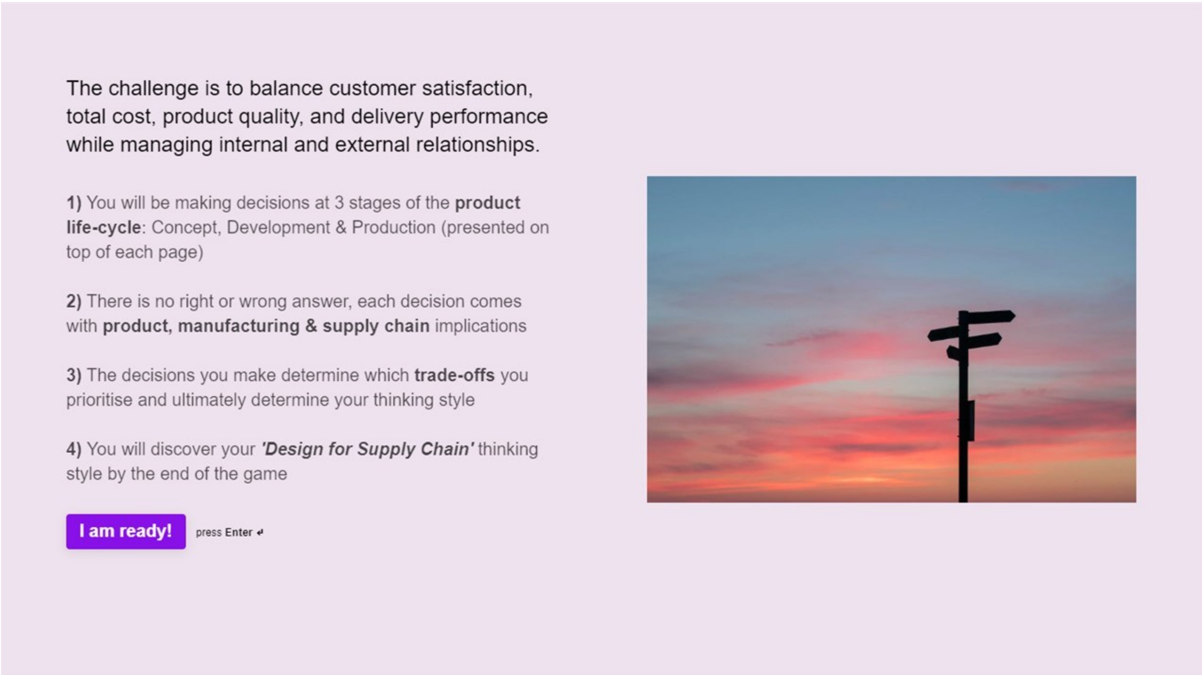
We will ask each participant to remember the symbol that they selected on the "Check Point" question. Each symbol leads randomly to a different treatment. The key is the following:

#	Treatment 1
$	Treatment 2
%	Treatment 3
&	Treatment 4
€	Treatment 5
§	Treatment 6
@	Treatment 7
£	Treatment 8

After completion of the online questionnaire, we will deliver the scenario in paper to each participant, we will reveal the manipulation and will discuss the implications. We will reflect on the role of *Design for Supply Chain* in past projects, supplier integration and risk visualisation for successful NPD outcomes.

11.6 The Powertrain Game





“ **Hello! We're glad to have you here!**

You are a senior project manager in an automotive manufacturer, recognised for its high-performance cars.

The company has decided to launch a fully electric vehicle (EV) sports car. *The annual forecast volume is 25,000.*

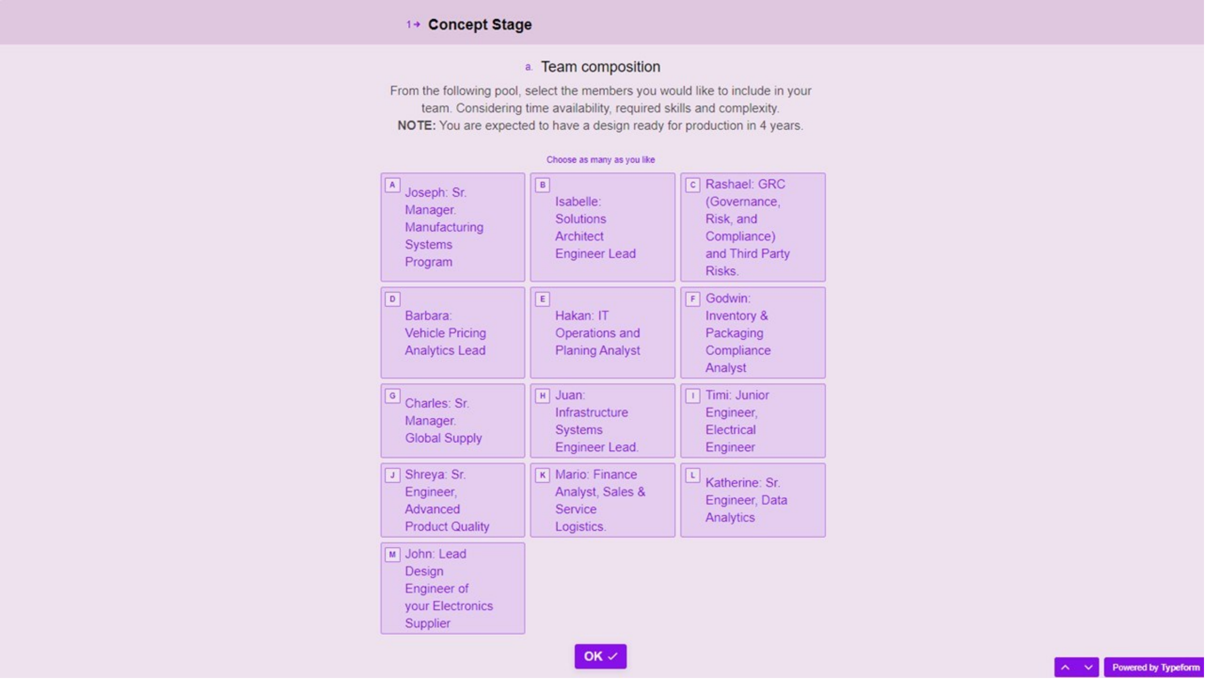
Given your experience & expertise, you were selected to lead the development of the EV Powertrain (battery, e-motor, power electronics, thermal-management modules), *which is expected to represent 45% to 55% of the total cost of the new EV.*

