ASPECTS OF THE DESIGN AND CONTROL OF MANUFACTURING SYSTEMS SUBJECT TO DEMAND UNCERTAINTY

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Doctor of Philosophy

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SYNOPSIS

The recent explosive growth in advanced manufacturing technology (AMT) and continued development of sophisticated information technologies (IT) is expected to have a profound effect on the way we design and operate manufacturing businesses. Furthermore, the escalating capital requirements associated with these developments have significantly increased the level of risk associated with initial design, ongoing development and operation. This dissertation has examined the integration of two key sub-elements of the Computer Integrated Manufacturing (CIM) system, namely the manufacturing facility and the production control system. This research has concentrated on the interactions between production control (MRP) and an AMT based production facility.

The disappointing performance of such systems has been discussed in the context of a number of potential technological and performance incompatibilities between these two elements. It was argued that the design and selection of operating policies for both is the key to successful integration. Furthermore, policy decisions are shown to play an important role in matching the performance of the total system to the demands of the marketplace.

It is demonstrated that a holistic approach to policy design must be adopted if successful integration is to be achieved.

It is shown that the complexity of the issues resulting from such an approach required the formulation of a structured design methodology. Such a methodology was subsequently developed and discussed. This combined a first principles approach to the behaviour of system elements with the specification of a detailed holistic model for use in the policy design environment. The methodology aimed to make full use of the "low inertia" characteristics of AMT, whilst adopting a JIT configuration of MRP and re-coupling the total system to the market demands.

This dissertation discusses the application of the methodology to an industrial case study and the subsequent design of operational policies. Consequently a novel approach to production control resulted, a central feature of which was a move toward reduced manual intervention in the MRP processing and scheduling logic with increased human involvement and motivation in the management of work-flow on the shopfloor. Experimental results indicated that significant performance advantages would result from the adoption of the recommended policy set.

Key Words:CIM, MRP, AMT, Policy Design, Manufacture, Production Control, Simulation, Holistic Modelling.

CONTENTS PAGE

FIGURE		PAGE

TABLES PAGE

APPENDICES

ACKNOWLEDGEMENTS

I should like to register my appreciation of the co-operation and assistance provided by Fulcrum Communications Ltd (FCL). In particular, I wish to thank Mr D. Pinwell and Mr D. Gore for agreeing to the application of this research to policy design at FCL. I would also like to thank Mr D. Morgan, Mrs L. Fenn, Mr R. Evans and Mr J. Hall whose encouragement and healthy skepticism was greatly appreciated.

My thanks are also due to Dr. D. Love of Aston University for his continued support and guidance and also to Dr. J.E.T. Penny for supporting my continued work.

I would especially like to thank my colleague, Mr D.I. Gooden whose contribution was invaluable.

Finally, I must recognize the tremendous effort and undoubted self sacrifice of my wife without whom this work would not have been started or finished.

1. INTRODUCTION

1.1 Research Area

The recent explosive growth in Advanced Manufacturing Technology (AMT) and the continued development of sophisticated Information Technologies (IT) is expected to have a profound effect on the way we design and operate manufacturing businesses. Furthermore, the escalating capital requirements associated with these developments have significantly increased the level of risk associated with initial design, ongoing development and operation.

Traditionally, research has concentrated on the sub-elements of the total manufacturing system such as process technology, labour organisation, production control etc. Workers such as Ward (1987), Skinner (1969), Hill (1985) and Game (1987) have recognized the strategic importance of the manufacturing system and have proposed that design, development and operation should be viewed in global terms. At the macro level, a number of methodologies for the design of such "total manufacturing systems" have been proposed for example, Skinner and Hill. However, the problems attending the integration of the separate specialist elements which together make up the manufacturing system, have received very little coverage.

This dissertation will examine the integration of two key elements of the manufacturing system, namely the manufacturing facility and the production control system. This research will concentrate on the interactions between a Computer Aided Production Management (CAPM) system and an Advanced Manufacturing Technology (AMT) based production facility.

1.2 CAPM, AMT and Their Integration

In all but the simplest of scenarios, the highly complex nature of the modern manufacturing environment demands that a suite of sophisticated information based tools be available. For example, the diversity of products and parts coupled with rapid changes in demand and engineering specification, places production and purchase order scheduling beyond the ability of manual or statistical control. In addition, effective management demands that information on subjects as diverse as, work in progress (WIP), stock levels, order lateness, bills of material (BOM), financial forecasting and vendor performance, be readily available. Consequently, sophisticated CAPM tools have developed over the last two decades. Of these, Manufacturing Resource Planning (MRP II) is considered to offer the most complete suite of tools and is the most widely implemented.

Over a similar time span, significant changes have been associated with manufacturing hardware. For example, improvements in cutting and process technologies have significantly reduced operation cycle times. Similarly, advances in control, tooling and metrology have significantly reduced batch set times. In addition, work handling has benefited from the advent of robotics and Automated Guided Vehicles (AGVs). Consequently, the basis of production facility design has altered. The boundaries of these technologies by their nature, are ill defined and often overlap. Consequently, the generic term AMT is often used to describe a manufacturing facility which employs one or more of these technologies.

Integration of these two elements (MRP & AMT) poses a number of interesting problems, all of which are based on the following potential incompatibility of these two technologies. AMT facilities are often characterized by an ability to exploit short batches, and to enjoy low WIP levels and rapid system response. However, the traditional view of the MRP environment assumes stability of demand, large "optimised" order quantities and the use of WIP buffers to negate flow imbalances. Consequently, a traditional approach to integration would result in a mismatch of capabilities and a loss of performance potential.

It will be demonstrated that a holistic approach must be adopted if sub-elements of a manufacturing system are to be successfully integrated. Within this framework it will be argued that the design and selection of operating policies for both of these sub-elements is the key to successful integration. Furthermore, policy decisions will be shown to play an important role in matching the performance of the total system to the demands of the marketplace.

1.3 Research Methodology

The methodology of this research will have two aspects. Firstly, the principles and assumptions underpinning policy decisions and design will be re-examined in the light of the changing technology base, changes in business needs and recent work concerning the validity of the underpinning assumptions. Particular attention will be paid to the interactions between policy decisions at different levels within the system.

This review will identify the key issues involved in policy design for the total system. This in turn will focus the research on the more pertinent areas.

The second aspect of the research will involve the development of a methodology for policy selection in the total system environment. This will then be applied to an industrial case study.

1.4 Industrial Case Study

The case study involves Fulcrum Communications Ltd (FCL), a wholly owned subsidiary of British Telecommunications Plc. FCL produces numerous high quality electronic, telecommunication and computer based products. Recently, considerable restructuring of its operation has taken place, as a result of which, the manufacturing division was faced with a completely new product range, customer base, production volume and product technology.

Investments were made in highly automated plant, which would form the basis of a Flexible Manufacturing System (FMS) and offered numerous configuration and control options. In addition, implementation of an MRP II system (Unisys' Total Manufacturing System (TMS)) was initiated.

The company understood the need to integrate these two entities and develop coherent control policies for the operation of the whole system. The potential for conflict between the individual requirements of these two sub-systems and the complexity of their interactions was recognized. The subsequent difficulty in planning for effective integration was compounded by the near "green field" nature of the manufacturing facility, resulting in the almost total absence of relevant historical data.

For the above reasons, it was considered that a collaborative research project with FCL would provide an excellent vehicle with which to refine and test the policy design methodology. In 1985 an agreement was implemented in which Aston University was contracted to design (and later implement) a coherent set of control and operational policies covering customer demand, production control and manufacturing facility operations.

It was agreed that the research team would consist of two members of Aston University staff on a full-time basis and one or more members of FCL staff on a part-time basis. In consideration of the commercial as well as academic importance of this work full business reporting procedures were included in the project management. The initial project time scale was to be two years commencing in July 1985. This was later extended to a length of two and a half years to include some additional research work and the implementation stage of the recommendations.

2. MANUFACTURING RESOURCE PLANNING (MRP II): THE ISSUES

2.1 An Introduction to MRP II

In Chapter 1 it was stated that the highly complex nature of today's manufacturing environment demands that a suite of sophisticated information based tools be available. Furthermore, it was noted that of the CAPM systems Manufacturing Resource Planning (MRP II) is the most widely implemented and potentially versatile system.

2.1.1 Concepts

The origins of MRP II can be traced back to early "order point" production control systems and have been reported extensively (Orlicky (1975), Plossl and Wight (1967)). MRP II is an extension of MRP (Materials Requirement Planning) which in turn is based on the following simple concepts:

The Master Production Schedule (MPS). The MPS extends to the "horizon" and defines manufacturing intent as product requirements, within each time bucket. Figure 1. represents the structure of an MPS.

Bill of Material (BOM). This defines each top level item (saleable product) in terms of the structure of each constituent part. Figure 2. is a schematic representation of a typical BOM for one product.

Stock. Material held at a location prior to release, either finished stock awaiting sale or constituent stock awaiting conversion to the next level in the BOM. In MRP, work is considered to flow from one stock location to the next.

Lead time allowance. A value used to offset the requirements of each part number, by an estimate of the time required to complete the necessary work (ie, the time required for material to flow from one stock location to the next).

Work in Progress (WIP). Parts in-between stock locations.

Order Quantity Per Period.

Product Type

Period	1	2	3	4	5	6
AAA	40	0	0	34	12	0
BBB	4	12	12	4	6	2
CCC	3	3	3	3	6	6
DDD	25	25	25	0	0	25
EEE	30	15	0	15	30	15
FFF	45	30	15	0	15	30
GGG	5	5	5	5	5	5
HHH	10	20	30	40	50	60
III	80	80	80	40	20	10

Figure 1. A Typical MPS.

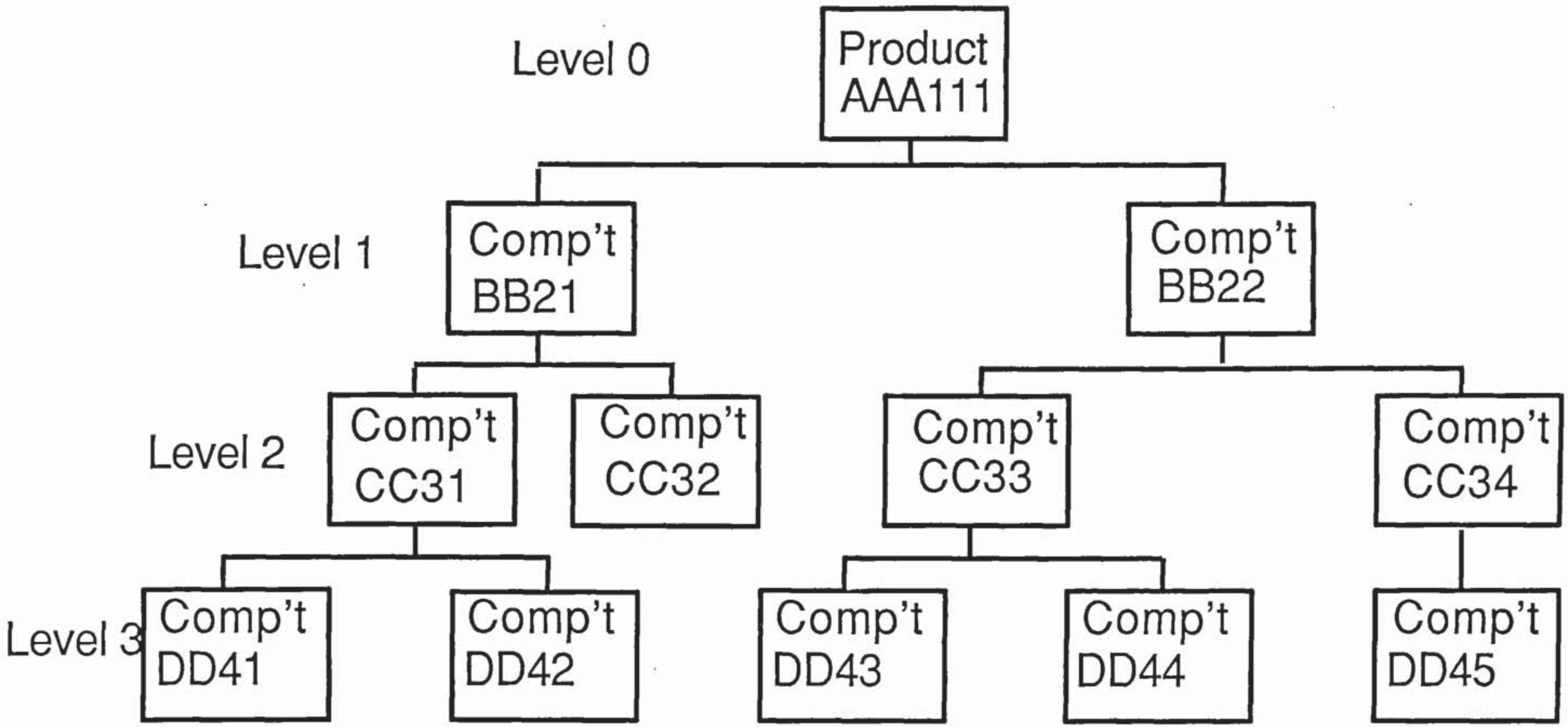


Fig 2. A Typical BOM.

2.1.2 Technique

The primary control mechanism of MRP II is the issue of purchase and WIP order schedules. The usefulness of all other planning and control functions (eg. stock level per part, progress reports, financial planning, etc.) ultimately depend on the accuracy and certainty of these schedules.

In deriving WIP and purchase orders, MRP employs the following technique. First two assumptions are made:

The lead time of each part under MRP control is assumed to equal a mean value (or linear function of lot size) and to be independent of external influences (eg. shop load, production route etc.).

Manufacturing capacity is considered to be infinite during the order generation calculations. Consequently, effects such as the sequence in which work flows to individual work centres (wc) and particular wc loading, is ignored.

On the basis of these two assumptions the MRP explosion and netting process looks at the MPS, BOM, lead times, stock levels and WIP to produce suggested orders which are offset by the cumulative lead times of the parts in question.

At this point the Capacity Requirements Planning (CRP) module is run to identify capacity bottlenecks on a period by period basis. Individual demands are then altered to balance load against capacity.

It is important to note that both the MPS and lead time contain elements of uncertainty. Consequently, the orders generated by MRP II will also be subject to uncertainty.

2.1.3 Control Policies

Modern MRP II systems are usually supplied in a generalized form with numerous options offered for each of a number of control policies. Policies and parameters form an interacting chain descending from customer demand to raw material supply. At the highest level are those, which by their nature impact on the interface between Manufacturing, Marketing, Sales and Financial groups. These relate to the policies applied to customer demand (actual and perceived) in the generation of the Master Production Schedule (MPS). Examples include:

The extent of forecast demand in the MPS
The forecasting algorithms applied
The level in the Bill Of Materials (BOM) at which the MPS is applied.
The degree and extent of change permitted in the MPS.

At the next level are those policies which affect the translation of customer demand into production and purchase order schedules. Examples of such parameters within MRP include:

Ordering Policies
Lot Sizing rules
Lead time allowances
Safety stock/safety lead time policies

It has long been recognized that the choice of individual policies will affect aspects of the performance of the separate elements within the production system. This has formed the basis of numerous studies (Silver & Meal (1973), Wagner & Whittin (1985), Biggs et al (1980), Arumagum (1985), etc). However, it will be shown that a coherent view, in terms of total system performance, has not developed. This deficiency has serious consequences for those seeking to integrate sub-systems. Chapter 5. will develop this argument further and will seek to define a coherent holistic view.

2.2 MRP II, Technique or Philosophy?

When examining the accumulated knowledge relating to MRP II, it is tempting to form the opinion that it is a manufacturing philosophy. Indeed the early workers in the field, (Wight, Orlicky and Plossl) suggested as much. This is not too surprising when it is considered that the 1960's into which MRP was born, represented a period of rapid development in business thinking.

The philosophy of this era was known as Corporate Planning. In manufacturing terms, end product requirements were planned against predominantly forecast demand. Long production runs were then planned to minimize standard costs and maximize individual work centre utilization. The low cost of capital was such that buffer stocks and high levels of WIP were used to negate any flow imbalances and further maintain high levels of utilization (Chapter 3 details why high levels of WIP are required to maintain high work centre utilization).

The objective was to achieve sales of the planned production through the market advantage offered by reduced costs. By today's standards the business environment of the time was characterized by low capital costs, minimal international trade imbalance, and long product life cycles. In addition, factors such as, high levels of engineering change and customers demanding short delivery times, were not major issues.

Since these were the formative years for MRP, the Corporate Planning philosophy became embedded in the literature relating to policy design. For example, it was often suggested that once generated, the MPS could and should remain firm (eg. Orlicky (1975)). Lot size and stock policies were often designed with the purpose of maintaining work centre utilization regardless of whether or not a particular work centre was loaded to full capacity.

Since the 1960's, international business pressures, high capital costs, explosive product diversity and reducing product life cycles, forced a shift in business philosophy away from the planned approach toward the strategic approach (strategy implies coherent objectives achieved through flexibility of tactic). The 1970's saw the adoption of Strategic Planning. By the early 1980's, this in turn had been replaced by Strategic Management in "leading edge" companies.

Operationally, the instability of the marketplace inevitably became reflected in the MPS. In many industries competition became increasingly dependent on the ability to achieve short delivery lead times. Coincidentally, the high real cost of capital and the high rate of obsolescence, discouraged the use of safety stocks and make to stock policies, against a largely forecast demand.

Unfortunately, this level of change has been ignored by many MRP researchers and implementors. Wemmerlov (1979) referred to the legacy of doctrines emanating from the troika of Orlicky, Plossl and Wight, most of which were based on 1960's thinking.

It is the author's contention that MRP II is fundamentally a production control technique, in which the assumption of independent constant lead times and infinite capacity are required. These assumptions are made primarily to simplify the computational procedures. It is arguably, both inappropriate and inadvisable to constrain the operation of a manufacturing business to the needs of the production control system. Consequently, philosophical issues should be limited to those relating to the truth of the two assumptions. If there is doubt as to their validity, then means should be employed to correct any deficiencies within the system.

2.3 MRP's Failure

In the mid 1970's MRP II was hailed as the saviour of American Industry against the ravages of international competition. At this time the

American Production and Inventory Control Society (APICS) initiated a ten year crusade to encourage its use.

However, recently an increasing number of studies have reported widespread disillusionment with MRP. It is no longer the undisputed saviour. Reports have placed dissatisfaction with MRP implementations as high as 90% (Whiteside and Arbose 1984). Fox (1982) wrote;

> "During the past two decades United States industries have invested heavily in manufacturing systems. It is estimated that we have spent over $10 billion for MRP alone. While we have made progress, the results have fallen far short of even our minimum goals"

MRP users have complained of; nervous systems with WIP and purchase orders in a constant state of flux, long lead times, poor due date performance, resource imbalance (ie one part of the factory idle whilst another is on full over time), low stock turn and poor return on capital employed.

Meanwhile, the MRP industry (suppliers and implementors) have answered with equally valid criticisms of users, the most common being; poor database maintenance, lack of stock control and various problems with corporate culture. The latter point has commonly resulted from disparity between the marketing, sales, production control and operations management functions.

This dichotomy has generally been resolved around the belief that if the database was maintained at 95%+ accuracy, the corporate culture was receptive, and the management structure appropriate, then MRP II would succeed.

Unfortunately this has not worked in practice. In spite of the above, a number of valid complaints remain, primarily; poor stock turn, excessive lead times and a considerable degree of order rescheduling (Whiteside and Arbose (1984), Mather (1977)). This latter point can be the most insidious, in that it results in serious disruption of manufacturing and loss of faith in the production/purchase schedules (and hence MRP II itself). Anton and Malmborg (1985) discussing a case study, noted;

> "This study was initiated in response to a specific firm's problems with direct materials procurement. The MRP system at this firm had been virtually abandoned due to its inability to react to uncertainties in demand."....
>
> ...."Invalid production schedules translated into ineffective MRP planning and justifiably low user confidence."

Fortunately the UK's experience of MRP & MRP II has lagged somewhat behind that of America, with the result that our industry has only just begun large scale implementation. It is the author's contention that for the reasons discussed at the start of this chapter, whether or not to implement MRP II, is not an issue. Our primary concern should be to learn from the American experience and to find means of ensuring that we avoid the high potential for failure.

In section 2.1 it was shown that fundamentally MRP II is reliant on two assumptions. The first being that lead time is independent of external factors and secondly that it is valid to assume infinite capacity during the MRP netting and offsetting process. The success of an MRP II system is dependent on the truth of these assumptions.