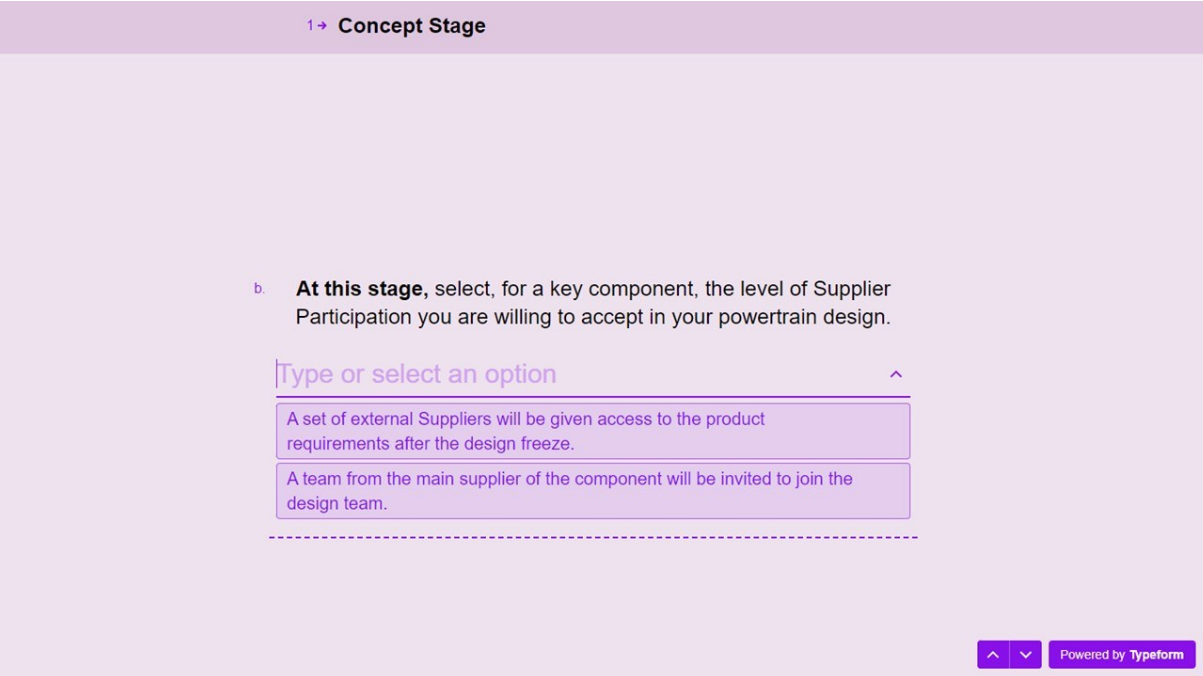
Continue press **Enter** ↵

1→ **Concept Stage**

1st Stage

Continue press **Enter** ↵


1→ Concept Stage
a. Team composition
From the following pool, select the members you would like to include in your team. Considering time availability, required skills and complexity.
NOTE: You are expected to have a design ready for production in 4 years.
Choose as many as you like
A Joseph: Sr. Manager. Manufacturing Systems Program
B Isabelle: Solutions Architect Engineer Lead
C Rashael: GRC (Governance, Risk, and Compliance) and Third Party Risks.
D Barbara: Vehicle Pricing Analytics Lead
E Hakan: IT Operations and Planing Analyst
F Godwin: Inventory & Packaging Compliance Analyst
G Charles: Sr. Manager. Global Supply
H Juan: Infrastructure Systems Engineer Lead.
I Timi: Junior Engineer, Electrical Engineer
J Shreya: Sr. Engineer, Advanced Product Quality
K Mario: Finance Analyst, Sales & Service Logistics.
L Katherine: Sr. Engineer, Data Analytics
M John: Lead Design Engineer of your Electronics Supplier
OK ✓
Powered by Typeform


1→ Concept Stage
b. **At this stage,** select, for a key component, the level of Supplier Participation you are willing to accept in your powertrain design.
Type or select an option
A set of external Suppliers will be given access to the product requirements after the design freeze.
A team from the main supplier of the component will be invited to join the design team.
Powered by Typeform