The author will argue that the truth of these assumptions is dependent on extra-system factors (such as the environment of the company in question) and intra-system factors (such as the control policies used and the capability of the manufacturing resources). It will be further argued that the reason for the high level of failure discussed above, lies in the poor understanding of these factors, with the choice of operational policies often being inappropriate and commensurate with this lack of understanding.

Workers such as Goldratt (1981), (1984) and Fox (1983) have adopted a stringent view of MRP's assumptions, arguing that they are fundamentally invalid and will consequently undermine MRP's success. However the author will argue that whilst always desirable, absolute truth is often unattainable in the complexities of real world systems. Furthermore, it will be argued that a close working approximation to validity can be achieved by careful policy design within defined operational boundaries. Indeed this argument will be inverted and this research will assume that assumption validity is a fundamental goal of policy design.

2.4 MRP Policies and Parameters: Poor Decisions

It will be argued that poor policy/parameter decisions have occurred for three reasons; the first lies in the low level of priority given to policy decisions by MRP implementors,the second lies in the inadequacy of the assumptions made by successive researchers in the field of policy design, and the final reason lies in the failure by successive researchers to adequately allow for the complex inter-relationships between policies/parameters whilst investigating their effects and suitability. This is in part due to a lack of understanding of the effect of policy decisions on the performance of a manufacturing company. However, it has also been impossible to assess the relative merits of alternative policy strategies without an experimental facility. This issue will be discussed in more detail in Chapter 5.

2.5 Wrong Priorities

The majority of MRP implementors place a relatively low level of importance on the choice of policies and parameters. Most modern implementation project plans are preoccupied with data accuracy, stock control and organizational issues, at the expense of policy design.

Figure 3. shows a typical implementation plan suggested by Fisher of Price Waterhouse (1981). Out of 25 detailed items, the selection of policies and parameters are dismissed with four lines. No provision is

made for an evaluation of the policy/parameter options during the system selection stage. Additionally, policy design is assumed to be right first time as there is no provision for review or modification. It would be wrong to overly criticise Fisher or Price Waterhouse, as this plan is typical of its ilk.

The generally poor understanding of the effects of policy/parameter decisions is such that a common recommendation is to implement MRP using the pre-MRP policy and parameter values. The view is that somehow the "system" will automatically adjust for any deficiencies in choice. This can be evidenced by the common use of business measures designed to encourage performance to the arbitrarily assigned parameters. Examples include due date performance, lead time variance, percentage stock-out, exception message volume, etc. (see Mather (1986)). In view of the points made above, this approach can be seen to be treating the symptoms and cannot be an effective substitute for a set of coherent control policies.

2.6 Wrong Assumptions

Over the last two decades, there has emerged a consistent mismatch between the assumptions made by MRP researchers and the dramatic changes in both marketplace and business philosophy.

Section 2.2 discussed the rapid rate of change in business philosophy over the last two decades and noted that MRP researchers had largely ignored these changes. The following examples highlight this point:

In the late 1970's a plethora of papers on "optimal" or "economic" lot sizing were produced with the common assumption that the MPS could and should be held firm (the corporate planning approach) (De Bodt et. al. (1980) cite the following; Biggs et al (1979), Blackburn and Millen (1979), Chand (1980), Graves (1979), McClaren (1977)).

Phase 1: Study.

First cut education.
Establish Project Team and assign responsibilities.
Review present Functions.
- what are we doing now ?
- what can MRP do for us?

Select MRP functions.
Determine and detail manpower requirements.
Project review.
- education
- financial justification.

Set timetable.

Phase 2. Development.

Detailed education and training.
Inventory accuracy 95%.
Hardware / software research.
Hardware /software installation.
Structure BOM to system (90%).
Load system with BOM & Inv'try.
Test system parts.
Expansion of MRP capabilities.
Write policies and proceedures as needed.
Taylor program spec to company.
Review with top management.

Phase 3. Installation.

Master schedule preparation
- review with marketing - sales forecasts.
- *set proceedures for MPS revisions.*

Set lead times.
Review paper flow.
Pilot Programme.
Expand MRP capabilities.
- shop flooor control.
- routeings, capacity requirements.

Monitor system.
- late orders.
- actual production v scheduled.

Cost / benefit review.
Ongoing support.
Financial Review.

Fig 3. A Typical MRP Implementation Plan

The assumptions underpinning the above research were in complete contrast to the contemporary and current business needs (with international pressures tending toward increasing MPS volatility). Indeed even now MRP policy research in the environment of MPS demand uncertainty, is very limited. De Bodt and Van Wassenhove contributed a valuable series of papers to this area (1980, 1982 and 1983). Changes were made to the MPS which reflected the actual level of uncertainty encountered in a case study. Orders were then recalculated by MRP and the process repeated. They tested numerous order and stock policies and their results raised serious doubts over the applicability of much of the earlier work. A number of serious questions were raised regarding many accepted MRP platitudes.

The advent of the Just In Time (JIT) approach has questioned the collective wisdom of long production runs and plants balanced with high levels of WIP. JIT suggests that lots should be released on an "as needed" basis. Again until recently this approach was ignored by MRP researchers, the implication being that JIT was considered an alternative philosophy to MRP. This returns to the earlier point that MRP is not in itself a philosophy (2.2).

The last decade has seen a recognition of the limitations inherent in the use of standard costing techniques, both as operational measures (such as "utilization") and comparative measures, in policy design. There has been a subsequent emergence of Marginal Costing and Cash Flow measures for operational performance in "leading edge" companies (Goldratt (1984), St John (1984), Jones (1987) and Aucamp (1984)). Again this has not been reflected in policy design. This will be shown to have particular relevance in Chapter 3.

This mismatch of assumptions results partly from the time required for changes in business philosophy to be reflected in requirements for research into operational problems. However, researchers in Materials Management could be accused of myopia in the selection of the bounds of the systems under consideration.

2.7 Policy Interactions

Policy interactions can be considered at two levels; firstly interactions of policies within MRP (eg. order, pan size, minimum order and minimum stock policies) and secondly interactions between sub-elements of the total system (eg. lead time, batch size (MRP policies), priority rule and resource management (shop policies)).

The traditional approach to policy design (MRP and shop) has been to test various alternatives at a single policy level. Examples include Silver & Meal (1973), Blackburn & Millen (1979), McClaren (1977), Graves (1979), amongst many others. Interactions between policies at one or more levels have been largely ignored. The reasons behind this are twofold.

Firstly, the implications and importance of policy interactions were not understood. This has often been exacerbated by policy design being the responsibility of disparate groups. For example, the specification of MPS policies often originate from the strategic levels of a company's management; academic research in this area is often the domain of business schools. MRP policies such as order policy, stock policy, etc are the domain of the operational layer of corporate management and much of the academic research has been conducted in management science and operational research departments. Finally, many of the shop related policies are influenced by production engineering departments both industrially and academically. One consequence of this separation of effort, has been an incomplete understanding of the peripheral issues to a particular policy level. Examples of this have been discussed in relation to the invalidity of some underpinning assumptions.

The second reason behind the somewhat myopic view of policy interactions has been the lack of experimental facilities with which to undertake such a study. The archetypal research vehicle has been a single level stochastic simulation of the MRP system with little or no modelling of the production system. Furthermore, variability in the MPS was generally ignored (Silver & Meal's work (1973) is typical of the genre). Over the years the degree of sophistication increased, but only marginally. By the 1980's, the models used included stochastic production elements which were capable of varying actual lead time by sampling distributions. The models used by Hoo-Gon et al (1984) and Arumagum (1985) are typical examples. However, the complex interactions between product route/mix, capacity, lot size and priority etc., were generally beyond the scope of distribution driven models. It is possible to make the observation that the manufacturing system as a whole (that is the production control element and the production hardware) have not been satisfactorily modelled as an integrated system.

The lack of understanding of the interactions at both levels (production control and shop) will be shown to be fundamental to the poor performance of MRP. Chapter 3. will review the major issues in MRP policy design in the light of the above comments on assumptions and interactions. Chapter 5. will examine policy interactions in the context of the complete system of influences.

3. MRP POLICIES AND PARAMETERS: A REVIEW

MRP and MRP II research has its roots in traditional production control (eg "order point" control) and significant contributions have arisen over the past two decades. However, the last 6 years have seen an explosion in the number of papers and articles published on the subject. Oliver Wight's comments to the effect that the youth and importance of the subject was evidenced by the paucity of academic research, is no longer true. A recent interrogation of two "on line" databases revealed in excess of 20,000 references on the subject area (interestingly the sample of these papers examined showed only a small proportion to be of serious value).

To date policy research has concentrated on the following aspects of MRP:

- Planning horizon
- Lot sizing techniques (purchase and WIP)
- Stock policies (safety stock)

and more recently:

- Lead time allowances
- Safety lead time
- Demand uncertainty
- Re-scheduling techniques

3.1 The MPS

3.1.1 Demand Uncertainty

In the preceding chapter it was noted that the MPS contains an element of uncertainty in the timing and sizing of product demand. The extent and nature of this uncertainty is determined by both external and internal factors. These influences can be investigated by utilizing the typical operating scenarios shown in Figure 4.

The customer order to delivery time represents the period of time between the point of receipt of a firm order and the customer's required delivery date. Scenario 1 represents the situation where the customer's lead time is greater than the total composite lead time. Consequently, purchase order and WIP orders can be actioned against firm demands (customer orders). The probability of re-scheduling is at a minimum.

Scenario 2 represents the situation where manufacture and assembly lie within the customer's lead time, but raw material purchase does not. Thus if the risk of losing customer orders through material shortage is to be minimized, some element of forecast demand must be used to initiate raw material purchase. Modern MRP II systems offer several alternatives for this situation.

In Scenario 3, only assembly operations fall within the customer's lead time. Consequently, both raw material purchase and manufacture must be initiated against forecast demand.

Finally, Scenario 4 represents the situation where the customer lead time is such that all operations must be actioned against forecast demand.

From the above, the relationship between customer order to delivery time and the composite lead time for products is seen to be the key to understanding the operational effects of uncertainty in the MPS.

Externally the market segments in which the company operates, largely dictate the customer order to delivery time. The traditional view is that composite lead time is largely fixed by the product and production technology. It is therefore typically considered that the operating scenario is largely determined by external forces. However, it is the author's contention that MRP policy decisions have a direct and significant influence on composite lead time and thus operating scenario. Consequently, policy decisions should ultimately be viewed in the light of current and future Market Strategy and should form a

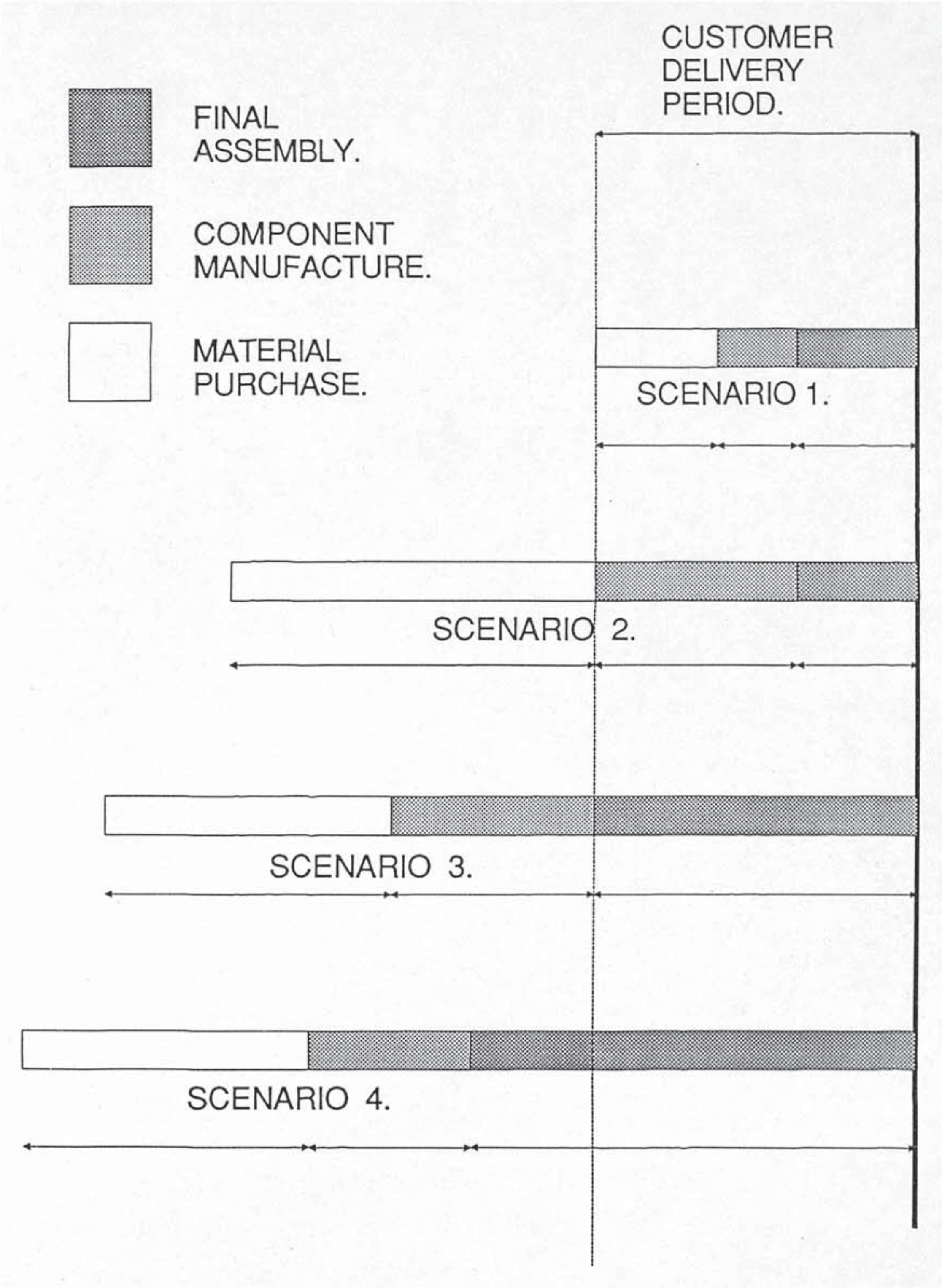


Fig 4. Typical Manufacturing Scenarios.

significant part of any Manufacturing Strategy. Furthermore, policy design should not necessarily be seen as static. The suitability of the trade-offs inherent in policy choice should be subject to review in the light of changing conditions.

3.1.2 MPS Horizon, Lead Time and Rescheduling

The MPS horizon is of importance for a number of reasons. Operationally, the length of the horizon has a direct relationship with the computing power required to host MRP and the time required to perform a regeneration. Thus there is a cost penalty associated with excessively long horizons.

Conversely, the horizon must be at least as long as the largest cumulative lead time of the parts under MRP ordering control (as outlined above).

Baker (1977, 1979A & B) investigated the horizon length on nervousness and determined that the horizon length should be equal to the natural order cycle of the forecast products. However, although his experiments pioneered the rolling schedule technique (ie. periods are added to the end and subtracted from the beginning of the MPS between successive regenerations) he did not consider uncertainty. Thus, the relevance of the natural order cycle is questionable. Furthermore information regarding product natural order cycle is frequently either not available or of questionable quality.

Minifie and Heard (1985) examined the presence or otherwise of an eleven period forecast fence on performance and found no correlation. However, the full results are not published and they concede the need for further work in this area.

3.2 Lot Sizing Techniques

3.2.1 The Development of Lot Sizing

Much of the early work relating to lot sizing was based on refinements of "order point" techniques. The goal of early researchers was to minimize overall cost by balancing the high stock holding costs (associated with large lot sizes) against the high set-up costs (associated with small lot sizes). The most basic of these techniques are the "Economic Order Quantity" (EOQ) and "Economic Lot Size" (ELS) models (for purchased and manufactured parts respectively). These techniques consider costs and quantities on an annual basis and are therefore classified as "static", in that lot size remains constant from period to period.

In 1958, H.M. Wagner and T. Whitin produced a dynamic version of the ELS model. This used a dynamic modelling technique to relate lot size to short term fluctuations in demand. The following years saw the development of a plethora of lot sizing techniques using dynamic modelling or heuristic techniques (or a combination of both). The following are among the most widely researched; Silver-Meal (1973), Least Unit Cost, Part Period Balancing and Least Total Cost (descriptions can be found in Orlicky (1975), and Peterson and Silver (1979)). In all of these techniques, the criteria used to define optimality were essentially the same as those used in ELS (set-up costs and stockholding costs).

In 1979 U. Wemmerlov reported in a limited survey, that of the available techniques, Lot-For-Lot was ranked second in his table of usage. This appears, at first, surprising in view of its low esteem as "non-optimum" solution (although a number of researchers have commented on the considerable increases in MRP processing time associated with many of the optimum seeking techniques). The same year also saw a growing awareness of the problem of "nervousness" defined as "frequent rescheduling of previously planned orders following an MRP regeneration". Wemmerlov and Carlson et al (1979) attributed this to the use of "optimal" lot sizing techniques.

3.2.2 The Validity of Using Set-up Costs in Lot Sizing

R. St John (1984) and D.C. Aucamp (1984), in separate articles, voiced considerable dissent with traditional lot sizing research. Aucamp was primarily concerned with the definition and use of set-up costs in lot sizing algorithms. His arguments are based on a criticism on the use of inappropriate standard costing measures. He wrote;

> "The usual procedure for calculating setup costs essentially calls for multiplying the setup time by the regular hourly wage rate of the operator who performs the labour. The problem with this approach is that total regular hours are usually fixed in the short run. Thus, the effect of an extra setup is not to increase regular time wages, but to reduce regular time output. Set-up costs must therefore take this into consideration."..... "It is argued that current load status should be taken into consideration in determining setup costs."

Aucamp goes on to recognize that in the dynamically loaded workshop, set-up costs associated with a not-fully-loaded work centre are effectively zero. His arguments continue to the effect, that only marginal costs should be considered in determining lot size. This simple but powerful argument has a profound effect on the applicability of many of the previously unquestioned lot size studies.

St John concurs with Aucamp on the use of marginal set-up costs and extends the argument to inventory costs. However, he concedes that the marginalist's view of inventory would result in only a minimal reduction of this cost element. In his evaluation of the effects of adopting marginal costs in lot sizing, he concludes that it would greatly favour the adoption of a lot for lot policy in the environment where the natural order frequency is high.

3.2.3 Lot Sizing Re-evaluated

In view of the points made above, it was considered prudent to re-evaluate some relevant work. De Bodt et al (1983) produced a valuable and significant study of lot-sizes and safety stocks, using a hybrid simulator incorporating an MRP production control model and a stochastic production facility model. Their work evaluated the relative merits of eight lot-sizing rules in the single level case with real end-product demand uncertainty. The rules evaluated were; Economic Order Quantity, Updated EOQ formula, MRP adjusted EOQ, Period Order Quantity, Least Total Cost, Least Unit Cost, Silver-Meal and Lot For Lot.

Their work was one of the first to incorporate MPS variability. Consequently, they produced a number of important results. Notable among these, was the poor performance of traditionally recommended lot sizing rules such as Silver-Meal (1973), concurred with the points raised by Minifie and Heard (1985) discussed in Chapter 5.

Among their results they produced a ranking of the eight rules in terms of total annual cost using traditional standard costing measures. This is reproduced in Table 1.

These results rank lot for lot last in terms of total costs. However, the preceding arguments about the inadvisability of using standard costs cast doubt on this ranking. It is proposed that since order related costs are fixed in the short term, a marginalist's view can be approximated by ignoring these cost elements. On this assumption, De Bodt and Van Wassenhove's results were re-worked to produce Table 2.

This re-analysis strengthens rather than detracts from their main conclusion; that demand uncertainty in the MPS has a tremendous effect on the cost affectivity of "optimal" and "economic" lot sizing. Four of the most widely recommended techniques now achieve the worst performance. The most notable finding of this re-evaluation is that the much maligned lot for lot rule achieves the lowest annual cost (followed closely by the similarly demand driven POQ). This result extends the arguments of St John and Aucamp (that LFL is favoured) to conditions of demand uncertainty.

It should be noted however, that these results are restricted to the single BOM level and that further work is needed to verify this for the multi-level case. Furthermore, the element of doubt associated with the approximated calculation of marginal costs also provides scope for further work. Notwithstanding these points, it should now be obvious that non-optimised demand driven rules, such as lot-for-lot and POQ, offer significant potential and must figure prominently in any assessment programme. Caution must be exercised where the natural order sizes are small, as this is likely to have a harmful effect on bottleneck resources. This will be discussed in more detail in Chapter 5.