Development Stage

2nd Stage

Continue press Enter ↵

Powered by Typeform

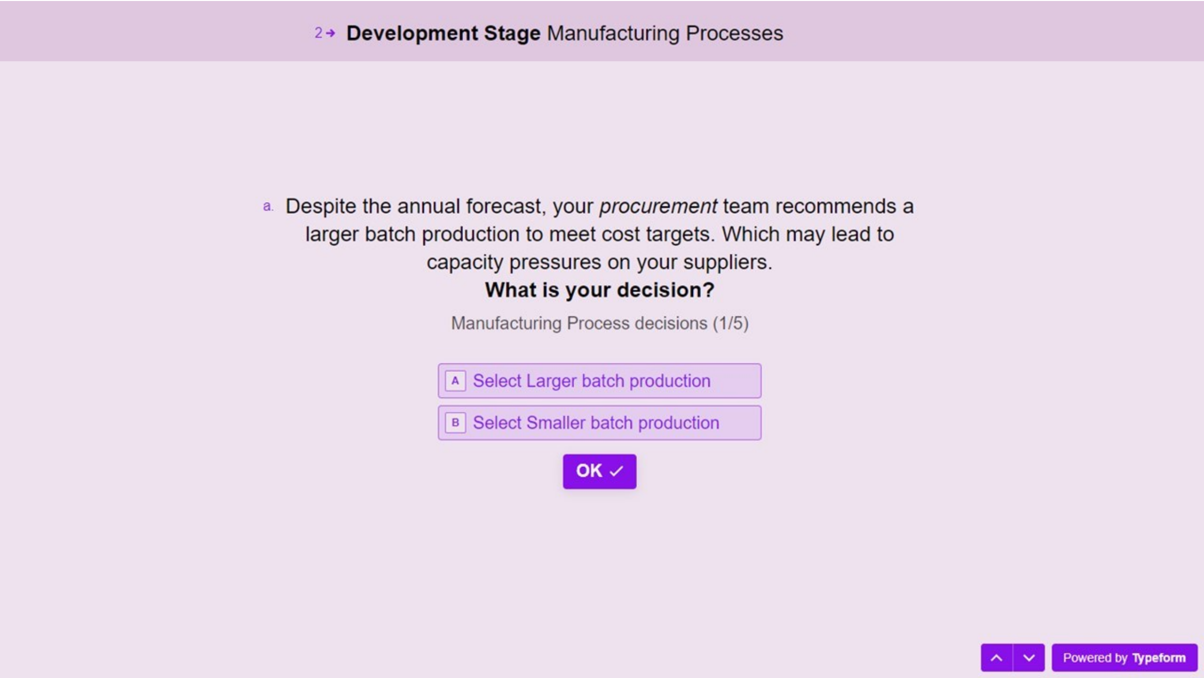
2→ **Development Stage**

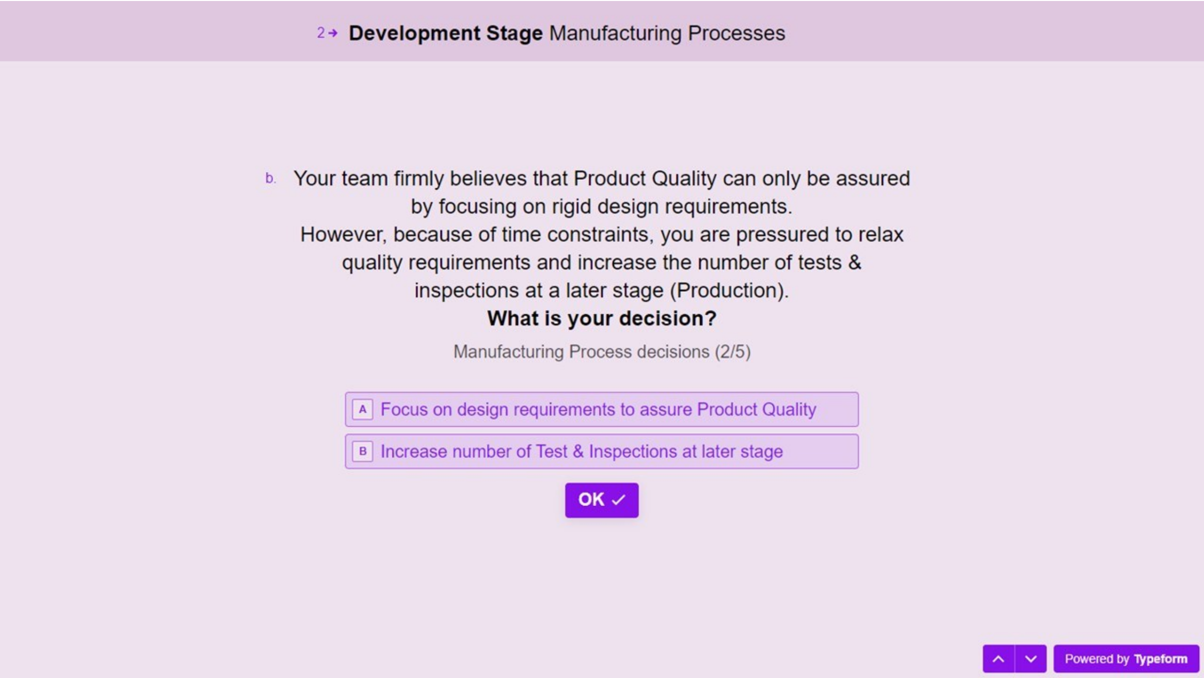
Manufacturing Processes

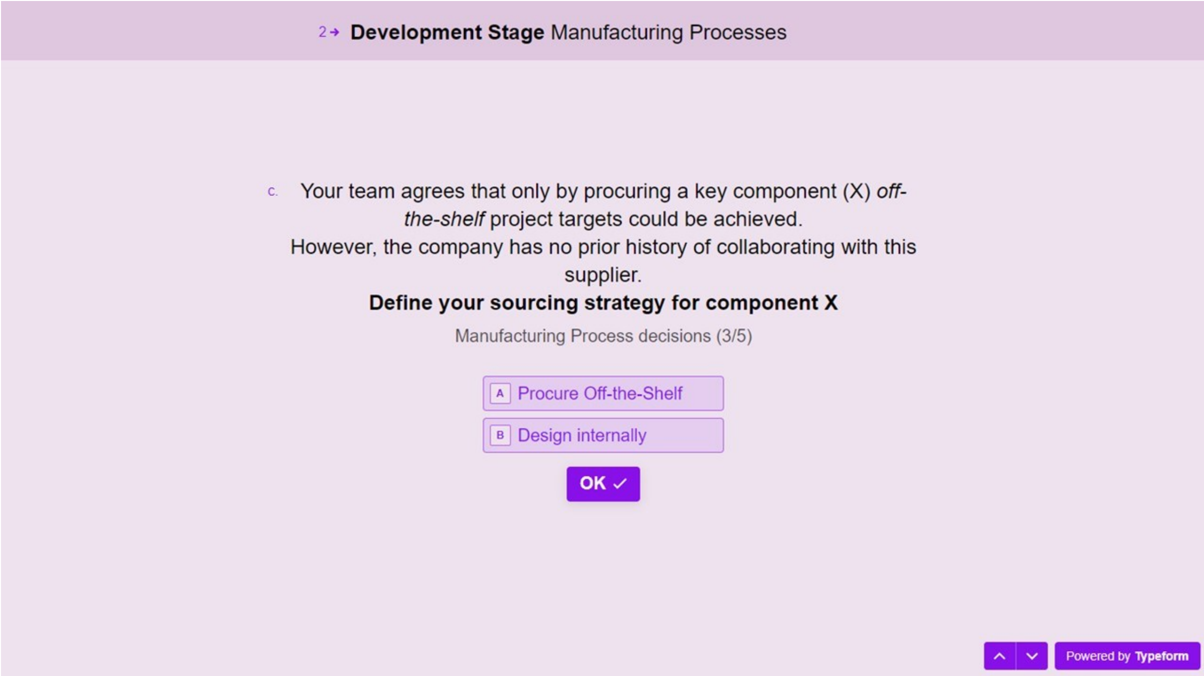
For the next five decisions, you will set up the Manufacturing Processes of the new Powertrain.

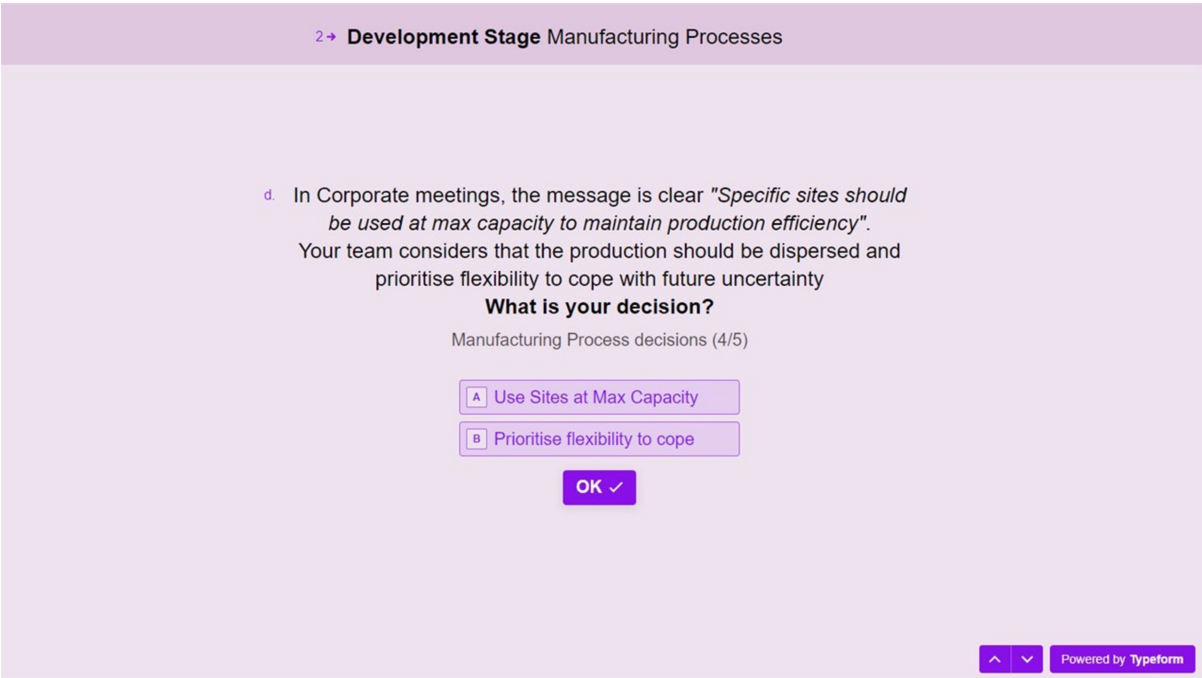
Continue press Enter ↵

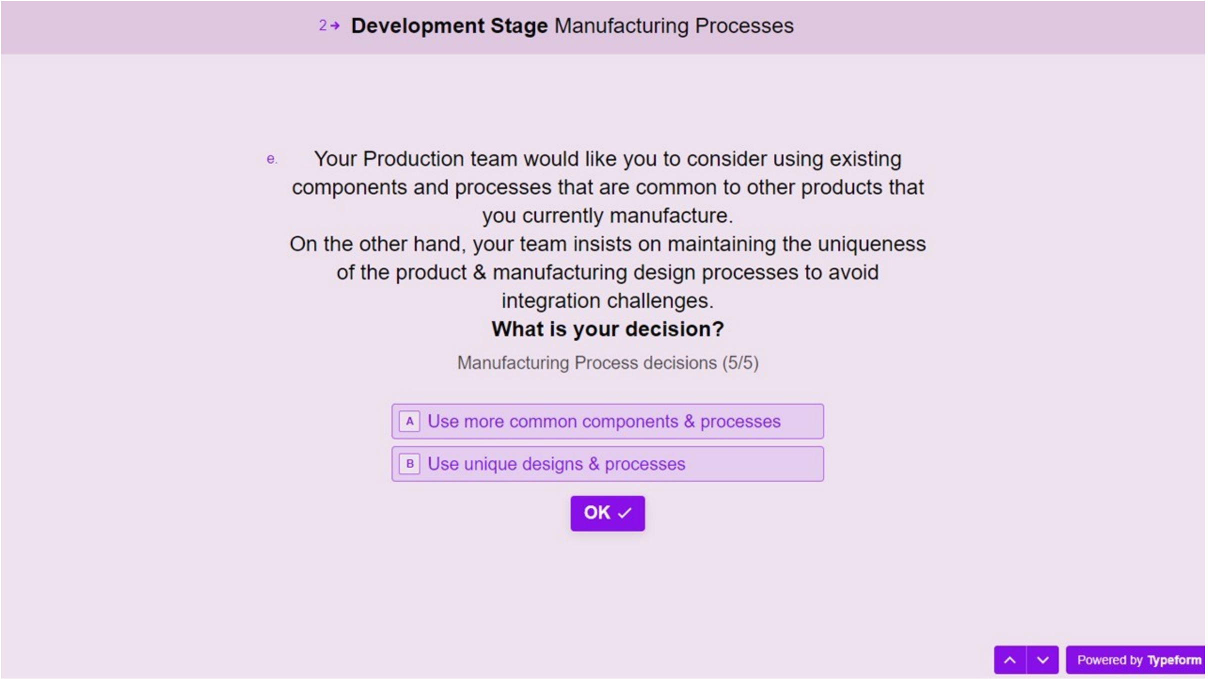
Powered by Typeform

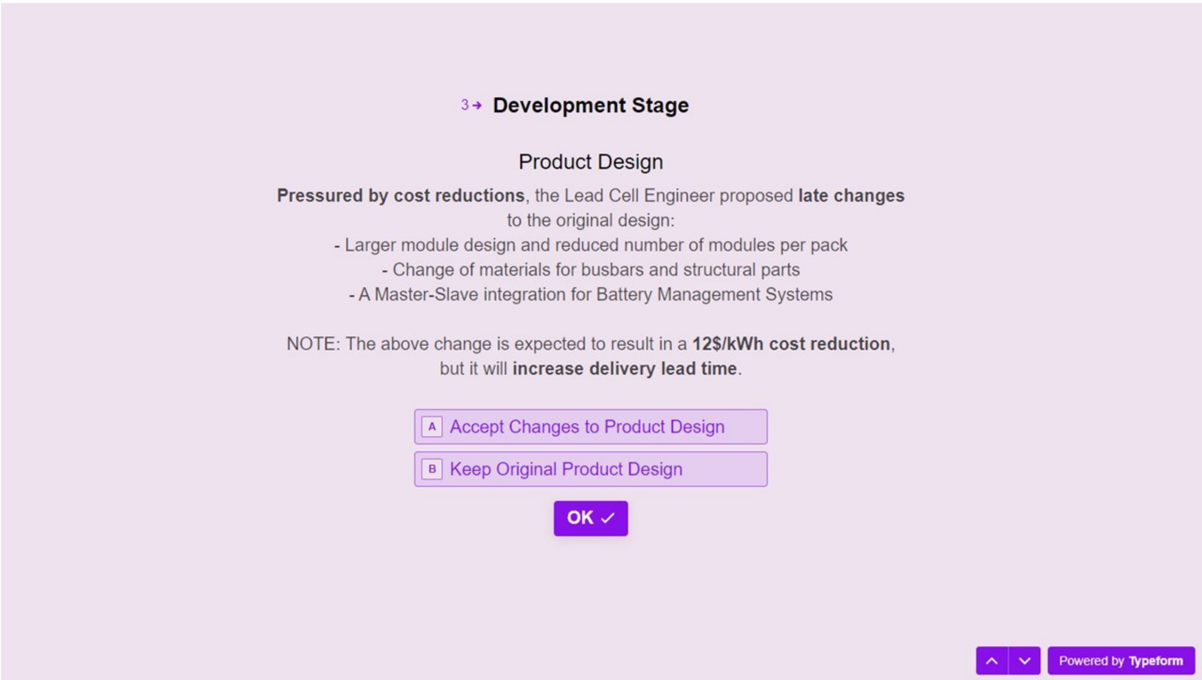

2→ Development Stage Manufacturing Processes
a. Despite the annual forecast, your *procurement* team recommends a larger batch production to meet cost targets. Which may lead to capacity pressures on your suppliers.
What is your decision?
Manufacturing Process decisions (1/5)
A Select Larger batch production
B Select Smaller batch production
OK ✓
Powered by Typeform


2→ Development Stage Manufacturing Processes
b. Your team firmly believes that Product Quality can only be assured by focusing on rigid design requirements.
However, because of time constraints, you are pressured to relax quality requirements and increase the number of tests & inspections at a later stage (Production).
What is your decision?
Manufacturing Process decisions (2/5)
A Focus on design requirements to assure Product Quality
B Increase number of Test & Inspections at later stage
OK ✓
Powered by Typeform


2→ Development Stage Manufacturing Processes
c. Your team agrees that only by procuring a key component (X) off-the-shelf project targets could be achieved.
However, the company has no prior history of collaborating with this supplier.
Define your sourcing strategy for component X
Manufacturing Process decisions (3/5)
A Procure Off-the-Shelf
B Design internally
OK
Powered by Typeform


2→ Development Stage Manufacturing Processes
d. In Corporate meetings, the message is clear "Specific sites should be used at max capacity to maintain production efficiency".
Your team considers that the production should be dispersed and prioritise flexibility to cope with future uncertainty
What is your decision?
Manufacturing Process decisions (4/5)
A Use Sites at Max Capacity
B Prioritise flexibility to cope
OK
Powered by Typeform