It is important to note that irrespective of the above, the increase in stockholding costs generated by "optimal" lot sizing represents additional cash outlay. This is of particular significance to any company implementing MRP.

3.2.4 Lot Size, Load Imbalance and "Nervousness"

St John raises several further objections to "optimal" lot sizing. The first of which is the potential increase in lumpiness of the production work load and the invalidation of any rough cut capacity plan.

> "However any lot sizing that occurs below the top level of the product structure during the explosion process of MRP completely invalidates the rough cut capacity plan, except on a cumulative basis over the entire planning horizon. Even though capacity may be adequate to cover the planned work load in total, the effects of lot sizing are to batch, shift and clump production needs into extremely unbalanced load patterns."

Rank	Rule	Stock Cost $/year	WIP Order Cost $/year	Total Cost $/year
1	EOQ-N	139,900	77,500	217,400
2	LTC	115,200	118,700	233,900
3	LUC	117,100	117,500	234,600
4	EOQ-MRP	117,100	118,300	235,400
5	SM	109,600	128,700	238,300
6	POQ	100,400	150,500	250,900
7	EOQ-O	109,200	152,200	261,000
8	LFL	89,600	227,100	316,700

Table 1. De Bodt et al's Ranking of Lot Policies

Rank	Rule	Cost ($/year)
1	Lot-for-lot	89,600
2	Period Order Quantity	100,400
3	Economic Order Quantity	109,200
4	Silver Meal	109,600
5	Least Total Cost	115,200
6	Least Unit Cost	117,100
7	EOQ - MRP	117,100
8	EOQ - N	139,900

Table 2. A Ranking of Lot Policies With a Modified Cost base

Lot Size Rule.	% Stock out/year.
EOQ-O	3.9
EOQ-N	2.6
EOQ-MRP	2.5
POQ	3.9
LFL	3.9
LTC	2.7
LUC	3.1
SM	3.3

Table 3. Percentage stockout v Lot Size Rule, in an environment of demand uncertainty

Utilization.	Average Flow Time
.60	2.50
.80	5.00
.85	6.67
.90	10.00
.925	13.33
.95	20.00
.975	40.00

Table 4. Flow time and Utilization for a single machine system

St John continues the argument to note that Biggs Hahn & Pinto (1980), Collier (1981) and St John (1983) had shown the effects of lot sizing on work load balance to be dysfunctional.

A further and related objection expands on Wemmerlov's attribution of system nervousness to the interaction between changes in demand (primarily at the MPS) and lot-sizing. The necessity for the "firm planned order technique" to cope with nervousness, is attributed to lot-sizing. St John;

> "Perhaps the most frequent use of the firm planned order technique in MRP systems, where human intervention is invoked to override the normal MRP logic, is in response to the need for protection against dynamic lot-sizing methods."

Wemmerlov and St John, amongst others, have noted the link between nervousness, MPS uncertainty and lot sizing. Unfortunately, general solutions to the problem of nervousness are limited to the intuitive assumption that, increases in lot size beyond that determined by lot for lot, result in increases in rescheduling (nervousness). This lack of knowledge is compounded by the absence of both MPS demand uncertainty and any attempt to determine the effect of interactions between lot sizing at different levels in most MRP research. This has been discussed at length by Minifie and Heard.

A further point regarding lot size is that, "optimal" or "economic" techniques are often perceived to offer some degree of protection against poor customer service levels. De Bodt (1982) et al include an investigation of this in their work discussed earlier. Interestingly, they found that the larger batch sizes resulting from these techniques did not result in any significant increase in service level, for the single level case. Their findings were reproduced in Table 3. Further work is needed to verify these results for the multi-level case.

3.3 Manufacturing Lead Time

3.3.1 The Development of Lead Time Policies

Manufacturing lead time lies at the very heart of any MRP or MRP II system. It is through the lead time offsets that production schedules are created. The view expressed by the early workers in MRP, such as Orlicky, was that if allowances were approximately correct, the "system" would operate.

The most simplistic method of setting lead time is the "Generic Policy". Under this an average lead time is applied to each group or family of parts.

There are two potential problems with this approach. The first relates to due date variance. The very nature of an average "generic" lead time will result in members of the genre having variously, insufficient or too great an allowance. Order lateness, resulting from inadequate time offset, can be overcome by setting the generic allowance equal to the maximum in the group. However, the consequences of this will be an excess of WIP and stock as the faster moving parts are completed early.

The second problem concerns work load lumpiness. If we consider a product which is assembled from a number of sub-assemblies (each of which contain a number of parts, which in turn are assembled from purchased components) the use of generic lead time offsets will result in the orders at each level of part, maturing at the same time. The net effect over a product range would be to increase the lumpiness of demand at each level. The local capacity overloads resulting from this, will compound the due date variance effects discussed above.

A more detailed approach adopted quite early in the history of MRP was to consider lead time to be dependent on product route and transport time. Queuing time at individual work centres was generally considered as part of the transport allowances. The few significant contributions to this topic generally concentrated on the formulation of lead time

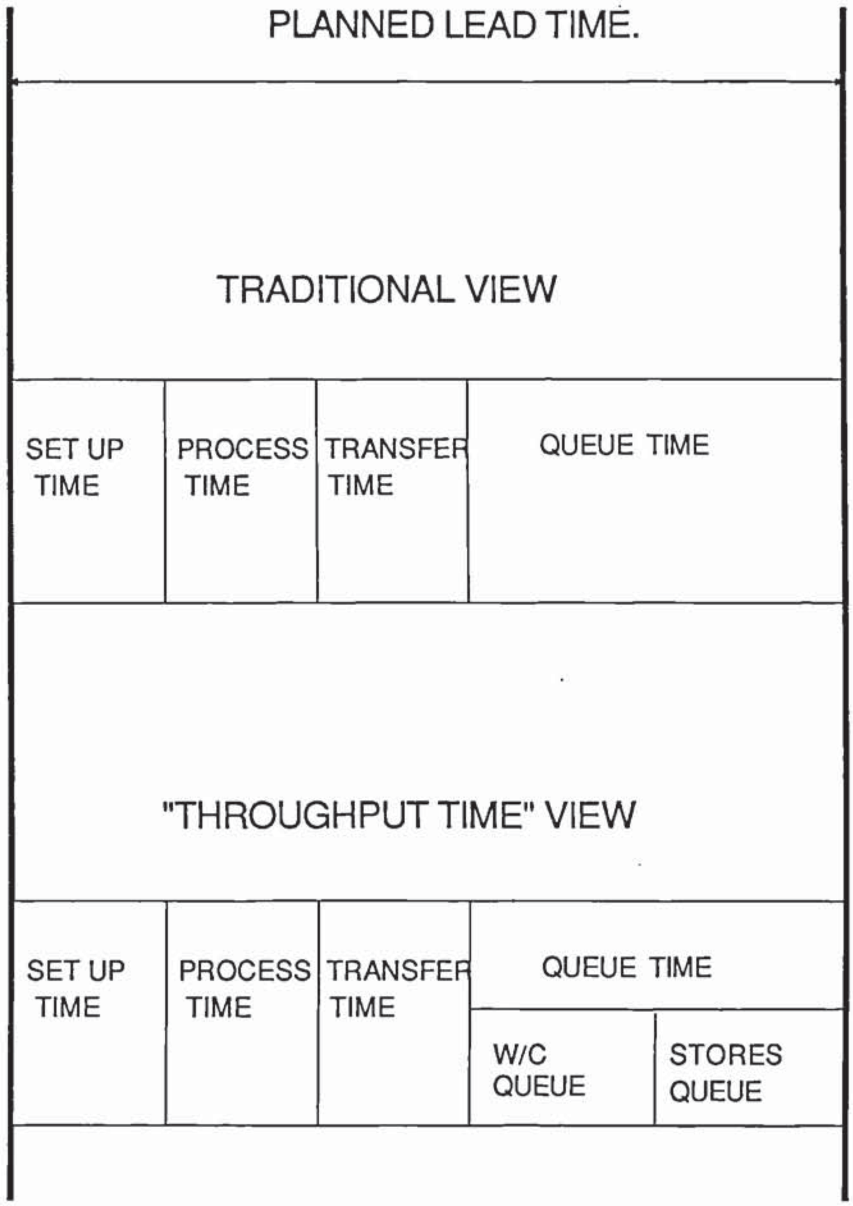


Fig 5. Plossl and Heard's Modified Lead Time Model.

policies, based on a historical view of the organization under consideration. For example, Orlicky (1975, p84) suggests setting lead times for components by means of a formula such as:

$$A = j.n. + k$$

where; A = lead time allowances
n = number of operations
j,k = constants

A number of studies into the relative merits of such policies have been published (eg Conway et al (1967), Kanet (1981) and Baker & Bertrand (1981)). Whilst it was demonstrated that the choice of policy would have a significant effect on shop performance, the view of lead time as an independent variable with respect to other MRP parameters, persisted.

In 1984 Heard and Plossl proposed a modified model of lead time which recognized; set-up, process, transport, and queue time. To these elements they added stores processing time. Figure 5. details this model. Their paper takes issue with the accepted view that up to 95% of lead time is queue time. They suggest that stores queue time forms a significant element, which is compounded by flow time variance resulting in early orders languishing in the stores.

However it will be shown (Chapters 8.9 and 10) that flow time (i.e. the time actually taken to manufacture a batch) is dependent on; lot size, utilization level, process routing etc. and that previously accepted views on these issues have resulted in WIP levels consistent with 95% queue time. It is felt that the addition of stores time to the lead time model is useful only when considering composite lead time. Furthermore, the concept of stores queuing compounded by lead time variance could be something of a dangerous "red herring". It is the author's opinion that the main issue is to re-evaluate flow time and flow time variance in the light of more recent thinking on MRP policies (ie. lot sizing and capacity utilization). Hopefully, this will contribute to a reduction in both flow time and variance, in turn reducing the magnitude of the stores queue issue.

Possibly as a result of the limited research into lead time, a folklore has developed around the subject, most significant in which is the "lead time syndrome". Simply stated, the lead time syndrome was based on the observation that increased lead times begat increased WIP and missed due dates. This in turn encouraged further increases in lead time allowances, triggering an upward spiral in terms of WIP. Added to this folklore, was the feeling that many MRP users were failing to control high levels of variance in actual lead times.

3.3.2 Lead Time Load and Capacity

In 1982 Kanet published what should be regarded as a milestone in the understanding of lead time. Foremost in the many points made was the re-affirmation of the distinction between lead time allowance and flow time (actual time taken), first made by Conway et al in 1967. Using this distinction, it can be seen that, whilst lead time allowance is an independent variable, flow time is heavily dependent on numerous policy and capacity interactions. Kanet uses Little's queuing formula (discussed in Conway et al), to relate WIP to flow time:

$$N = R.F$$

where; N = average number of jobs in the system
R = average rate of order launch (jobs arriving)
F = average flow time

Kanet goes on to discuss flow time. Using the following simple queuing model:

$$F = (1/Or)/(1 - U)$$

where; U = utilization
Or = average rate at which work can be processed

He demonstrates that flow time is heavily dependent on the average utilization of the production shop. Table 4. and Figure 6. represent this function. Kanet notes;

> "This sensitivity of flow time (and thus WIP) to changes in U is often not appreciated by management. Most readers are well aware of the type of pressure that a marketing group can bring to bear on those of us who have to represent manufacturing. This pressure can take the form of requesting additional unplanned production from the manufacturing division. Suppose such a request occurs which causes shop utilization to increase from .9 to .95. This represents only a 5.5% increase in output and when looked at in that light it becomes difficult to argue that such a change would be too difficult to accommodate. However, as shown (in Table 4.) such a change might result in a doubling of flow times and WIP. The question must be asked: is a 5.5% increase in output worth a doubling of inventory? Clearly small changes in utilization can have a dramatic effect on flow times and work in progress inventory."

It is recognized that the validity of using a simple single work centre queuing model to quantify the complex interactions within a production shop, is in the strictest sense, questionable. However, the effects shown are valid for an individual work centre and it is assumed that these effects will, in principle, relate to the dynamic production shop problem. Further work is required to verify the magnitude of this effect in the uncertain environment of the multi-level, multi-work station production facility. This point will be discussed further in the design of experiments.

3.3.3 Lead Time and Lot Size

One of the most powerful and yet misunderstood factors affecting lead time is lot size. It has been demonstrated that the traditionally accepted views on this subject regarding costs and customer service, are invalid and that the non-optimising demand driven rules such as lot for lot and POQ, are now seen to offer significant potential over the predominantly larger lot sizes produced by "optimal" techniques. This section will discuss the effect of lot sizing decisions on queuing and thus, flow time.

It is commonly accepted that queuing time can account for 90% of flow time (Orlicky 1975). If we consider a single work centre, at which work is being processed sequentially and at which a queue has not formed, then the total time spent by the lot at that work centre is:

$$T = n.P + S$$

and the queue time for each component in the lot is:

$$Q = (n - 1).P + S$$

where; T = total time
Q = queue time
n = lot size
P = process time per component
S = set-up time per batch

If set-up time is considered as a multiple (m) of process time, then:

$$Q/T = 1 - 1/(n + m)$$

This function of queue ratio is plotted against batch size in Figure 7. for three values of (m) typified by the following processes employed in the manufacture of PCB's at BT Fulcrum:

m = 0.5 inspection, repair
m = 1 manual insertion
m = 5 semi-automatic insertion and flow solder operation

From Figure 7. it can be seen that at non-queued work centres, significant reductions in the queue element of flow time could be gleaned from the use of small lot sizes. However, it should also be clear that the ideal lot size will vary from process to process. Additionally, any potential reductions in lead time must be viewed in the light of capacity constraints since this relationship does not hold for work centres at which a queue of batches has formed. This further highlights the need for a total view to more fully investigate the determinants of flow time.

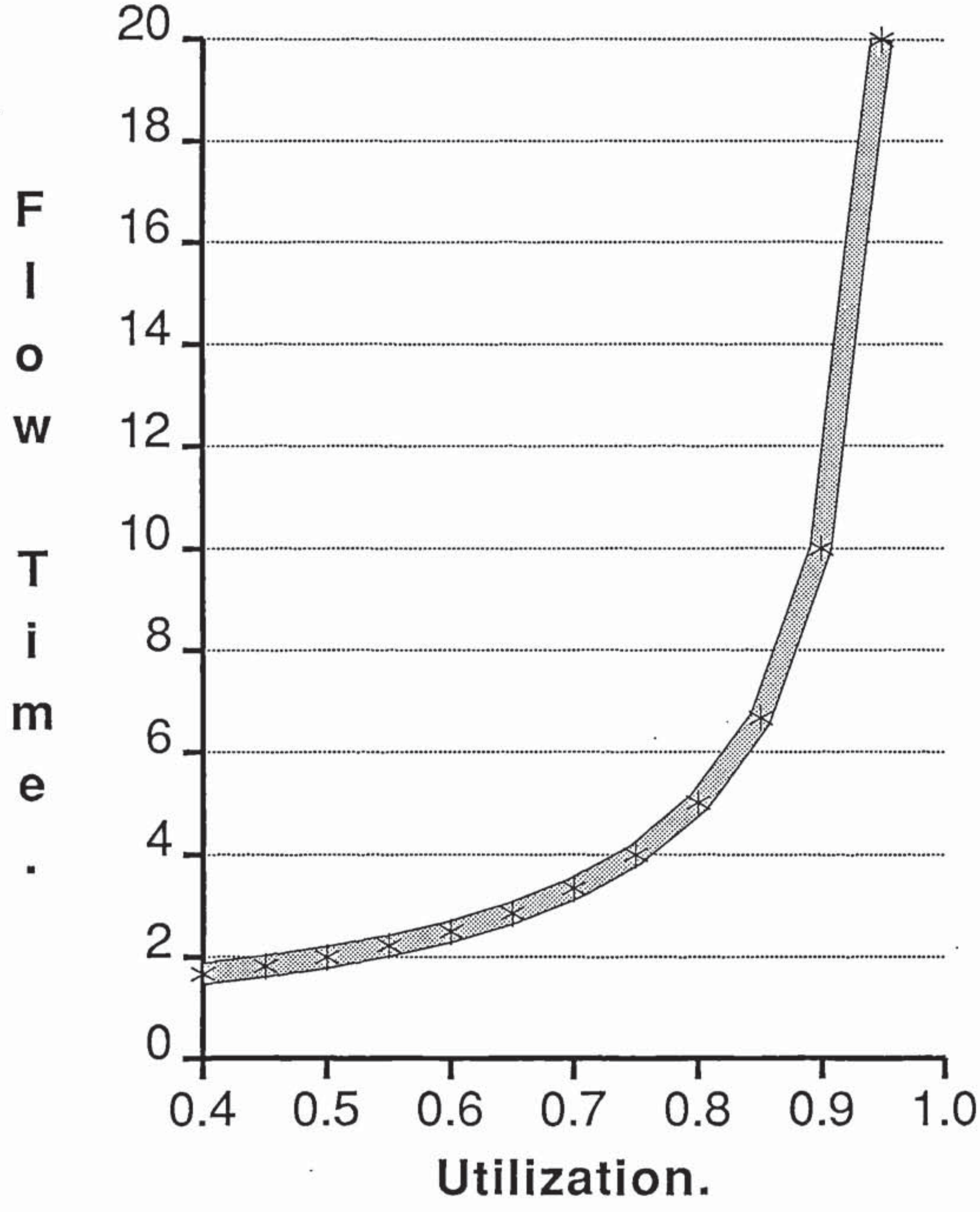
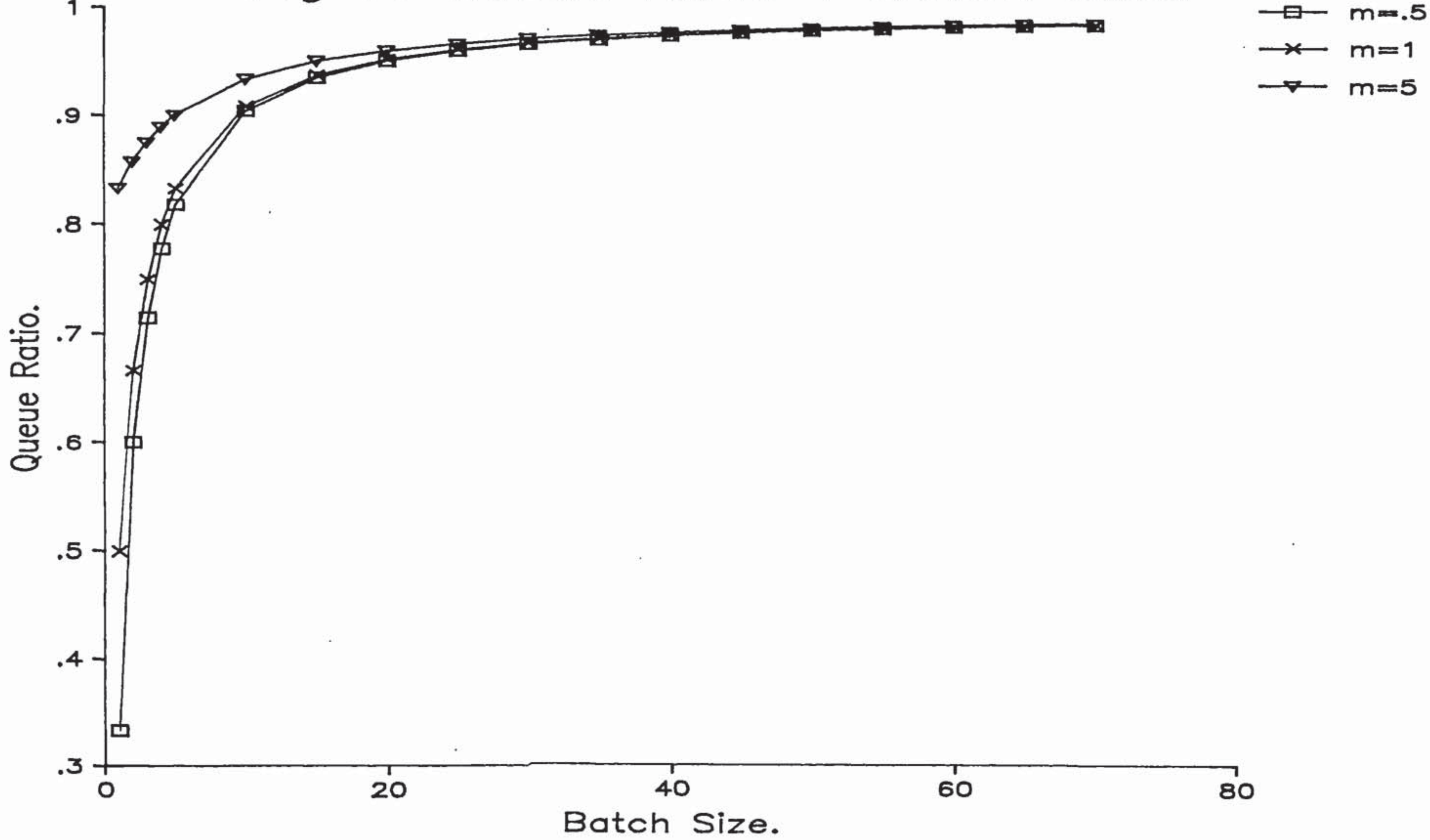


Fig 6. Kanet's Non Dimensional Plot of Utilization and Flow Time.