2→ Development Stage Manufacturing Processes
e. Your Production team would like you to consider using existing components and processes that are common to other products that you currently manufacture.
On the other hand, your team insists on maintaining the uniqueness of the product & manufacturing design processes to avoid integration challenges.
What is your decision?
Manufacturing Process decisions (5/5)
A Use more common components & processes
B Use unique designs & processes
OK
Powered by Typeform


3→ Development Stage
Product Design
Pressured by cost reductions, the Lead Cell Engineer proposed late changes to the original design:
- Larger module design and reduced number of modules per pack
- Change of materials for busbars and structural parts
- A Master-Slave integration for Battery Management Systems
NOTE: The above change is expected to result in a 12$/kWh cost reduction, but it will increase delivery lead time.
A Accept Changes to Product Design
B Keep Original Product Design
OK
Powered by Typeform

4→ **Production Stage**

3rd stage

A combination of new *trade limits*, *environmental regulations* and *financial problems* for one of the main suppliers of a key component might cause **severe production delays** to the new Powertrain.

You are called to face this challenge.

Continue press Enter ↵

Powered by Typeform

4→ **Production Stage** *3rd stage* A combination of new t…

a. The supplier has warned the procurement team that the design of the Powertrain is causing them many production constraints and as a result financial problems (e.g. due to additional cost for tooling).

What set of measures would you propose?

- ✓ Temporarily increase orders to this Supplier to ease its financial stress
- ✓ Temporarily relax quality testing requirements for this Supplier
- ✓ Temporarily assign members of your team fully dedicated to the Supplier to identify process improvements

A Set of measures **A**

- ✓ Request your Procurement team to search for different suppliers for the component in the short-term
- ✓ Ask your team to work on design alternatives that would replace the component sourced from this Supplier in the medium-term
- ✓ Increase internal control by promoting a more Vertical model in the long-term

B Set of measures **B**

OK ✓

Powered by Typeform

4→ **Production Stage** *3rd stage* A combination of new t…

b. Drawing on this recent experience.
What strategy would you promote to mitigate exposure to similar supply chain challenges in future projects?

Please select the strategy that you think will have the most significant impact.

- A Work on improving the alignment of internal goals (e.g. design specs, and production requirements) and the accuracy of information by using common understandings
- B Mapping out all the Product & Supply Chain Processes to better visualise the challenges of fulfilling the demand (with Supplier Participation)
- C Establish relationships with more Supplier to reduce dependency and meet production requirements
- D Leveraging the Company's capabilites to help key Suppliers to achieve their own goals

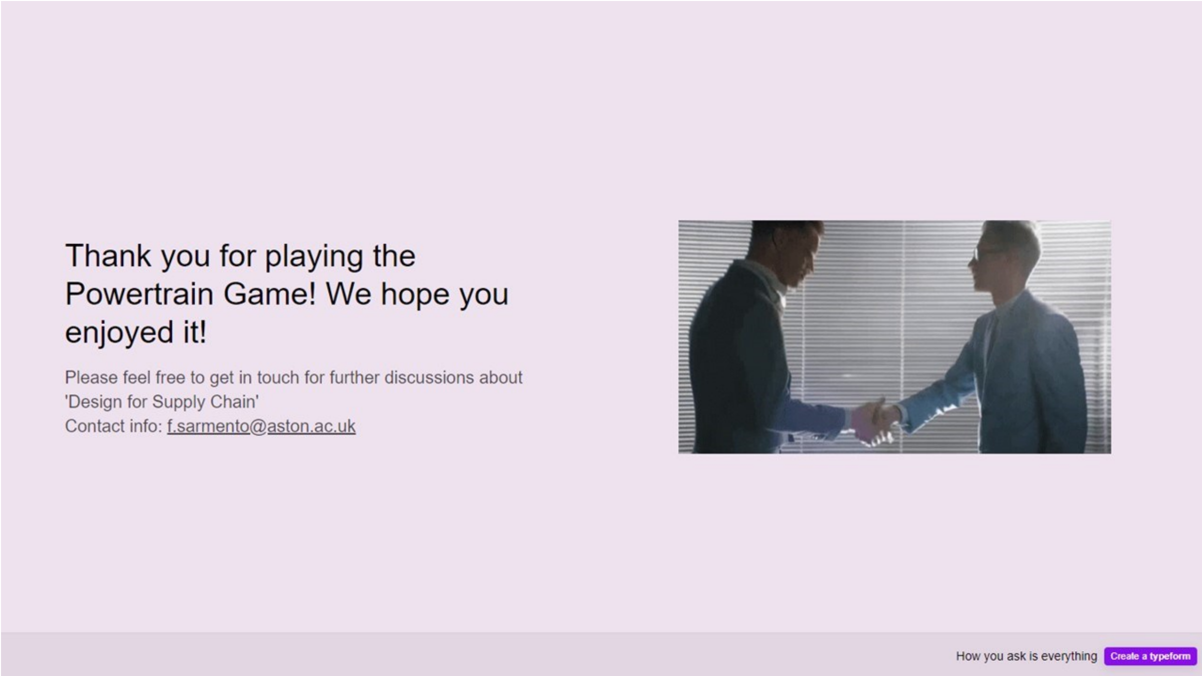
OK ✓

Powered by **Typeform**

“ Let's now uncover what type of *'Design for Supply Chain'* thinker you are – and how you can use that insight to optimize your supply chain strategy.

Show me the results! press **Enter** ↵

Powered by **Typeform**



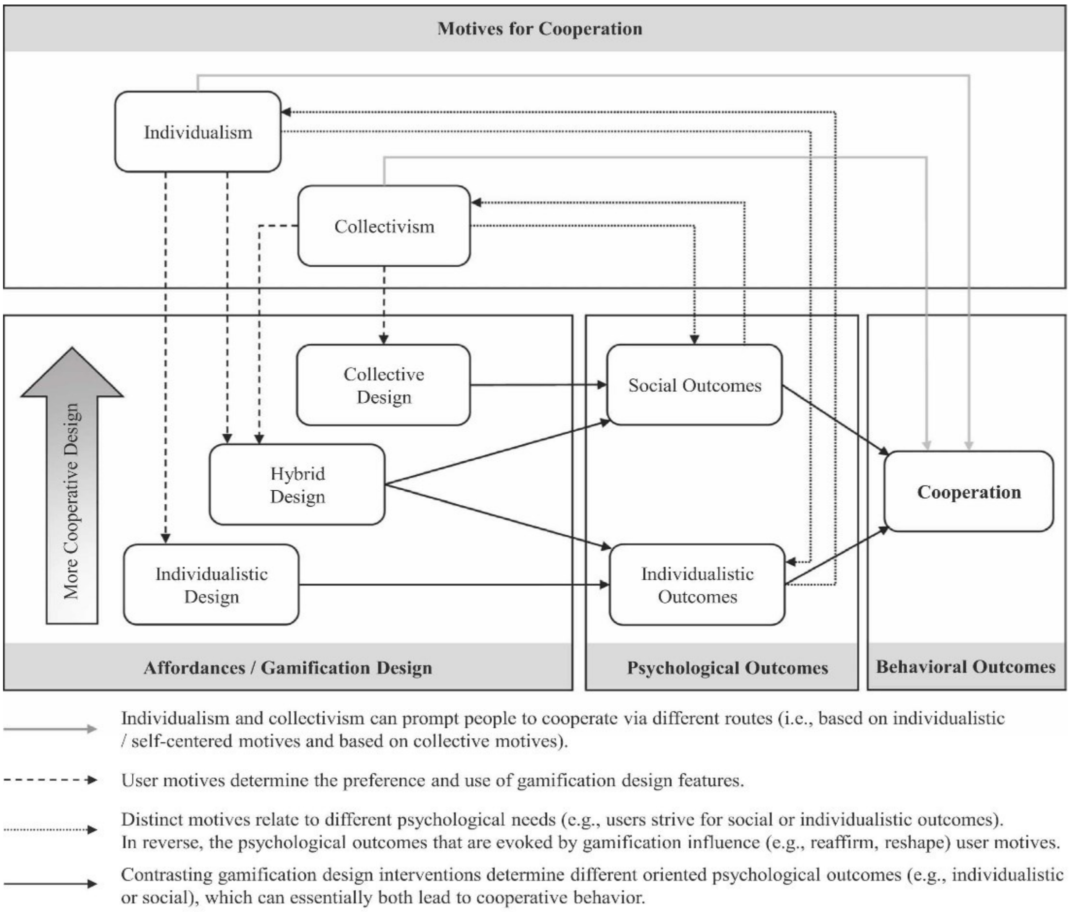


Figure 11.3 – Game Design Approach for Cooperation sourced from Riar et al. (2022)

11.6.1 *Score Rules for Powertrain Game Profile type*

Questions:		Description			Scoring
1a	**If you**				
	M	Supplier			
	AND				
	G	Sr			
	AND any				
	J	Sr			
	A	Sr			
	Add	10		to	for collaborate with Supplier and a
	If you				
	Subtract	5		to	for not considering complex costs
1b	**If you**				
	B	Invite			
	and select				
	M in 1a				
	Mutiple	score	1.25		for
	If you				
	B	Invite			
	and NOT				
	M in 1a				
	Divide	score	1.25		for
2a	**If you**				
	B	small			
	Add	1		to	to separate Cost & Quality
	If you				
	A	larger			
	Subtract	1		to	to separate Cost & Quality
2b	**If you**				
	B	assure			
	Add	2		to	to separate Cost & Quality
	If you				
	A	test&inspections			
	Subtract	1		to	to separate Cost & Quality
2c	**If you**				
	B	design			
	Add	1		to	to separate Cost & Quality
	If you				
	A	procure			
	Subtract	1		to	to separate Cost & Quality
2d	**If you**				
	B	flexibility to			
	AND score is greater than				to push score to strategic thinking
	Add	5		to	without penalising the coherency of
	If you				
	A	max			
	Subtract	1		to	to separate Cost & Quality

2e	If you				
	Questions:	unique			
	Add		1	to	to separate Cost & Quality
	If you				
	A	common			
	Subtract		1	to	to separate Cost & Quality
3	Changes to Product in Development				
	If you				
	A	accept			
	Subtract		5	to	to reflect the priorty of
4a	Answer to Supplier disruption in				
	If you				
	A	measures to			
	AND score is greater than				to distinguise between collaboration &
	Mutiple	score	1.5		a participant with score greater than 10 has been
	If you				
	B	measures to			
	AND score is greater than				a participant with score greater than 12 has been
	Divide	score	1.5		you should be penalised for not being
	If you				
	A	measures to			
	AND score is equal or				a participant with score lower than 10 has
	Mutiple	score	1.1		you get some points for now considering
	If you				
	B	measures to			a participant with score lower than 5 has
	AND score is equal or				But if your score is negative you can be
	Mutiple	score	1.5		If score is
	Subtract		5	to	is score is
4b	Mitigating Stratagies to address				
	If you				
	A	Supplier diversification			**you are more concern**
	AND score is greater than 15				> 20 means that you been
	Subtract		5	to	If A is your option means that you regreat this and
	If you				
	B	Work on Internal			**you are**
	Divide	score	1.25		dividing by a positive number will bring you
	If you				
	C	Mapping out			**this is an effective internal and external**
	AND score is not greater than 25				already
	Multiply	score	1.25		to push to the extremes to
	If you				
	D	Leveraging			**this is the selection for**
	AND score is greater than 25				> 25 means that you are in
	Subtract		5	to	deduct 5 points to bring you back
AND if score is between 5 to 15					5 to 15 means that you are in
	Add		5	to	adding 5 points will give you a change to
	AND if				0 to 5 means that you are in
	Add		15	to	adding 5 points will push you to collaborative