Fig 7. Queue Ratio v Batch Size.



3.3.4 Lead Time, Lot Size and Bottlenecks

Goldratt (1981) and Fox (1982 and 1983), have introduced the concept of a variable lot size. This builds on the distinction between a process lot size and a transfer lot size. Goldratt adopts a network view of the manufacturing facility and shows that the throughput capacity will always be constrained by one bottleneck at which throughput demand exceeds capacity. The location of the bottleneck will be determined by factors such as product mix and resource management.

Goldratt's philosophy is that at non-bottleneck resources, spare capacity should be used to facilitate small lots and thus reduce flow time. Whereas the capacity of the bottleneck resource should be maximized by reducing (wherever possible) the number of sets (eg. by combining small batches of the same type). In the situation where the bottleneck is toward the end of the operation sequence, this process is straightforward; a queue will naturally form at the bottleneck from which batches can be combined. There is a potential problem with this in that an upper limit will need to be set. It is suggested that an analysis of set to process time ratio (such as detailed above) would allow the determination of transfer lot size (for non-bottlenecks) and maximum process lot size (for bottlenecks).

Goldratt extends his arguments to scheduling, where a mathematical programming technique replaces the MRP logic. Schedules are produced to optimize the throughput of the bottleneck resource using a proprietary goal function.

This system is marketed by Creative Output under the name OPT (Optimised Production Technology) and has been reviewed by Barekat (1986) and Fox (1982 and 1983).

Whilst OPT is marketed as an alternative to MRP II, many of the concepts embodied within it are perfectly compatible with more modern thinking on policy decisions, the key elements of which have been outlined in the preceding sections. It is therefore proposed to examine the usefulness of those elements which are compatible with MRP, in particular lot splitting/combination, in this work.

3.4 Safety Stock/Safety Lead Time Policies

The inevitable variances in due date performance, whether resulting from forecast error, capacity bottlenecks or even process failure, will often result in a reduced customer service level. Two alternative techniques have been commonly applied to reduce this problem.

The first is to hold safety stock at all or some of the following levels; raw material, manufactured parts, sub assembly, or finished goods. Numerous strategies for determining safety stocks, have been proposed. It has been suggested that safety stock should be held at the point of minimum diversity. For example, company A. produces a multiplicity of products from a limited number of raw materials; hence it would be proposed that safety stock is confined to raw material. Company B. however, produces a multiplicity of products from a multiplicity of raw material, but with a small number of modular sub-assemblies. In this case it would be proposed that stock would be held at the sub-assembly level.

One problem with this philosophy is that it ignores the relationship between customer lead time and composite lead time. Figure 8. compares customer lead times with manufacturing lead times for companies A and B. In both cases it can be seen that the operating scenarios are such that safety stocks at the point of minimum diversity would not ensure a 100% service level. Obviously both cases have been selected to highlight this point, but it can be seen that the operating scenario does have significant effect on the choice of stock policy.

Significantly Wemmerlov (1979) reported widespread skepticism towards safety stocks and noted that several companies, in his limited survey,

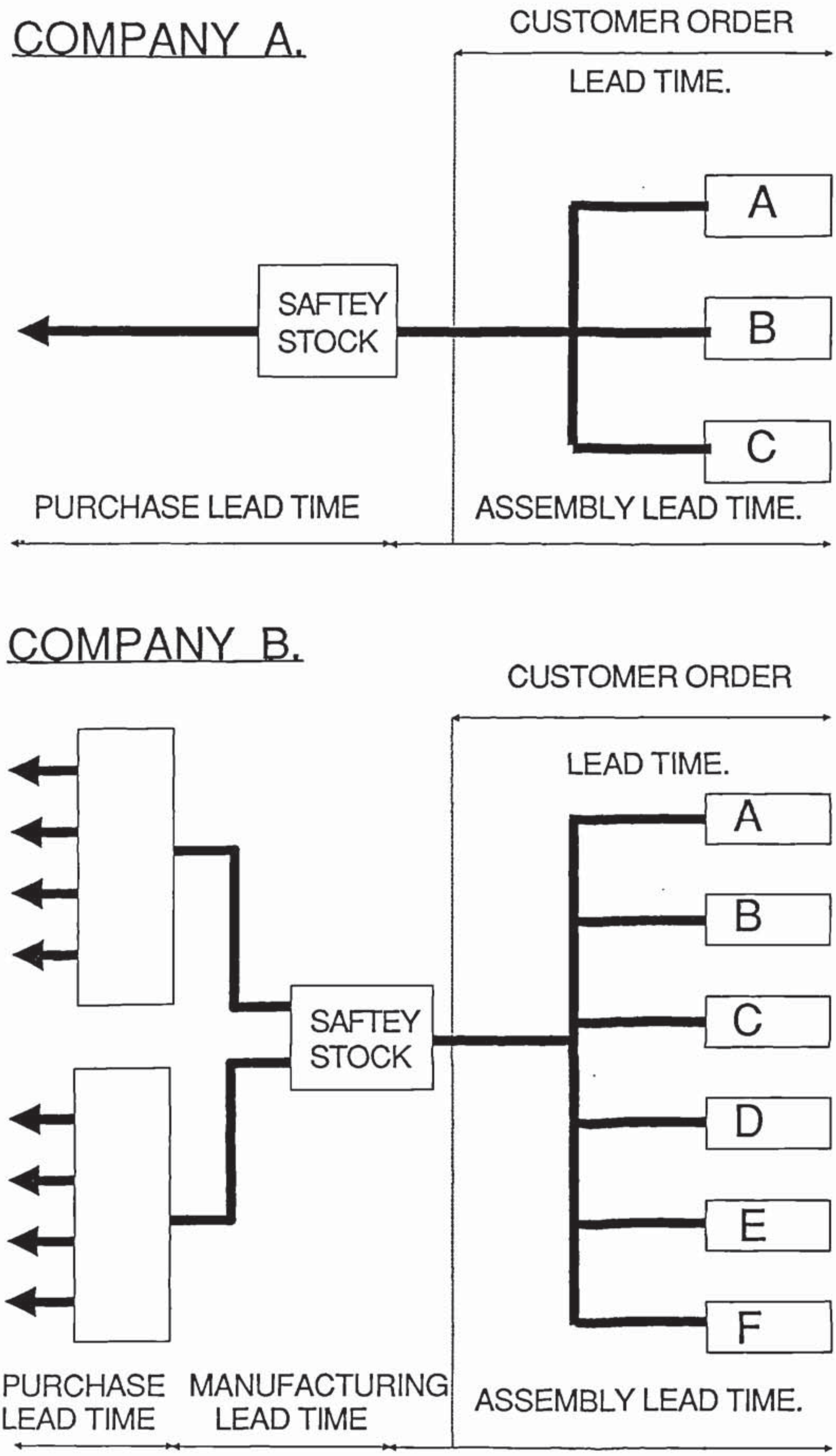


Fig 8. Saftey Stock, Customer Lead Time And Composite Lead Time.

aimed at reducing or eliminating them. One argument against their use, was the distortion of priorities and the consumption of capacity by replenishment orders.

Another argument recognizes the pressure within manufacture to maintain equipment and labour utilization at arbitrarily high levels (ironic in view of the harmful effects on WIP and lead time outlined by Kanet (1984)). The result of these can be to "produce to stock" during periods of low activity. The author has observed one particular company sustain an operating loss of $300M whilst operating to this principle in an environment of engineering and market change.

Minifie and Heard discuss a secondary effect of safety stock policies, that is, as a damping function on the order variability of the product level stocked. However they noted that this has not been effectively researched and is not therefore fully understood.

Safety lead times can offer an alternative to safety stocks as a means of increasing customer service level. However, there is much confusion in this area. For example, a distinction must be drawn between safety lead time and safety due date. Although this distinction may at first glance, appear pedantic, the two have different effects on many popular priority rules. For example, safety lead time results in an order being launched early, but the due date would not change. If the popular "least slack per op" rule was in operation, performance to due date would not be enhanced by launching early. However, adoption of a due date offset (safety due date) would not affect the priority rule and an improvement in due date performance could be expected.

A common problem with both these approaches is that lead time increases will invariably lead to an increased exposure to MPS uncertainty. This in turn is likely to increase the level of order variability. Whether this is sufficient to negate the advantages of safety lead time/due date, will depend on the relative strength of the two effects.

It is the author's opinion that the priority for MRP implementors should be to determine the natural level of nervousness using more modern thinking on lot size, utilization of capacity and lead time as primary attenuators. Investments in stock or WIP through safety stock or lead time increases should only be made when these costs can be set against demonstrable savings through increased customer service and the marginal cost saved through reduced order processing.

3.5 MRP Policies and Parameters: A Summary

The traditional approach to MRP policies and the attendant deficiencies of such an approach, provide a valuable insight into the reported problems of; poor stock turn, long delivery lead times, low customer service level and system nervousness.

Most of the previously accepted views on policy design have been shown to be invalid for one or more of the following reasons:

Demand uncertainty, primarily in the MPS has been ignored by successive researchers.

Policy interactions within and between the various BOM levels have also been ignored.

Invalid cost bases have also used by comparative studies.

Recent work suggests that the stock turn problems have been caused by the use of "optimal" or "economic" lot sizing. These techniques have been shown to be limited by the assumptions required for validity and to be inappropriate to the majority of industrial environments.

The above point in conjunction with old thinking on lead time, capacity and utilization, has resulted in long composite lead times. Recent work on this topic has also provided an insight into poor customer service.

Examples of the numerous and complex interactions between MRP policies, includes the following; system nervousness is determined by lot size policy and MPS uncertainty, MPS uncertainty is determined by the relationship between composite lead time and customer lead time, and composite lead time is in turn affected by lot size policy. Additionally, a potential amplification mechanism exists which generates a push toward ever increasing WIP, flow time and system nervousness.

Further work is required to quantify the constituents and effects of the above mechanisms. Taking due cognizance of this, it is argued that MRP research must be conducted in an environment which does not include the above deficiencies. Consequently, work in this area must allow for interactions and uncertainty and must judge system performance from a realistic stand point.

4. THE AMT BASED MANUFACTURING FACILITY

4.1 Introduction and Business Environment

There has been continuous and significant progress in manufacturing knowledge throughout this century. However, this development has undergone many changes of direction. The first three decades saw significant advances in management and organisational techniques. This era was characterized by the emergence of mass production, made possible by the principles of scientific management, pioneered by F W Taylor and used to great effect by Ford, Carnegie, etc.

The following three decades witnessed some further refinement of these principles. However, the most significant advances were in the area of process technology. Within the metal cutting industries, our understanding of the metal removal processes resulted in the continual emergence of new tool materials. The most significant of which were the "High Speed Steel" (HSS), Carbide, ceramic (eg. CYALON) and crystalline (eg. Cubic Boron Nitride) groups. These combined with the metallurgical advances in stock materials to produce both new groups of machinable materials and dramatic improvements in removal rates. The metal forming industries (pressing, forging, stamping, etc.) achieved similar improvements and produced ever larger pressings with deeper drawn sections. Towards the end of this period emerged the new industries of plastics and electronics. The plastics industry again witnessed an explosion of material types and a steady reduction in unit cycle times.

The electronics industry was somewhat different in that the most significant advances were related to miniaturisation. Photo-reduction and masking combined with semiconductor technology, the printed circuit board (PCB) mounted transistor, and ultimately the microchip. This enabled the production of smaller and cheaper analogues of older electrical products such as TV's, and radios etc. However, more significantly it facilitated the production of low cost logic circuits.

The subsequent computer revolution requires little explanation.

One consequence of the emergent electronics industry, was the possibility of greater control of manufacturing processes. Initially, applications complemented and then replaced mechanical and pneumatic automation systems (eg. first generation Numeric Control (NC) machine tools.) By the start of the 1970's, the advances in process technology discussed above had been combined with early NC systems to produce dramatic reductions in cycle times. This dovetailed neatly with the requirements of the business needs and philosophy of the time; the Corporate Planning approach assumed long production runs with limited product ranges. By the early 1970's it was argued that most of the potential improvements in unit cycle times had been achieved.

At this time, the effects of a number of earlier, long wave economic cycles, became apparent in a dramatic shift in manufacturing business needs. Chapter 2. discussed this in relation to production control. The major characteristics were; a significant increase in the cost of capital, a demand for increased product variety, a demand for shorter delivery periods, reduced product life cycles and intense international competition.

Within the manufacturing facility these pressures produced the following effects; a tendency toward smaller batches and more frequent set-ups, shorter lead time allowances, and an increase in the variety of parts on the shop-floor. Unfortunately, these changes occurred at the time when production facilities were optimised for a more stable environment. One consequence of this was that the benefits of short unit cycle times were often negated by the work centre input queues resulting from repeated set-ups. By the late 1970's, it was typically estimated that less than 20% of manufacturing throughput time was accounted for by the sum of process times, the remainder being comprised of inter work centre queuing, transport time etc. This was discussed at length in Chapter 3. At this time it was argued that advances in Manufacturing Technology (along traditional lines) would have little impact on a manufacturing companies' performance.

4.2 A New Direction For Advanced Manufacturing Technology

By this time the initial applications of electronics to the manufacturing process had been supplemented by later generation equipment of considerably enhanced capability. Developments were many, varied and often crossed functional boundaries. Such equipment became grouped under the generic title of Advanced Manufacturing Technology (AMT), the production aspects of which can be sub-divided into four main groups; process, inspection, work handling and integrated control.

Developments in process technology resulted in Computer Numerical Control (CNC) and Direct Numeric Control (DNC), multi-purpose work centres. Primarily intended for the metal cutting industries, these would typically combine the functions of a lathe, mill and grinding machines. Numeric control of multiple axes would be employed to facilitate the machining of three dimensional surfaces and the combination of multiple operations. DNC machines have the further capability of remote loading of the control programmes and current status feedback.

The electronics manufacturing industries saw the introduction of CNC and DNC component insertion machines such as Dual In-line Package (DIP) Insertion Machines with similar capabilities.

Developments in spatial, tactile and vision control technologies, led to the emergence of sophisticated automated inspection equipment, such as multi axis co-ordinate measuring machines. The main use of which is the automated dimensional inspection of complex individual components or entire batches of simple components. Such equipment gained extensive use in the aerospace and automotive industries. Other developments within this group include the use of vision systems for measurement of surface quality (eg. paint defects) and functional testing of electronic circuits by computer analogies of circuit input/output environments.

The work handling group is less well defined in that one of its principal members, the Industrial Robot, is used both for work handling and processing. However, both this and its cousin, the Automated Guided Vehicle (AGV), offer considerable potential in the field of work handling. Other related developments include "smart conveyers" and component picking systems.

The final group is possibly the most recent and least developed but is poised to create the greatest impact. The Integrated Control Group provides the capability of linking and co-ordinating the previous three groups and has developed out of the advances made with DNC work centres. With the advent of remote NC part programming and DNC, there arose the need to download NC programmes in a machine readable form from a centralized electronic store. Early systems would typically use a single mini computer to hold and transmit NC part programmes for a group of machine tools. The Digital Equipment Corporation (DEC) PDP series became a near industry standard for such applications. Further developments culminated in fully computerised supervision of the shop floor, using equipment such as bar code readers, to log work movements. Manufacturing facilities combining the above three elements with integrated control became known as Flexible Manufacturing Systems (FMS).

The business pressures of the mid 1970's were such that the 80% slack time (discussed in Chapter 3.) became the target for manufacturing managers. It was anticipated that the major components of this costly element (transport, queue and set time) could be significantly reduced by the application of AMT to reduce set times, control work movements and reduce labour costs. Internationally, many "leading edge" companies embarked upon FMS projects, with encouragement and backing from central governments.

Although many projects were widely publicised (often as part of the Corporate Marketing Strategy), such endeavors are commercially sensitive and have received very little rigorous academic examination. However, reviews are available on some notable projects, eg Lucas Girling Ltd (1985).

4.3 Characteristics of an AMT Facility

The characteristics of an AMT based facility include; a reduced labour requirement, greatly reduced operation set-up and process times, precise tracing of WIP and control of its movement, and low WIP levels. The first three of the above contribute to business performance by a reduction in direct costs.

However, a major and challenging consequence of this technology is the possibility of controlling all shopfloor work piece movements. Subsequent reductions in WIP levels are facilitated by; the smaller batches made possible by shorter set-up times, and the considerable scope for the use of improved scheduling and sequencing rules. Thus exercising more appropriate control over when particular jobs are started, expedited or delayed.

In mechanical terms the AMT based facility could be classified as one of low inertia. The flexibility afforded by the control of work movements and shorter production runs, resulted in improved response to changes of input (production plan).

4.4 Operational Policies Relating to AMT

It can be seen from the above that a number of policy design issues are raised in the context of controlled work movement. The performance of an AMT based facility would be affected by choices regarding:

batch size rules
scheduling and sequencing rules

The first of these concerns the design of an "efficient" batch quantity, recognizing the low inertia characteristics of the shop. If it is accepted that AMT would reach "leading edge" companies first, then it is likely that the production plans for the AMT facility would be generated by an MRP system. This policy is therefore inextricably linked to the order policy decision relating to the feeder MRP system. This was discussed at some length in Chapters 2. and 3.; the only addition to these arguments being that due account should be made of the shorter set-up times associated with AMT.

The second of the policy areas can be subdivided into two main categories; priority or sequencing rules, and shop scheduling rules. Priority rules operate at work centre level and allow decisions to be made when there is competition for a single resource. There has been considerable research into this general area and numerous rules have been suggested, including Least Slack (LS), Least Slack Per Operation Remaining (LS/OR), Earliest Due Date First (EDD), LIFO and FIFO. For example, Dar-El & R A Wysk (1980) evaluated six rules against various combinations of shop environment (referring to Panwalker et al (1977), Rochette (1975), and others). Their work centres on a simulation of the manufacturing shop driven by a stochastic order generator. The scope of their results is limited by the assumption of deterministic top level demand (ie. order uncertainty is ignored). Pegels & Naryan (1976) include an evaluation of modifications to the Critical Ratio rule (similar to least slack) in their work, using similar assumptions and order generation.

Shop scheduling rules operate at the shop or facility level and seek to determine optimal loading sequences for each work centre. Several mathematical programming techniques, such as Mixed Integer Programming (MIP) have been used to determine these sequences. Choobineh (1984) reviews the most significant and presents a mixed integer programming (MIP) solution to the determination of product mix within a period. One limiting problem with such techniques is their instability at significant levels of uncertainty (Crabtree 1986).

It is the author's contention that the performance of a priority or scheduling rule will be greatly influenced by the nature of the orders produced by the feeding system. This is consistent with the findings of Harl & Ritzman (1985). Therefore such decisions must be viewed in the context of the complete system of influences. This will be discussed in greater detail in Chapter 5.

4.5 AMT's Disappointing Performance

A consequence of the commercially sensitive nature of AMT projects, is the difficulty of rigorously examining their cost performance. Whilst many projects were considered to be technical successes, by the mid 1980's concern as to their commercial worth was being discreetly raised by practitioners.

In 1984 Ingersoll Engineers confirmed their worst fears by publishing a damning appraisal of AMT projects. Numerous instances of commercially dubious applications of AMT were cited. A number of reasons were suggested including; inappropriate cost justifications, poor consideration of the effects of automating single elements of the total facility and too great an emphasis on the "zero operator" shop floor. Ingersoll described the contemporary applications of AMT as "islands of automation" with higher levels of integration hindered by the lack of standards for network communications.

Without exception these arguments point to the lack of a system view of AMT. Workers such as Hill (1983), Skinner (1969) and Ward (1987) had recognized the strategic nature of AMT investments on the grounds of total costs and their potential positive contribution to the business. However, requirements for systems were often distorted by short term business pressures and failings in other seemingly unrelated and more traditional areas of the business. For example, standard costing systems make a distinction between direct and indirect operations. However, the development of special finishing processes, novel machining processes and inspection requirements, lead to a number of arbitrary and inappropriate definitions. The consequence was a tendency to concentrate AMT investment in those areas defined as direct, where potential savings in standard hours were readily calculable. This resulted in bottlenecks in areas where old ways remained. Attempts to cure long term and deep rooted industrial ills with an "injection of technology" were proving misguided.

4.6 Summary

The emergence of AMT has been shown to offer some significant tools with which to address the problems of the contemporary manufacturing environment. In particular, the advantages afforded by short cycle times, short set times and shop-floor control have the potential to significantly reduce the "inertia" of the manufacturing facilities.

It is probable that the disappointing performance of many AMT projects is related to a myopic view of the bounds of their design and operation.

Many of the issues relating to AMT operational policy design are seen to be inextricably linked to policy decisions at the production control and MPS level. Therefore, the holistic approach to policy design proposed for the MRP element must be extended to the manufacturing facility. In addition, recent thinking on work flow (including concepts such as throughput and bottlenecks) and an understanding of the correct role of utilization and other measures of performance must be applied to policy design in this area. This will be discussed in detail in Chapter 5.

5. A MANUFACTURING SYSTEM VIEW OF POLICY DESIGN

5.1 Introduction

Chapters 2., 3. and 4. have examined two key elements of the manufacturing system. These are production control and the manufacturing facility. It has been shown that both MRP and AMT have not as yet achieved their full potential. Furthermore, decisions regarding operational policies have been shown to be in need of further development with many deficiencies in the body of knowledge being evident. Support for this argument can be found in the works of Minifie and Heard (1985);

> "Previous research projects have established the effects of a limited number of performance measures in highly simplistic environments. In general, these experiments were carried out in simulated environments barely rich enough in realism to permit the manipulation of the experimental variables. Other policy variables were effectively held constant in that multiple values for them were not allowed. Consequently, some powerful interactions between various policy variables may have been overlooked. The conclusions of previous research are also open to question with respect to the richness of simulated environment, the set of policy variables studied, and the performance measures used".

In Chapters 3. and 4. it was argued that the reported poor performance of MRP and AMT was due to a traditionally myopic view of policy design, system boundaries and performance measures. This hypothesis will now be extended to the complete manufacturing system. It is argued that a coherent view of the role and design of operational policies in the context of the complete system, is a prerequisite to successful integration of the various elements.

5.2 The Total System and Policy Interactions

Figure 9. depicts three mutually supportive productive elements of a manufacturing business; the market, manufacturing control and supply.

Each element participates in an interactive chain of demands and responses, inputs and outputs.

The market provides an input to the MRP system in the form of the MPS. This is translated into time phased demands on the supply elements (production shop and suppliers) by MRP processing. The production and purchase schedules so produced are then actioned by the two supply elements, with closed orders ultimately resulting in supplies to the customer.

Within this system there are three prime levels at which policy decisions are of interest to this work:

Market: Forecast, Horizon, Order Aggregating, Review Period, etc
MRP: Horizon, Order Policy, Stock Policy, Lead Time, etc
Supply: Stock, Priority, batch size, resource utilization, etc

At the market level, policy decisions determine the manner in which customer demand (both perceived and actual) is translated into the Master Production Schedule in terms of size, timing and certainty.

At the MRP level policy decisions have a similar effect on the production and purchase plans produced, again determining size, timing and certainty.

The characteristics of the production plan, measured in the same terms, will affect the ability of the supply elements (eg. the production shop) to achieve the planned requirements.

The performance of the supply elements will also be influenced by the policies applied at that level, which will in turn affect the stock levels at the next higher level. This will influence the next MRP run and ultimately the supply of saleable items.

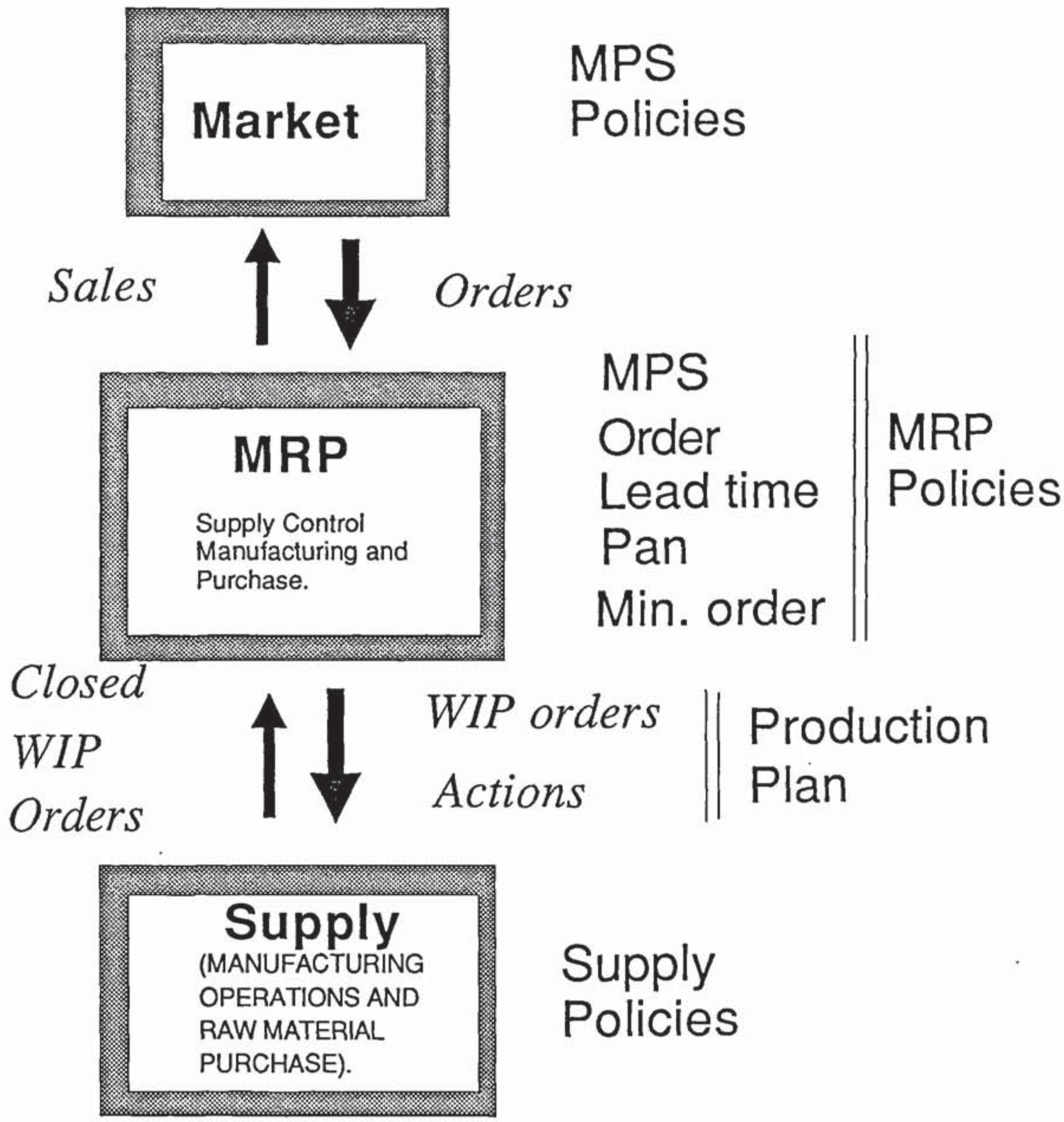


Fig 9. A Three Element Model Of The Manufacturing System.

It can be seen that in the context of the total system, policies form an interlinked chain, the design of which will have an effect on the performance of a manufacturing business. One of the fundamental assumptions of this work is that these effects are significant and determinable. Minifie & Heard (1985) note;

> "MRP system performance is quite sensitive to operating policy choices. While this sensitivity has been somewhat appreciated previously, little attention has been directed toward the potential interactions of the various policies among themselves and with specific environments."

A useful analogy can be drawn between an integrated manufacturing system and an automotive engine management system. Modern car engine management systems can (by varying; ignition timing, fuel injection and gearing) make the same mechanical components perform as a fuel efficient family car, or as a high performance sports car. The control functions used to vary the timing etc. are analogous to the control policies/parameters in a manufacturing system. For example, it is hypothesized that judicious use of these could alter the characteristics of a manufacturing facility from; high WIP, high utilization, and slow response, to; low WIP, moderate utilization, and quick response.

Consequently, an understanding of policy design is required which must extend beyond the boundaries of sub-systems (Market, MRP, FMS etc) to encompass all the key elements and must be directed by the needs of the business. Furthermore, such a view must be capable of reconciling the interactions between policies both within and between the various levels at which they are applied.

5.3 Some General Requirements for Policy Design

5.3.1 A New Approach to Policy Evaluation

Any research in this area needs to reconcile the almost limitless permutations of policies, resulting from the large number of policy levels and the diversity of choice at each. It is probable that a departure from the traditional research methodology will be required.

The contemporary approach to policy research, outlined in the preceding chapters, is to adopt a semi-naive view, in which large numbers of specimen policies are tested at a limited number of levels. If the arguments regarding policy interactions and the subsequent need for a system view are accepted, the naive approach would necessitate the evaluation of large numbers of policies at all levels. Such an approach is advantageous where little is known about the true nature of the system under investigation and it is important not to overlook a high performing combination.

It will be argued that some of the primary interactions within a manufacturing system can be understood if researchers are prepared to adopt a system view and discard inappropriate assumptions. It has been shown that a considerable number of previously recommended policies are limited in their applicability because of the simplifying assumptions underpinning them. Policies valid in the environment of demand uncertainty have been shown to be less numerous and do not include such notable benchmarks as the Wagner Whitin order policy.

Consequently, it is proposed that a more structured approach be adopted, which exploits relevant knowledge to focus the research effort.

5.3.2 Policy Design Environment

Accepting the argument that the choice of control policies will influence the performance of the total system (automotive analogy), then appropriate performance objectives must be defined. Ultimately, the performance of any manufacturing system must match the demands of the market place. In today's environment, a significant portion of manufacturing markets can be characterized by; short delivery times, uncertainty of demand and diversity of product specification. The environment in which these markets exist is characterized by; the high cost of capital, low inflation and intense international competition.

The contemporary view of policy design recognizes potential mismatches between the performance of the manufacturing facility and the demand of the marketplace. Policy design usually assumes the following:

1. It is assumed that the manufacturing facility is incapable of reacting to the uncertainty of the marketplace.

2. It is assumed that the facility must be shielded from raw market forces.

Consequently, the MRP and supply elements are de-coupled from the marketplace, usually by a combination of MPS and finished goods stock policies. Following this, MRP and supply policies are specified against local constraints and locally defined optimums. For example, smooth production plans are generated using "optimising" order policies. Attempts are then made to balance load against capacity at arbitrarily high utilization levels.

Any process which seeks to de-couple the market from the producing elements must result in the use of additional safety inventory. This can take the form of stock or WIP resulting from safety stock or safety lead time policies. The level of excess inventory will be related to the level of market uncertainty and the mismatch between customer delivery times and composite lead time. This excess inventory will then be subject to redundancy resulting from the market uncertainty from which it is shielding the supply elements. The level of redundancy will be proportional to market uncertainty.

It is interesting to note that it is the higher levels of market uncertainty present in the 1980s which has exposed the fundamental weakness of this approach. Over the last decade the changes in business environment have generated new pressures within manufacturing companies. WIP and stock has ceased to be an asset, purchased at low interest, with tax concessions and increasing in value with inflation. In real terms WIP and stock are seen as a liability, purchased with high interest loans, with little prospect of revaluation and subject to the risk of redundancy (high market uncertainty and change). Corporate strategies have abounded with adjectives such as "lean" and "fit" with respect to manufacturing. Consequently, the favoured performance characteristics of manufacturing companies include; low WIP, high stock turn and short cumulative lead times. In addition, manufacturing system designers seek to provide systems capable of producing several different product lines simultaneously.

5.3.3 Underpinning Policy Design

The characteristics outlined above, with the exception of the latter, have been closely associated with the Just In Time (JIT) philosophy pioneered in Japan. JIT has become synonymous with one enabling technique known as Kanban. This is a pull and replenishment based scheduling system using cards to signal replenishment orders. Discussions of JIT & Kanban can be found in Ingersoll Eng (1984), William (1985), Fox (1982). Manden (1981), Schrorer et al (1985) and many others.

JIT appears to suffer a similar identity crisis to MRP with persistent confusion as to whether each is a philosophy or technique. The author contends that unlike MRP, JIT is essentially a philosophy. Furthermore, it has been argued by Barekat (1986) and Belt (1985) that the central philosophy of JIT (make only what is required when it is required) has broader applicability than the Kanban technique. It will be assumed that with careful attention to policy design, MRP & AMT can be both successfully integrated and given the performance characteristics of JIT. This would also overcome an accepted limitation of the Kanban technique, the inability to cope with high variety production.

In seeking to design policies commensurate with the JIT philosophy, the flow of work and information within the manufacturing system becomes an important consideration. If WIP and stock levels are to remain low and customer demand is to be serviced, then work and information must flow efficiently within and between the elements of the system. In particular, it is considered that the low inertia characteristics of AMT need to be exploited to the full, such that the short flow times minimize the exposure to MPS uncertainty.

Goldratt (1981) and (1984) has researched the subject of work flow in some detail. This was partly discussed in Chapter 3. with reference to; OPT, capacity bottlenecks and batch splitting. Goldratt has restated the goal of manufacturing businesses: "to make money" (measured in Return on Investment (ROI)). He defines the financial measures used by a manufacturing concern as follows:

Net Profit (NP)- Absolute measure of how much money was made.
Return on Investment (ROI)- Relative measure of how much money was made against the level of investment.
Cash Flow (CF)- Absolute measure of liquidity.
Throughput - The rate at which money is made by selling products.
Inventory - The investment in purchased items not yet sold.
Operating Expense - The money spent in converting inventory into throughput.

Using these definitions he argues that the manufacturing goal becomes "to simultaneously increase throughput, while decreasing inventory and operating expense."

The traditional approach to policy design assumes that the optimum performance of the system can be achieved by optimising the constituent sub-systems. Goldratt disputes this and maintains that optimal system performance can only be achieved through a total system view and that the sum of the local optimums is not equal to the global optimum.

Against these points he has established nine rules which underpin throughput:

1. Flow (not capacity) must be balanced.
2. The level of utilization of a non bottleneck is not determined by its own potential but by some other constraint in the system.
3. Utilization and activation of a resource are not synonymous.
4. An hour lost at a bottleneck is an hour lost to the whole system.
5. An hour saved at a non bottleneck is a mirage.
6. Bottlenecks govern both throughput and inventories.
7. The transfer batch may not and often should not equal the process batch.
8. The process batch should be variable and not fixed.
9. Schedules should be established by looking at all of the constraints simultaneously. Lead times are the result of a schedule and cannot be predetermined.

In Chapter 2. it was shown that MRP policy decisions must be supportive of the underlying assumptions. This argument may now be extended to the other elements and formalized in the following rules:

1. Policy decisions at each level must support the assumptions underpinning the whole system.

2. Policy decisions at each level must support the business requirements in which the system must operate.

The two sets of rules outlined above will now be combined to form a framework around which a policy design methodology will be proposed.

5.4 A Policy Design Methodology

It is probable that policy design will often take place in an environment where the major decisions on production control systems and manufacturing facilities have already been made (since the importance of policy design in determining system performance is not generally recognized). It is this situation in particular that will be addressed by this work.

In defining the following policy design methodology it will be assumed that something is known about the marketplace in which the manufacturing company is to operate, the product ranges, the manufacturing hardware, and the production control system. It is accepted that the following methodology could require modification in the true "greenfield" situation. Such a case could form the basis for further work. The proposed methodology will have three stages:

Stage I will determine the basic performance characteristics of the separate elements of the total system. This will include an analysis of the marketplace and the capabilities of the supply elements. In addition, control policies will be grouped by element.

Stage II will be used to derive core policies commensurate with the minimum WIP and lead time condition. It is expected that this will reduce the likelihood of deficiencies between the market and the supply element characteristics and reduce exposure to market uncertainty. This stage will concentrate on deriving flow based policies and will include concepts introduced by Goldratt and JIT.

Stage III will then address any remaining mismatches in system performance. This will include the development of safety policies where necessary and as such will represent a limited departure from the JIT philosophy. It is probable that of the three manufacturing elements discussed above, the production control element would be the most configurable. Therefore, the basis of this stage will be to use the production control policies to reconcile any of the deficiencies outlined above.

These three stages should follow the following basic steps:
Stage I

1. Isolate those policies which must be determined to enable the system to operate. These

should include MPS horizon, lead time offsets, order policy, stock policy, and priority rule. Individual systems will also require a number of housekeeping policies which are necessary to maintain MRP logic. These do not directly affect the nature of the production plans produced and therefore will not be included in this analysis.

2. Group these policies by manufacturing elements. Those policies which determine the structure of the MPS will be categorized as the market group. Those which determine the manner in which the MPS is translated into the production plan fall into the production control group. Finally, those which primarily affect the supply group (apart from the production plan itself) will be grouped as such.

3. Define and characterize the demand from the marketplace in which the system is to operate.

4. Determine the behavioral characteristics of the supply elements. It is necessary to gain an approximate understanding of levels of WIP, flow times, sensitivity to mean batch size, capacity constraints etc.

Stage II

1. Formulate supply group policies most able to achieve throughput (and thus short flow times), recognizing and allowing for the presence of bottlenecks in the system. Goldratt's rules 1-8 are particularly relevant to this.

2. Expose the supply elements to the natural order environment of the marketplace (in terms of size, timing and uncertainty). This can be achieved by removing any batching or optimising policies in the market and production control elements (eg order policy, safety stock, production plan smoothing, etc.).

3. Re-establish production flow times as a result of these policies and reset the lead time policies in the MRP system. If full advantage has been taken of AMT's low inertia capability in step 2, then exposure to market uncertainty should have been minimized. Changes in lead time policy will affect the phasing of the production plan and thus its characteristics in terms of smoothness, timing and certainty. Therefore, these effects must be taken into consideration.

Stage III

1. Evaluate any mismatches between the performance characteristics of the production control and supply elements, and the marketplace.

2. Formulate safety stock and/or safety lead time policies to overcome any deficiencies.

3. Re-evaluate the performance of the total system with these policies in place and iterate as necessary.

5.5 The Need for a Total System Model

The above methodology requires a number of active evaluations of system performance. It is argued that an analysis of all the key influences on the manufacturing system (market, production control and manufacturing facility) is beyond the scope of a purely theoretical or mathematical analysis. This is because the assumptions required to make such an approach workable, would severely limit the applicability of the results. Chapter 3. has documented the failure of numerous respectable mathematical modelling techniques to adequately address a single policy decision in only one element of the total system (ie. batch size in MRP). Consequently, taking due cognizance of the limits of current knowledge, an experimental facility (eg. a model) is considered a mandatory requirement for research in this area.

There are a considerable number of possible approaches to this problem and a variety of techniques are available eg, simulation (discrete and continuous), critical path analysis, queue theory etc. Gooden (1988) produced a detailed appraisal of these and recommends the use of a hybrid model, using separate techniques appropriate to each of the three elements (market, production control and supply).

Support for such an approach can be found in the reported literature. Minifie & Heard investigated the effects of policy interactions at a number of levels within a manufacturing business using a hybrid model as the basis of study. A fully functioning MRP model was used to drive a factory simulator FACTORY (a description of FACTORY can be found in Melnyk 1980). The model included three levels of parts (purchased, manufactured and finished). It is notable for the inclusion of demand uncertainty in the MPS and the inclusion of all three elements.

A multi-variate analysis of variance (MANOVA) technique was used to establish sensitivity of rescheduling to the policy interactions between and within the various levels. In discussing the results they noted;

> "The presence of highly significant interactions casts doubts on previous research conclusions based on much more limited environments."

It must be noted that the model used by Minifie and Heard was limited in its capability to model production hardware oriented interactions (capacity, product mix, routing etc.) by virtue of the fact that actual lead time (flow time) was distribution driven. It is considered that this weakness limits the applicability of this model for policy design in the context of the total system.