Scales			
	-15	-10	Strategic thinker
	-10	5	Operational Master
	5	15	Product Expert
	15	25	Collaboration Manager
	25	35	Strategic thinker

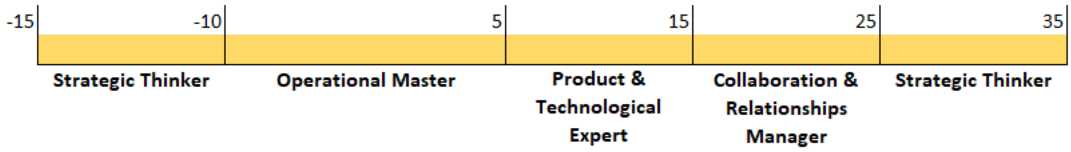


Figure 11.4 – Scales for computing the prolife types into the Powertrain Game

11.6.2 Workshop activity protocol – Powertrain Game

Introduction: Presentation of the *Design for Supply Chain (DfSC)* concept (5 min)
The aim is to introduce the concept of DfSC very informally.

Main Part: The Powertrain Game (60 min)

Playing the Game (10 min)
A flyer with a QR code for the game will be on the table for each participant. <u>The Game will be played individually.</u>

Discussion from the Game (45 min)

Concept Stage

Team Composition & Supplier Participation

(What is the reality in your Company?)

- Comparing & discussing the decisions
- Reflect on the benefits and challenges of supplier participation & what stage certain functions should be included (A company – furniture industry –used external personnel – mainly students – in the idea generation stage, with internal personnel brough out mainly to deliver on the ideas. This allow the cost to be minimised.)
- Which Supplier to select? Long-term relationship? Technology capabilities? Perceived flexibility? Easy to work to? What is more important?
- How about the coordination with the downstream part of the Supply Chain?
- Labour skills. How important is to have experience in leading similar type of projects? Does it make the employer more conscious on the importance of Design for SC in NPD projects?

Development Stage

Manufacturing Processes & Product Design

(Understand and prioritisation of requirements)

- Comparing & discussing the decisions
- What functional goals are prioritised in NPD at your Company?
- Does it help to have a Project Manager (Gatekeeper)?
- Connecting the Manufacturing Process & Product Design with Supply Chain Configuration: 1) How to balance the investments cycles? 2) What actions can be taken in your Company to visualise the connecting points and *trade-offs*?

Production Stage

Responding to Disruptions

(What friction mechanisms or challenges can lead to unwanted outcomes in DfSC implementation?)

- Comparing & discussing the decisions
- What reasonable information or type of relationship would require you to respond more efficiently to the disruption presented during the Production Stage?
- Company size. Resource availability. Power dynamics, etc. How do these factors influence the implementation of DfSC?

Expected benefits & outcomes

- What measures are used in your company to assess DfSC success?
- What is the perception of the benefits from your smaller Suppliers (Tier 2, 3, 4…).
- What are the alternatives to a DfSC approach?

Potential Outcomes for the Company

From this session the team will be given a change to:

a. Reflect, individually and as a team, on the impacts, benefits and challenges of adopting a *"Design for Supply Chain"* behaviour.
b. Benchmark their individual reasoning against the answers of other business Experts.
c. Collectively validate a roadmap for *"Design for Supply Chain"* implementation.

11.6.3 Validation Protocol

Design for Supply Chain principles

The design principles of concurrently account for the multifaceted functional (design, engineering, manufacturing, logistics, procurement) and supply chain decisions in NPD projects. These decisions, take by multiple teams and organizations, should aim to ensure mutual beneficial outcomes throughout the product lifecycle.

Our proposition is as follows:

> *'Design for Supply Chain' adds value to NPD projects, but practitioners do not have a clear conception of the challenges or the gains. Often outweighing the former and underweighting the later. The game is designed to allow them to recognise this bias.*

The Powertrain Game

During the Powertrain Game players make multiple decisions at 3 stages of *Production Lifecycle*: Concept, Development, and Production. The goal of the player is to satisfy Customer Requirements based on Total Cost, Product Quality & Delivery Performance while considering the ***trade-offs*** between Product, Manufacturing Processes and Supply Chain Design.

Outcome of the game for the players:

> *To Capture the complexity of the design decisions taken in PD, the reasoning behind those decisions, and their understanding of Supply Chain implications.*

Outcome of the game for the organisations:

> *In a Workshop activity, the organisation will have the opportunity to evaluate the embedment of "Design for Supply Chain" behaviour within their teams, uncovering different functional*

perceptions, and allowing them to devise actionable strategies to improve their teams' NPD performance.

You can interact with the Powertrain Game by clicking here

After the Game

A one-to-one conversation based on your professional experience, which covers primarily these two points:

- Is there a need in your organisation for changing behaviours towards incorporating DfSC principles in product development teams? Why? Why not?
- Do you see a gamified solution, like the Powertrain game, being implemented in your organisation to enhance DfSC thinking? What changes would you consider to improve future versions of the game?