Gooden (1988) has noted that imbalance in the capability of model elements is a general feature of many reported experimental facilities. Typically, those models which have addressed the total system have adopted one of the following routes. Models utilizing sophisticated production control elements have been linked to simplistic supply and/or market elements (eg. Minifie & Heard (1985) and Bott (1981) amongst others). Elsewhere sophisticated supply elements have been driven by simplistic market and production control elements (eg. Arumagum (1985), amongst others). Finally sophisticated market, production control and supply elements have been included, but simplistic single level product structures have limited the effects of policy interactions (eg. De Bodt & Van Wassenhove (1980)).

5.6 The General Specification of a Total System Model

Experimental facilities intended for research into total system behaviour, must allow for interactions and uncertainty and must judge system performance from a realistic stand point. The design of such a facility must include the three elements described above, namely, the market, production control and supply. Each of the model elements must realistically emulate actuality and allow for the full range of policy interactions.

Consequently, the market element must reproduce the characteristics of the market in question with regard to product mix, and the size, timing and uncertainty associated with demands. Results obtained from research using a few "typical" products with deterministic demands are unlikely to have been subjected to the complex interactions occurring in reality (where tens or hundreds of saleable product types with stochastic demands are the norm).

Similarly, the production control element must faithfully reproduce the complexities of control options and interactions occurring in reality. Distribution driven demand generators or single level approximations of MRP are incapable of emulating a multi level commercial MRP system with sufficient detail. The model used for this element must be capable of producing production plans which have been subjected to these interactions.

Finally, the supply element must allow for the route, resource and priority interactions evident in any production shop. The performance of this element must be influenced by the characteristics of the production plan and the control policies used. This requirement is fundamental to successful policy design since the ability of the supply groups to perform to a given plan is the basis from which manufacturing performance is judged. It is a test of both the validity of the plan (and thus the policies used to produce it) and the capability of the supply groups (and thus the validity of supply group policies).

5.7 Cost Base

From Chapters 2. and 3. it can be seen that simplistic unjustified use of standard cost elements will seriously undermine any research which attempts to address the whole system, since changes in system performance will undermine the cost base. The nature of total system modelling makes true performance evaluations (not the simplistic addition of standard cost elements) relatively straightforward.

It is considered that the specification of these measures must be determined relative to the requirements of each specific policy design study. However, total performance measures such as planned due date achievement, total inventory cost and composite lead time will be common to most studies.

5.8 Summary

Manufacturing system performance has been shown to be dependent on operational policy decisions. Furthermore, a holistic approach to policy design has been shown to be a prerequisite to the successful integration of MRP and AMT and the achievement of acceptable system performance.

The need to abandon contemporary attitudes and philosophies underpinning policy design has been demonstrated. This has been linked to a need to re-couple manufacturing systems to the demands of the marketplace, through the realisation of AMTs "low inertia" potential.

A policy design methodology has been presented which supports the above. Chapters 6., 7., 8., 9., 10. and 11 will discuss an industrial case study involving the application of this methodology to policy design in the manufacture of electronic telecommunications equipment.

6. INDUSTRIAL CASE STUDY

6.1 Introduction

This industrial case study is based on Fulcrum Communications Ltd (FCL) and in particular the manufacturing facility based at Fordrough Lane, Birmingham. The industrial complex at Fordrough Lane is fairly typical of a number of manufacturing sites in the UK with a mixture of 19th century and modern buildings. The site has had a varied history with a number of uses and owners. During recent times it has been owned by British Telecommunications Factories Division and was used for repair and overhaul of Strowger type exchange systems. Consequently, the facilities were designed around sheet metal and coil winding activities since these formed the major part of a Strowger exchange.

Following the reorganization and subsequent privatisation of BT, the factories division containing the Fordrough Lane site was reorganized to form Fulcrum Communications Ltd. Political and business pressures were such that manufacturing and supply activities were required to be at "arms length" from the main BT activities. Further reorganization resulted in FCL becoming a part of the international products division (IPD) of BT. FCL's mission is currently the design, manufacture and supply of digital communications equipment and related computer-based products. The principal market serviced by FCL is the parent company (British Telecommunication Plc) in the form of the operating and business groups. However, this does not exclude other external markets.

6.2 Products

FCL currently offers approximately 20 separate product ranges some of which (approximately 50%) are highly configurable. Product specifications range from single PCB products (eg a modem), to complete racked systems (eg a small exchange). All of the current and future products are based on microprocessor and PCB technology. Product value is divided approximately 80/20 between purchased and internally manufactured parts. Bills of material have between 2 and 7 levels. Figure 10. illustrates a typical BOM. This subject will be addressed in greater depth with reference to the FCL model in chapter 7. Turnover is approximately £200 million.

6.3 Manufacturing Facility

The Fordrough Lane site has in effect two separate manufacturing operations. The first one relates to the products outlined above, whilst the other specializes in the repair of Strowger based equipment. This latter area is a hangover from the site's recent history and is currently being phased out. This work is concerned only with the primary products of FCL and their manufacture and as such will ignore the latter group.

The products outlined above are typically manufactured in three stages. PCB manufacture is the first and includes; the insertion of electronic components into the bare board, flow solder operations and circuit testing. Sub-assembly includes the attachment of; rack system parts, cables and special components, together with the assembly of "mother and daughter" boards. Complete products are assembled into racked systems and tested (eg soak testing) in the final assembly area.

At present PCB manufacture and assembly are housed in the building known as H1, whilst final assembly and test is housed in H2. Both of these are recent additions to the site and are purpose built for electronics manufacture, with clean areas and anti-static measures. Figures 11. and 12. illustrate the layout of these two shops.

A total of 150 operators are involved in the manufacture of products in these areas. PCB manufacture is the most capital intensive and uses mainly unskilled operators. Sub and final assembly are labour intensive

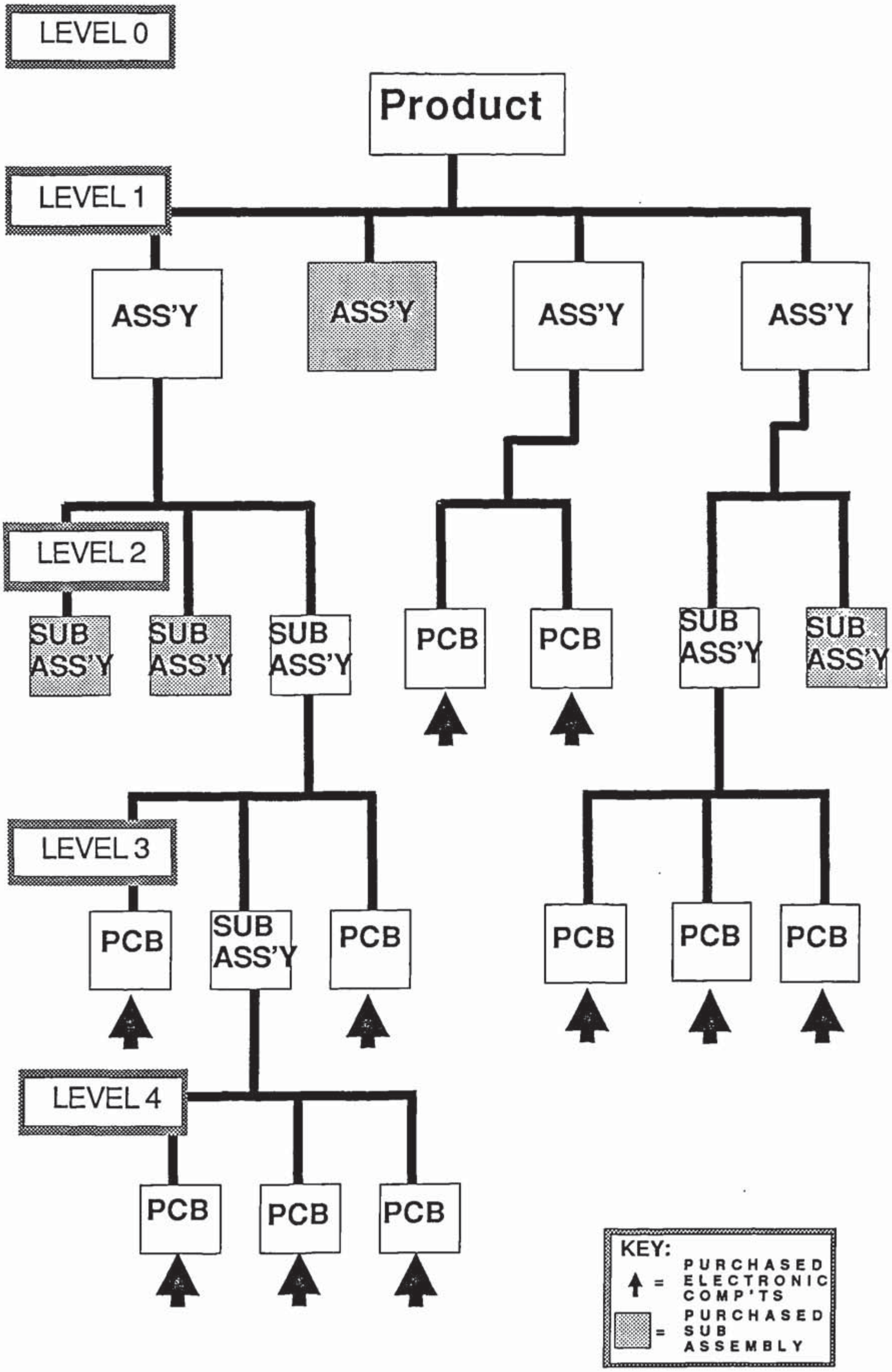


Fig 10. A Typical FCL Product BOM.

and require a generally higher skill base. Additionally, labour organization remains based around the technical grade structure of the Civil Service.

In line with a new direction for Fordrough Lane, a substantial capital investment was made in PCB manufacture. This included two flow solder machines, CNC dual in-line package (DIP), CNC axial and CNC radial insertion machines, 10 NC light guided semi-automatic insertion machines, and sophisticated circuit and functional testing equipment.

The above equipment was assembled into an AMT based facility which was capable of numerous configuration and control options (eg organization along flow line, cell or batch principles). Most of the equipment could be organized to work with small batches (5-20). At the start of this work the equipment was arranged for medium batch operation with a pseudo flow line layout (Figure 13.).

The sub and final assembly areas were not formally organized. This resulted from the labour intensive nature of these operations and the significant changes in format required by different products and product mixes. For example, the assembly of a batch of 10 large systems would require a different labour organization from the assembly of several hundred single PCB products. Thus, a flexible approach to these operations was adopted and based around a pool of skilled labour.

6.4 Production Control

Following the reorganization of the Fordrough Lane site and the changes to both market and product ranges it was agreed that production control in the new environment was beyond the capabilities of the existing stock control system. Following some initial studies (including significant contributions by Aston University) it was decided to install a fully operational MRP system. Of the many systems available, it was decided to implement TMS (Total Manufacturing System) offered by

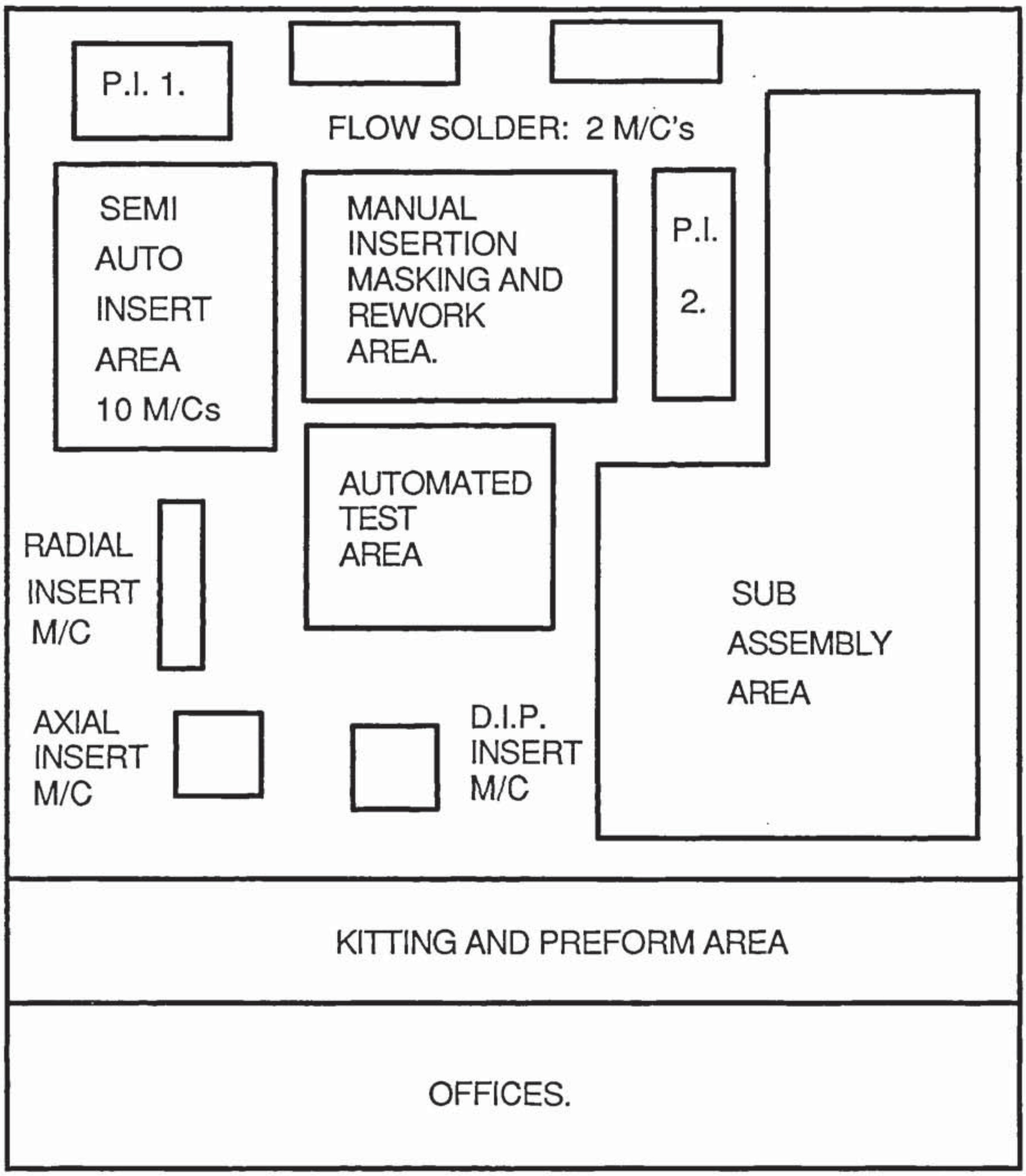


Fig 11. H1 Production Shop.

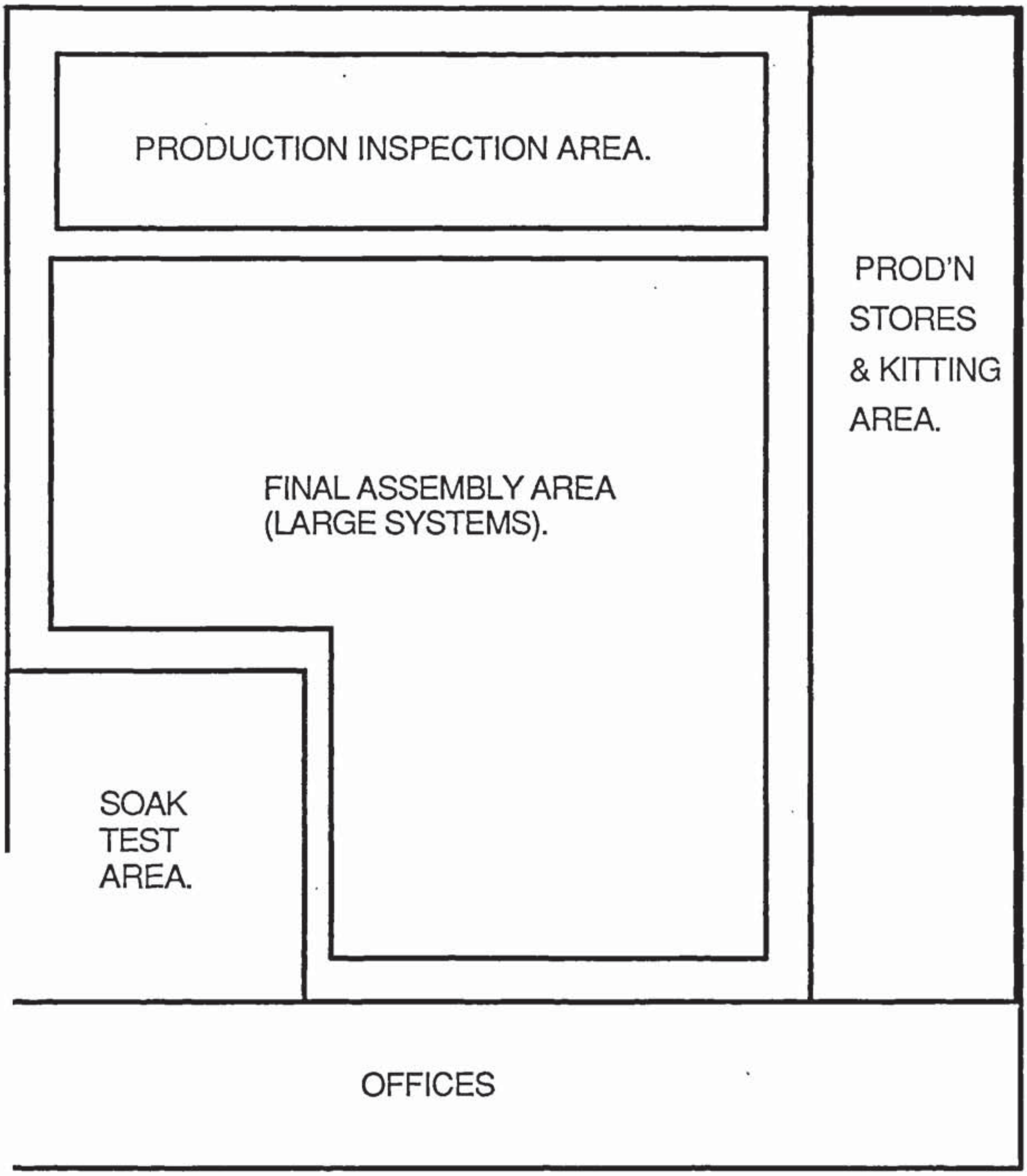


Fig 12. H 2 Production Shop.

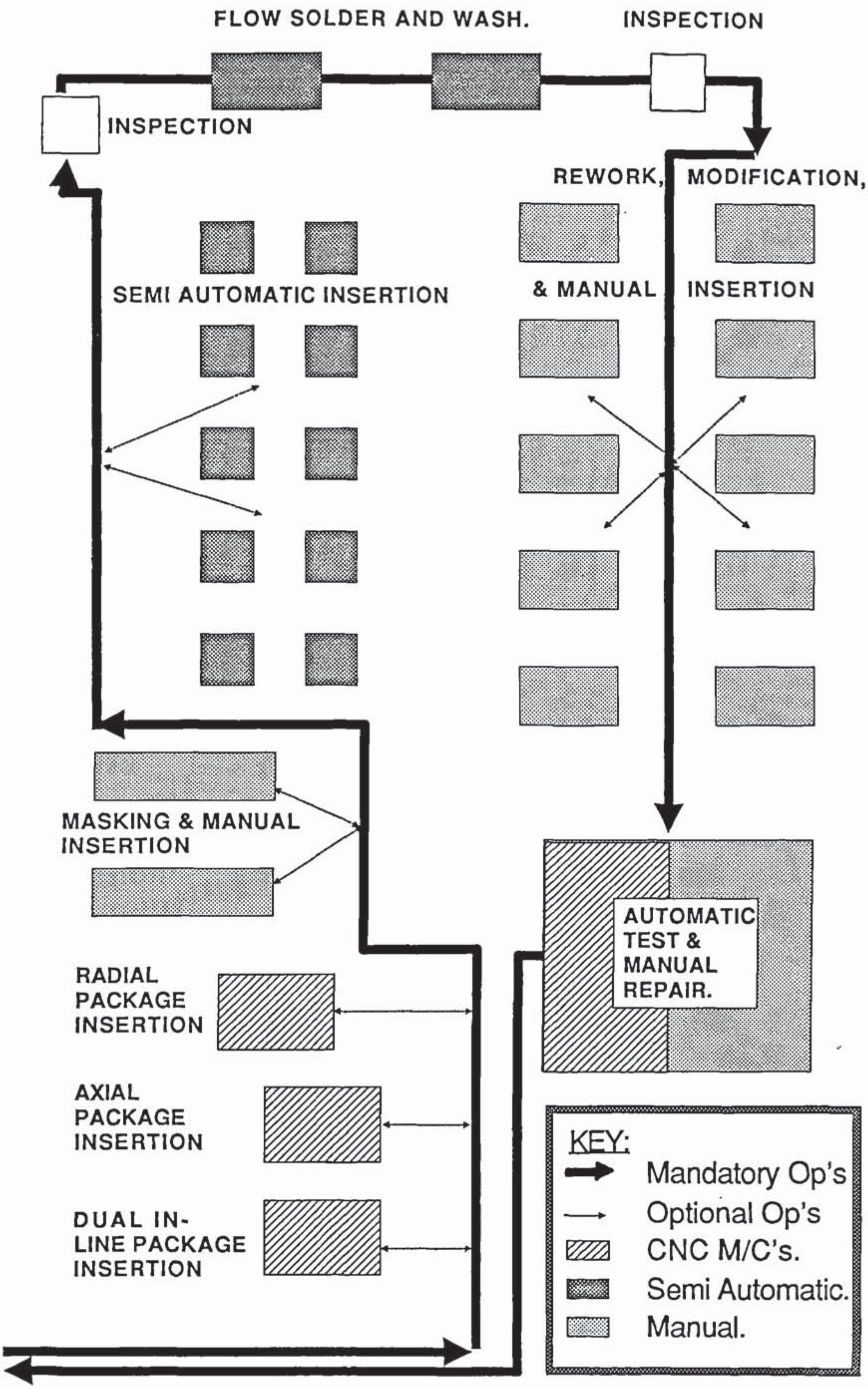


Fig 13. Pseudo Flow Line Layout of H1.

Burroughs (now Unisys).

TMS is a sophisticated CAPM system designed along modular lines. Configurability is a notable feature of the package and it is possible for it to be set up in a number of ways (eg. as an order point system, MRP I or MRP II system, etc.) with appropriate modules being chosen from the available range. Figure 14. shows the full range of available modules and their interactions in system terms. TMS was initially configured to MRP I standard, the benefits of adopting an MRP II configuration were under investigation.

FCL are unusual in enjoying the ability to run TMS on either of two Unisys mainframes. The first is an A9 of 12 megabyte core memory and 2 gigabyte storage, to which is attached 140 user terminals. The A9 is used as the primary MIS machine. In addition to TMS it is used for a number of other tasks. The second machine is a B5900, with 6 megabyte core and 1.2 gigabyte storage and is used by the MIS group as a development machine with 10 user terminals. Consequently, TMS is maintained to the latest standard on both machines. In addition to this hardware, a number of LANs have switchable access to both machines.

Successful implementation of TMS was recognized as vital to the performance of FCL. Therefore, Coopers & Lybrand & Associates (Management Consultants) were engaged to manage the implementation of TMS. This included module software testing, generation of the bill of materials, stock security, data validity and user training etc. This C & L led implementation project proceeded along traditionally tried and accepted lines, adopting a project plan similar to that discussed in Chapter 3. (Figure 3.).

6.5 Policy Design Project

The changes to marketplace, product range and manufacturing facility resulted in operational similarities between the Fordrough Lane site

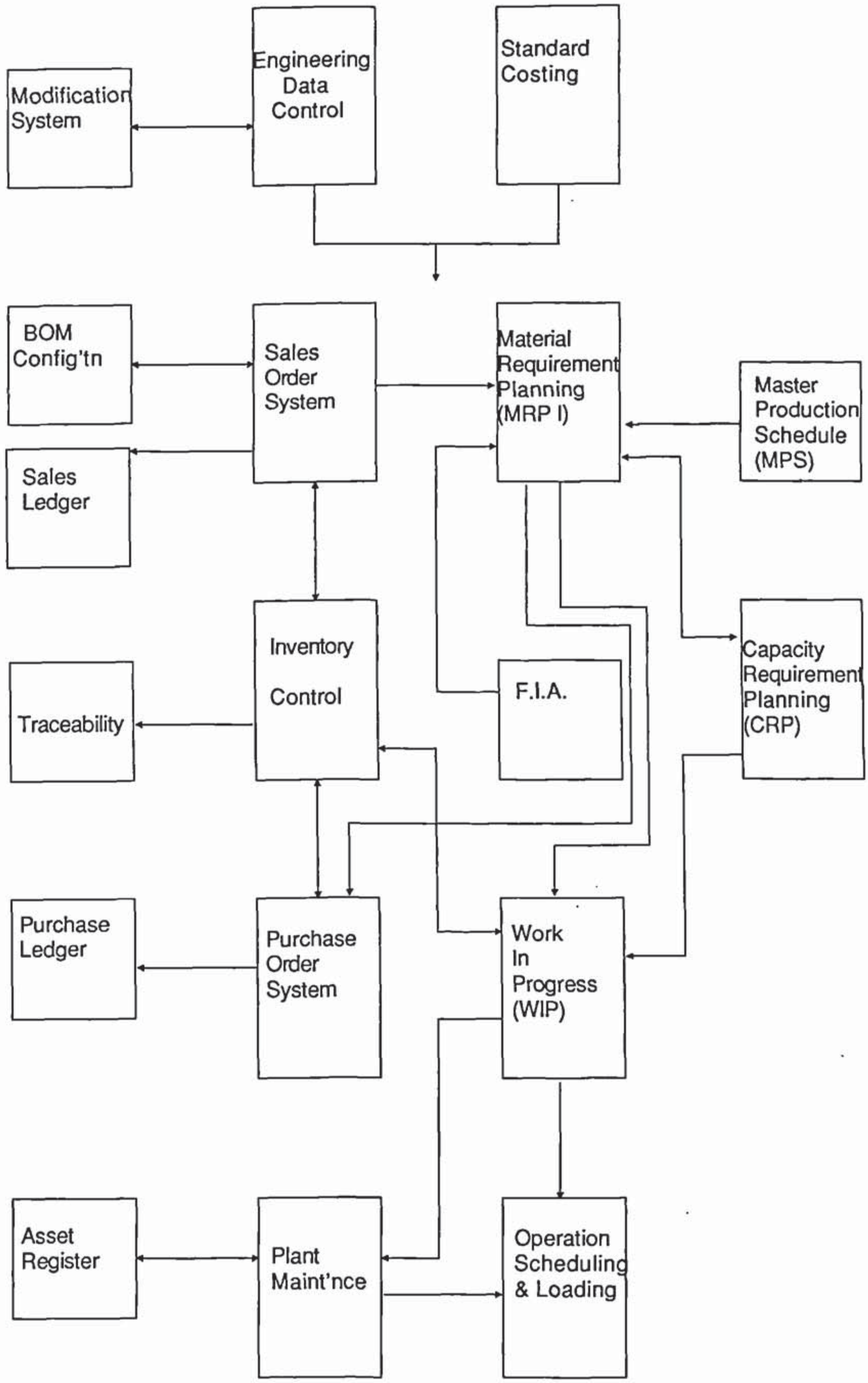


Fig 14. The Complete Range Of TMS Modules.

and a "greenfield" scenario. The implementation of MRP in a near "greenfield" environment is unusual and poses some significant problems in determining operating policies and parameters in addition to those outlined in the previous chapters. These were centred on the lack of historical data on which policy decisions could be based.

FCL management were unusual in recognizing the importance of policy decisions and the need for a coherent approach to their design. Furthermore, the potential for conflict between the traditional approach to MRP (with large optimised batches and a stable environment) and the AMT based manufacturing facility was recognized. This has been discussed in Chapters 4. and 5. These issues were closely related and again centred on policy design. Consequently, a separate but closely related project was undertaken by Aston University. This was to research this area and recommend a policy set for FCL. Since the PCB facility constituted the highest capital investment and product design was tending towards single PCB products, it was agreed that the project would concentrate on this area.

The policy design project was organized to run over a two and a half year period with Aston University providing project management and two full time researchers. One of these (the author) would be in a senior role and would focus on policy design issues. The other (Mr D.I. Gooden) would be in a more junior role and would address the specification and design of an experimental facility. In addition, to access to the necessary resources and information, FCL involvement included up to two engineers on a part time basis. Full project management procedures were adopted with close liaison being maintained between Aston University, FCL management and the C & L implementation project.

A great attraction of this project from an academic standpoint was that it provided an opportunity to test the policy design methodology presented in Chapter 5. in a live environment and subject to real business pressures. One aspect of the implementation work undertaken by C & L was that it was necessary to specify control policies to enable the system to operate. Since by necessity this had to be completed early in the implementation and prior to the completion of this research, C & L specified a policy and parameter set designed from a traditional standpoint. Timing of the two projects was such that data relating to twelve months of continual production using the original policy set (supplied by C & L) was available. This made possible a comparison between the factory operating under a traditional policy and parameter set and those designed using the methodology recommended in Chapter 5.

7. FCL POLICY DESIGN MODEL

7.1 Model Boundaries

The boundaries relating to the FCL policy design model were largely determined by the requirements of the methodology outlined in Chapter 5. It has been shown that any model used to support and implement this methodology must be designed around the following requirements:

I The model must by necessity include the three elements of the total manufacturing system namely the marketplace, production control and the supply elements.

II It must support policy interactions both within and between the various elements in the system.

III It must incorporate the ability to perform rolling schedule experiments in the environment of demand uncertainty. This requires that the market, production control and supply elements interact on a period by period basis with the master production schedule being rolled over also on a period by period basis.

IV The model must support the detailed and complex product and work flow interactions existing within the supply elements. Since competition for resources is a major issue within the supply areas, such constraints must be modelled resource by resource. Thus taking the example of a manufacturing facility, it would be necessary to model the manufacturing resources (ie work centres, operators) and their interactions with batch movements in their entirety.

The supply element of the model may be considered to have two parts, namely in-house manufacture and vendors. Whilst these two sub-elements have similar effects on the performance of the parent elements, namely production control and the marketplace, it can be argued that policy design for purchase is quite separate from policy design for in-house manufacture. For example, in-house manufacturing policies require decisions on priority rules and resource allocation, whereas purchase policies by necessity address vendors at a global level.

Chapter 2. outlined four alternative manufacturing scenarios. In these the relationship between raw material supply, cumulative production lead time and customer delivery requirements, were shown to affect the choice of purchase policy. Since this work assumes that manufacturing system policy decisions will significantly affect the cumulative manufacturing lead time, it would be inappropriate to predetermine policy decisions without an understanding of eventual cumulative manufacturing lead times. This problem was compounded at FCL because of the lack of historical data relating to cumulative lead times.

It was accepted that certainty of raw material supply will affect manufacturing performance to due date and will also influence such matters as raw material and intermediate stock levels. Whilst it was assumed that purchase policies can be designed to guarantee raw material supply, these policies cannot be optimised by resolving safety stock versus safety lead time conflicts (if the cumulative lead time is unknown). Therefore, purchase policies were treated as an entirely separate issue. This will require full investigation after the manufacturing system policies have been designed and performance, with respect to cumulative lead time, determined.

Support for this separate view can be found in the disparate commercial and political constraints within which the policies must operate. The manufacturing environment is largely within the control of manufacturing management and is influenced by the characteristics of the manufacturing system. Therefore manufacturing operational policy decisions mainly revolve around resource management issues. However, purchase policies are significantly influenced by political and economic considerations. These are external to the company which is aiming to design and operate such policies. For example, a carefully designed optimal purchase order quantity can be made completely invalid by an unforeseen vendor quantity discount or promotion. Similarly, vendor schedules can be rendered obsolete by political issues such as the discontinuation of component part supply.

A further important area concerning model boundaries, was the choice of products included in the study. One of the traditional approaches to this has been to base experimental study on a small number of typical products. The works of Schrorer et al (1985), Patel et al (1973) and Gaither (1982) are typical of this approach. However, shopfloor, work flow and resource interactions have been shown to be a fundamentally important part of policy design. The effects of these interactions will be significantly influenced by the number of different product types on the shopfloor, the mean and variance in their batch sizes, the nature of the manufacturing resources and the balance between load and capacity.

Investigations showed there to be in excess of 150 different sub and final assembly types and 200 different PCB types at FCL. Consequently, it was felt that there would be a number of serious validity problems if a small number of typical parts were used to model the BOM and shopfloor interactions of the above. One approach would have been to apply a small number of typical parts to a scaled version of the manufacturing facility. However, it was felt that this would still not adequately resolve the validity problem. Further study determined that 90% of the live production database could be represented by 20 configurable top level products, 80 sub assemblies and 160 PCBs. It was considered that this total of 260 part types was small enough to be included in total in the study and that the omission of 10% of the live parts (by work load), would not unduly affect the validity.

The research for which Aston University was contracted to undertake for

FCL was primarily concerned with policy design for the PCB manufacturing area, as this represented by far the largest capital investment. However, as can be seen from the previous chapters PCB policies could not be decided in isolation from the rest of the manufacturing facility. Therefore, the model used for policy design required that all of the BOM levels be included and that demands on the PCB area be influenced by the performance of the manufacturing facilities relating to the higher levels of the BOM.

One final consideration was that the MRP element in the model must have the equivalent of the control policy options available in TMS built into it. This posed a significant potential problem resulting from the fact that the very large number of different MRP systems available, whilst having broadly similar control options, have significant differences in their implementation and the subsequent effects of policy decisions.

7.2 Model Overview

Design development and determination of validity of the FCL model has been addressed in considerable detail by D.I. Gooden (1988). However, for continuity the salient points of model design and validity (as they relate to this work) will be included in this dissertation.

A hybrid modelling approach was adopted in which techniques specifically suitable to each model element could be combined. Gooden includes an analysis of the available techniques appropriate to each element and justifies the final design.

The factory element was based on the Optick discrete event based simulation package designed and produced by Insight International. This graphical package was resident on a TDI Pinnacle supermicro with a one megabyte core memory and a 20 megabyte hard disc drive. The TDI Pinnacle is based on 32 bit Motorola 68000 chip technology and is notable for its high processing speed. This together with the extremely flexible Optick package enabled rapid development of the necessarily complex model.

The development mainframe (B5900) was capable of running two separate databases simultaneously. Both of these had full access to TMS. Therefore, it was decided to use one of these databases to build a separate model of the live database and then to subsequently use TMS as the production control element of the total model. This significantly reduced the potential validity problems with this element of the model and enhanced the applicability of the results to FCL.

A data-driven model was used to represent the market element. This took the form of a database of period by period top level demands covering the entire MPS horizon (as specified and modified each period). For example, for period n the database held all of the top level product demands, specified by period and quantity and extending to the end of the horizon. For period n+1 the database held similar demands but these were rolled over one period and were subjected to market uncertainty. Thus, the demands for period n+1 showed cancellations and increases to demand relative to period n. Figure 15. demonstrates this principle. A number of separate databases were generated each of which extended for up to 52 weeks and included 52 sequential weekly manifestations of the MPS. The market model was resident on the TDI Pinnacle and market demands were passed to the B5900 on a period by period basis.

In addition to the above, two further databases were used by the model. The first of these was also resident on the TDI and included information such as routing, picklist, operation times, set times etc and related to the operation of the factory simulator. The second database was specific to TMS and included BOM structures, stock locations, live and suggested orders and numerous other data elements required for the processing of MRP.

The market, production control and factory elements were linked electronically such that their interaction would closely emulate the interactions of the real systems. One significant difference between the two, was that the interface between these elements in the real system relied on human intervention. Within the FCL model these functions were represented by a number of separate logic routines which replicated the actions of the master production scheduler, WIP planner and shop management.

The experimental facility resulting from the integration of the above three elements had three separate modes of operation. The first of these was an interactive mode in which production plans generated by the MRP element were downloaded and manually manipulated prior to the start of the simulator. The timespan of the interactive production plan could vary from one day to three years in length.

The second mode of operation was similar to the traditional method of MRP experimentation. A static MPS extending over a 12 month horizon was loaded into the MRP system. TMS and the factory simulator were then interacted on a period by period basis, with an MRP run preceding each period's simulated production. Alternatively, a 12 month production plan was generated from a single MRP run and loaded directly into the factory simulator. Since the MPS used in this mode was entirely deterministic, the differences between the production plans produced from a single or numerous MRP runs was limited to the horizon sensitivity of the control policies. Research has shown (Baker 1977, 1979A, & 1979B) that horizon sensitivity is limited to order policy decisions.

The final run mode included the rolling schedule multi-MRP approach with the environment of MPS demand uncertainty. This run mode perfectly matched the real world environment of FCL, in that production plans were released to the shopfloor on a period by period basis and each production plan was the result of a separate MRP run with MPS

Product A (example)

MPS Horizon (in months).

	1	2	3	4	5	6	7	8	9		
1	20	10	10	15	30		20	20	20		
2		10	10	10	30	30		20	20	20	
3			10	10	25	30		20	20	20	20
4				10	25	12	20	20	20	20	26
5					25	12	20		30	20	26
6						12	20	11	19	20	26

Sequential monthly statements of the MPS, showing changes in demand.

Fig 15. An Illustration of MPS Uncertainty for Example Product A.

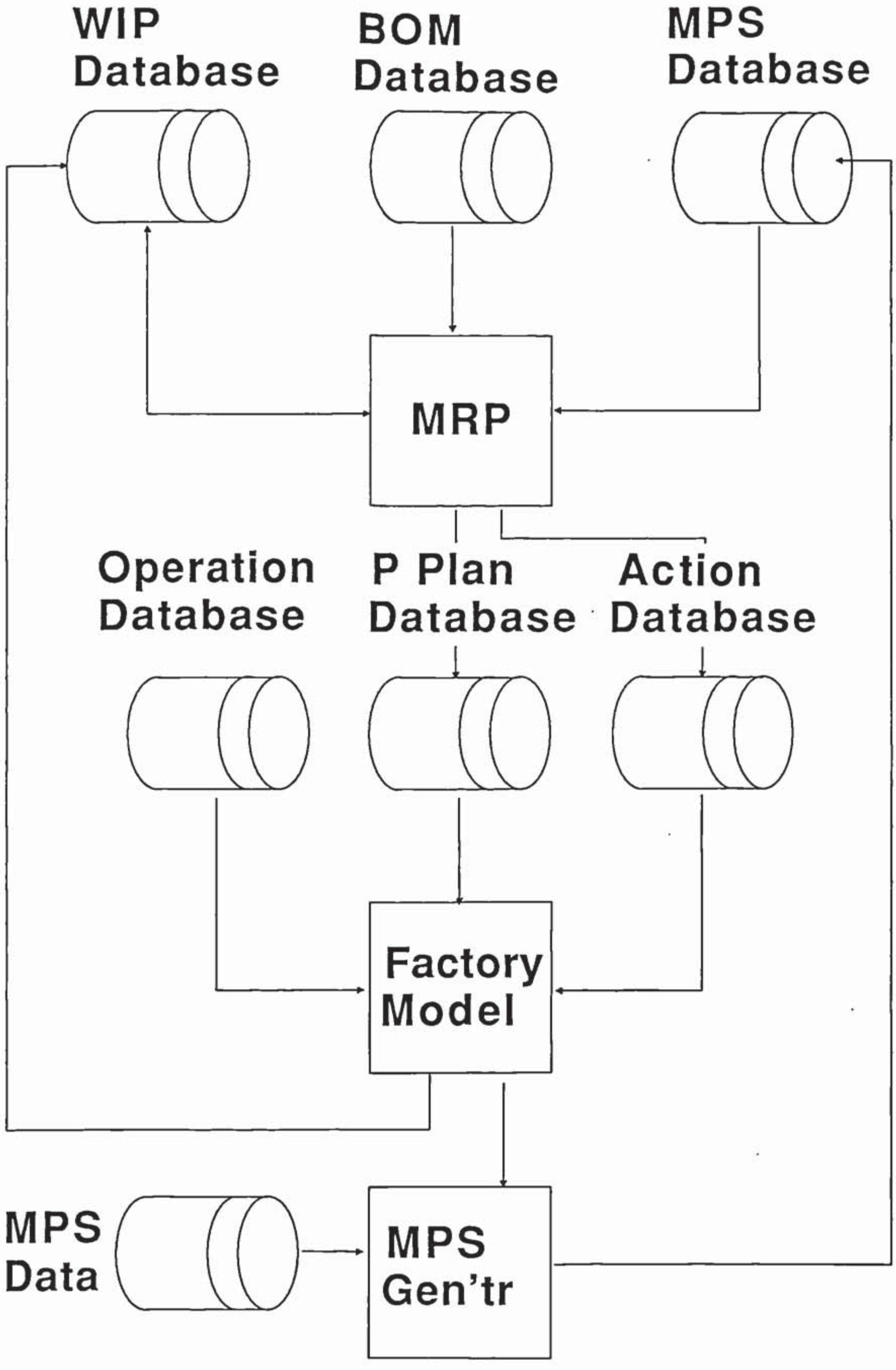


Fig 16. An Outline of the Model Element Interactions.

updates occurring in each period.

Figure 16. outlines the interactions of the various elements in the complete model.

7.3 Factory Simulator

7.3.1 Overview

As previously mentioned the factory simulator was designed and written to run under the Optick simulation package developed and marketed by Insight International. This package uses the three phase approach first developed by Tocher and discussed in Pidd (1984). This combines the benefits of event and activity based simulation models.

The Optick package is organized in such a way that structured programming techniques can be applied to model design and development. A typical model would include initialisation, graphics, event logic and interaction segments in the program. Event processing is performed under the control of the event processor executive. This, together with a shell event list is provided as part of the Optick package and conforms to the three phase logic.

The executive is not normally accessible to the model builder. However, any potential compromises in model logic can easily be overcome by one or more of a range of event processor interactions supplied with the package. For example, conditional events can be forced or suppressed using such routines and bound events can be rescheduled or cancelled in a similar manner.

In essence the Optick package, with the exception of the event executive, is supplied as a library of compiled sub-routines which may be linked and called from a Fortran host program. The host program is unusual in that it itself is a sub-routine called by the supplied executive program and must include calls to the other program elements (initialisation, graphics routines, etc).

The package supports both entities and lists. Lists may contain any number of other entities or lists and all may have up to 255 attributes each. Consequently, Optick can support list driven models (in which entities are passed from one list to another) or attribute driven models (in which entity states are identified by attribute values). In addition, both lists and entities have variable graphics attributes which are accessible under program control allowing considerable flexibility in the graphics capability.

The FCL model design was based on a list driven approach. Groups of lists and entities were made to represent work centres (permanent entities). Entities were used to represent the transient elements within the model (operators and batches of work) and were moved from list to list during the model operation.

Logically, the factory simulator represents three separate manufacturing elements (PCB, sub-assembly and final assembly). However, equivalency between the assembly and final assembly event routines allowed them to be combined logically. Therefore, the model was implemented as two separate elements with separate event processor segments running concurrently within the master programme.

Full use was made of the graphics capability of the package and the screen layout was designed to represent the three factory areas. Work centres were colour coded to represent state (ie production, setting and idle). Work centre input and output queues were displayed to give a visual representation of WIP levels and bottlenecks.

7.3.2 PCB Shop Model

Table 5. lists the machines and work centres used to produce PCBs at FCL. Each of these elements was included in the PCB model. An activity cycle diagram (ACD) was designed to represent the interactions

of the resources and the work elements in the PCB facility. This is discussed more fully in Gooden (1988). The processing logic was common for each work centre. Figure 17. illustrates a single work centre element of the ACD. The ACD was validated through detailed discussions with shop management and the operators.

Conflict for resources was resolved at the work centre input queues. That is, the transfer of a batch entity to a work centre input queue would create a demand on the setter and operator worlds appropriate to that work centre. If more than one batch entity was resident in any given queue, right of passage would be determined by resource availability and the priority rules in operation for that particular work centre.

Batches of work were considered to flow from the PCB area input queue (a manifestation of the PCB production plan) through the various work centres to the PCB stores. WIP was allowed to accumulate at the various work centre input and output queues and was at all times determined by the capability of the PCB facilities to work to any given production plan.

7.3.3 PCB Model Data

The factory simulator required data in the following areas; process times, set times, operation sequences and work centre and operator capabilities. A multi-stage approach to data collection was used. Operation sequences were gathered from two sources; the live TMS database and shopfloor planning documents. Any discrepancies between these data sources were resolved by discussions with the appropriate product planners.

Operation process times were gathered from three sources; the live TMS database, shopfloor planning documents and in addition the operators and shop supervision were consulted in detail. Conflicts in data from

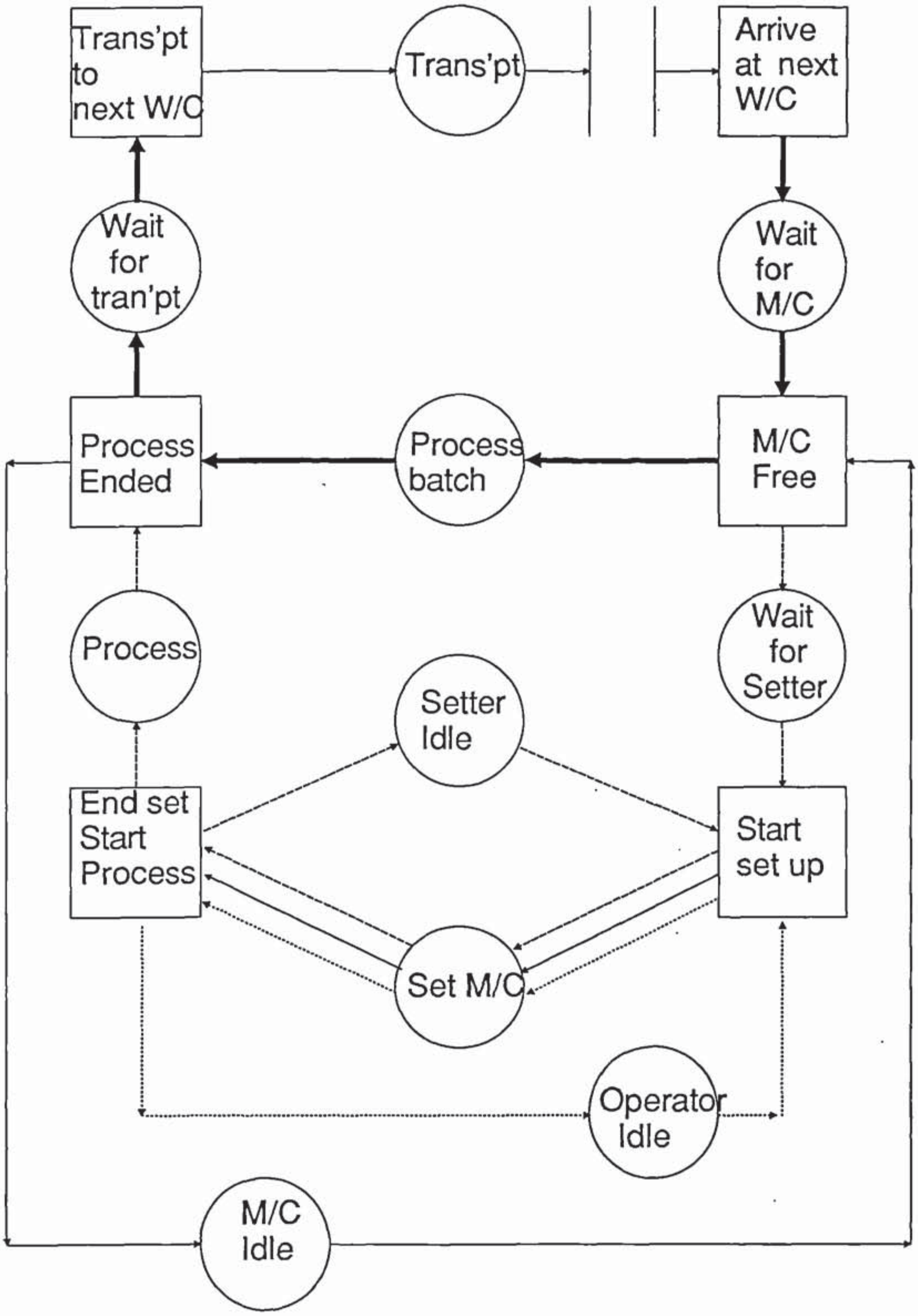


Fig 17. A Single W/C Element of the Model ACD.

alternative sources were resolved by consensus.

Operation set times posed something of a problem, in that it had been policy not to apply time standards to these operations. Consequently, a database was generated to represent set times for PCBs.

Since set time was a function of the number of components added to a given PCB, it was decided to use this as a criterion for set time determination. Three categories of PCB were defined, small, medium and large. Typical set times were then determined against each work centre and for each of the PCB sizes. Times were determined partly through the use of the FCL industrial engineering synthetics database and partly through detailed discussions with operators and shop supervision. Table 6. lists these times for each work centre against PCB category. On completion of this database, these values were applied to each PCB operation.

PCB manufacture at FCL is notable for the extremely low machine failure rate (less than 1% work centre downtime) and the near zero scrap rate. This latter point is a function of the type of PCB manufactured, in that non-conformance can usually be rectified without the need to scrap the boards. Re-work operations are planned into the manufacturing sequence and performed immediately after the flow solder operation. This is partly as a result of the high quality and reliability standards required of telecommunications PCBs. In addition to these points, the majority of operations are machined based and therefore there is very little variation in process time to be found.

One database was used to store the above data and during model operation this was held in RAM. Configuration was accomplished using Optick dataset routines. This enabled rapid access under model control. In addition, data relating to production resources was coded in the model software, but this could be accessed and modified by utilizing Optick manual interaction routines. Appendix 1. contains a

Work Centre	Description	Number of M/Cs
1	Dual-in-line-package (DIP) Insertion. (CNC)	1
2	Axial component insertion. (CNC)	1
3	Radial component insertion. (CNC)	1
4	Hand insertion & mask.	5
5	Semi automatic insertion with cut and clinch. (NC)	6
6	Semi automatic insertion without cut and clinch. (NC)	4
7	Inspection 1	2
8	Flow solder. (NC)	2
9	Hand insertion and finalise.	10
10	Inspection 2.	3
11	Automatic test area	4

Table 5. Work Centres used in the manufacture of PCBs

Work Centre	Set Time per PCB type. (in minutes)		
	Small	Medium	Large
1	40	55	70
2	35	45	55
3	40	55	70
4	5	10	15
5	57	91	125
6	57	91	125
7	5	5	5
8	10	15	20
9	6	8	12
10	5	5	5
11	5	10	15

Table 6. Operation Set Time Per Work Centre

sample of each of these databases.

7.3.4 Sub-assembly Shop and Final Assembly Shop

The activity cycle diagram of these two areas was designed and validated in a similar manner to the PCB shop. Both were found to be identical and therefore these elements were combined logically. This was accomplished by using a common set of event processes but creating separate groups of work centre entities for the two areas. Product routing information was used to maintain separation between the jobs.

This element differed from the PCB model in that sub-component availability was required before an assembly order could be started. Component stock availability was determined by the production output of the factory elements and was a measure of production plan validity.

The high skill levels associated with assembly operatives resulted in operation process and set functions being performed by the same labour group. In addition, assembly operation set times were found to be of minimum duration when compared to the process time. Therefore it was decided that event processing was not required for the setting operations.

Assembly model logic was based on a series of work areas (assembly benches) with access to a shared operator pool. The logic was such that one labour element (operator) would be assigned for each batch operation. Therefore, work was organized around one operator per batch per operation.

7.3.5 Assembly Model Data

The assembly model required data in the following areas; operation routes, process times, work centre capabilities, operator capabilities, inter-work centre transport times and pick lists.

Although the problem relating to set time data did not apply to the assembly areas, a problem relating to process times posed a significant hurdle. Unlike the PCB manufacturing area, time standards have not been applied to assembly operations in the same rigorous manner. At the end of the data collection phase, production routes had been planned for 60% of the modelled assemblies, and standard times had been allocated to approximately 50% of the assembly operations. Fortunately, many of the assemblies were found to be very similar in terms of their resource requirements. This missing data was therefore synthesized by comparing unplanned assemblies with planned assemblies and selecting relevant data. These assembly times and routes, were then discussed in detail with the relevant production planning and shopfloor personnel. Appropriate modifications were then incorporated into the data.

Data for the picklists for each assembly was taken directly from FCL's live TMS databases.

These two databases were again held in RAM during model operation and configured using Optick data set routines.

7.3.6 Work Flow

Work was considered to enter the elements of the facility model as a production plan, generated and downloaded from TMS.

In keeping with Goldratt's views on process and transport batches, a batch splitting mechanism was included in the production plan launching routine. This enabled TMS generated order quantities to be divided into a variable number of transport batches. The size (and thus quantity) of transport batches was placed under the control of an experimental parameter. Thus for example, an order quantity of 100 of a specific PCB type could be subdivided into five transport batches of size 20 at launch.

In the case of PCBs, work would be launched into the model at the date suggested by TMS and would flow, as permitted by resource interactions, from work centre to work centre following a production route specific to each PCB type.

A similar process was applied to assemblies with the following addition; on the appropriate launch date a test would be applied for sub-component availability. If a WIP order failed this test it would be delayed and the launch would be attempted at the start of each subsequent day. This daily test was in keeping with the rate at which information was uploaded to the live TMS database.

Launched work would be progressively transformed from a kit of parts into a completed batch. Completed batches (transport batches) would be placed in a common output list for daily stock updating.

Information regarding due date alterations would be accessed from the action messages downloaded from TMS and applied to the appropriate batches. This data was downloaded at the start of each period and collated by order number. The updating routines were designed to ensure that all the transport batches associated with a given order number would be updated. This information was used to maintain accurate due date performance measures and to drive some of the priority rules. This latter aspect will be discussed in greater detail with respect to experimental design in Chapter 9.

A full listing of the simulation program is given in Appendix 2.

7.4 MRP Model

TMS is a modular based system and the live version used by FCL uses most of those available. Whilst it would have been possible to copy all of the modules from the live system onto the test (model) database, many of these were not relevant to our needs. Investigation determined that those directly involved in the generation of WIP orders through MRP processing were limited to; WIP (work in progress module), STK (stock module), EDB (engineering database) and the MRP module.

The WIP module was used to maintain data on work in progress. Data was recorded against order number and recorded order quantity, component type, operation level etc.

The stock module, as it name implies, was used to maintain data on stock. Data was collated against stock locations and data elements included component types, quantities and measures of the availability of free stock (for example, the quantity allocated against other orders).

The engineering database was used to maintain all the data relevant to product information and included bills of materials, operation sequences, process and set times, etc.

The MRP module provided the link between the above three elements. The master production schedule was stated within the MRP module. During an MRP run, information from the other modules was used to accomplish the netting and explosion process. The suggested order and action message report so produced were the primary outputs from this module.

The primary requirement in the building of the FCL MRP model was the generation of a test database. With the exception of a number of housekeeping activities (such as initialising stock locations, buyer and planner codes, etc.) this was limited to the generation of test product structures. In keeping with the policy to model the majority of the FCL products and components, a copy of the live EDB was obtained.

Analysis of workshop load against product type revealed that 90% of the FCL factory throughput was accounted for by 16 top level products. The data obtained from the live database was then edited to remove dormant products and purchased parts. To this data was added information gleaned from the marketing and sales departments. The refined database was then loaded into the EDB module within TMS.

Any attempt to use a commercial MRP system as the production control element in a total system model must address the problem of MRP processing time. For example, a single MRP run using TMS on the live database at FCL, requires between 4 and 8 hours of processor time. It is obvious that if this performance applied to the FCL model it would severely limit the investigative capability. However, it was known that MRP processing time was dependent on the number of allocations and orders within the system. There existed therefore some confidence that the removal of several thousand purchased items would greatly reduce MRP processing time. Initial trials indicated MRP processing runs in the order of 30 minutes with the test database.

Since the MRP model was intended to be used with the FCL factory simulator outlined above, there was some scope to utilize some of the data elements required by the simulator. In particular, TMS under normal running generates date stamped operation lists. Whilst these are a necessary part of MRP output for a real factory, this data was redundant information when applied to the total model, since a comprehensive product route database was an integral part of the factory simulator. Consequently, it was possible to remove this part of the MRP processing. In addition, a number of other small housekeeping modifications were made to the MRP processing logic, which together with the above, yielded significant savings in MRP processing time.

The MRP model was configured to run under a variable length cyclical batch program which allowed several modes of operation.

7.5 Market Model

The data driven nature of this model, reduced building to the collection of data relating to product demand, on a period by period basis. Unfortunately, the recent changes at FCL limited the availability of data to the previous 12 months. Consequently, a database was generated which contained 46 weekly manifestations of the MPS. This included all the period by period MPS responses to changes in the market (Appendix 3).

Since the market model constituted one of the primary control inputs to the experiments, several other market databases were generated. These were made to differ from the historical one in terms of; product mix, average demand, and demand lumpiness. Each of these databases were stored on the TDI Pinnacle and transmitted to the MRP module in TMS at the end of each production period. This topic will be discussed further in relation to the design of experiments.

7.6 Model Interfaces

Operation of the FCL model occurs in one of three operational modes (interactive, static MPS and Rolling schedule with demand uncertainty) each of which required the automatic interaction of the three model elements. This required a communication interface to enable the two computers to transfer data. The TDI Pinnacle conforms to the ASCII code standard and uses configurable RS232 input/output ports and a choice of handshaking protocols. The Unisys B5900 conforms to the EBSIDIC standard and uses the Unisys proprietary twisted pair terminal lines, with a poll/select protocol. A P1000 buffered protocol converter (supplied by Pink Computing) was used to reconcile these two different communication standards.

The need to incorporate logic routines to replace the usual human interface was discussed earlier. These were incorporated into the communication routines at the model interfaces. On the B5900 a number of programs were written to convert the MRP standard output to a format which was usable by the TDI Pinnacle. In effect, the suggested order report produced by the MRP processing was edited down to the suggested orders and action messages relevant to the next period's production. These orders were then released to WIP within TMS and downloaded to the TDI Pinnacle. In addition, a further group of programs were written to upload; the MPS, closed WIP and sales (from the Pinnacle at the end of each period's simulated manufacture) into the TMS database prior to the next MRP run. This suite of programs was run on the B5900 under the control of a batch program which was configured to run experiments of a variable number of cycles.

Within the factory simulator a number of routines were added to control the download of production plans and open order action messages and the upload of closed WIP orders, MPS's and sales. The complete cycle of interaction is shown in Figure 16 (p 102).

7.7 Deterministic Design

Within the area of simulation, there has been much debate over the pros and cons of deterministic and stochastic design.

With reference to simulating the production shop environment, it is often argued that stochastic models give more reliable results than deterministic models (eg Emshoff & Sisson (1970), Mize (1979) and others). This argument is based on the need to include the random variability of processes in the study.

In the production shop environment, the major variable elements are process times, production routes and resources. Of these production routes and resources are fixed in the FCL case. The former was a consequence of part type. However process times could be considered to be stochastic.

The importance of including variability of process times is especially important when a small number of typical products are used to model the complex multi-product environment. Since it has been shown that simulation studies in this area usually adopt this approach (Chapter 5.), the need for stochastic elements (for this approach) can be understood.

It was argued that the primary influences in the flow of work are interactions between the various product routes and product mix. This has been shown to be a function of the policies used within MRP and the product range modelled. The inclusion of stochastic time elements will not overcome any omission in this area.

The ability of the factory simulator to reproduce the work flow interactions has been shown to be a fundamental requirement. As a consequence of the above points, the flow of work was considered not to be influenced by variations in the performance of the resource elements. Whereas transient load/capacity, product mix, route interactions and MPS uncertainty, were considered to have a significant effect.

The issue of completeness was recognized in this work and, as such, 90% of all production parts were included in the study. Thus, the full complexity of shopfloor work flow interactions were replicated. It is argued that the large number of part types passing through the simulated factory at any moment in time (each with separate process times and batch sizes), greatly diminished the need for induced process time variability. Furthermore, analysis of the FCL data discussed above, indicated a very low level of inherent variability. On this basis, and accepting these arguments, the factory simulator was designed to be deterministic.

Further support for this argument can be found in the development and use of deterministic models to solve the problem of live production scheduling. For example, in separate studies, Pegels and Naryan (1974) and Rogers et al (1980) have discussed the use of models representing live production shops to analyze production planning decisions. Both of the models presented included all of the production elements and were deterministic. These models were used to predict the consequences of planning decisions over very short timescales and, as such, were exposed to a rigorous test of applicability and confidence.

One important consequence of the deterministic design was the effect on experimental design. A deterministic model, by its nature assumes 100% confidence in each performance measure (ie each experiment when replicated, resulted in exactly the same result). This required a departure from classical experimental design in that replications and statistically derived measures of confidence were unnecessary.

It is argued that it is preferable to design a deterministic holistic model and derive confidence from the completeness of that design, than to subject the results obtained from a limited representation of reality, to detailed statistical verification.

7.8 Model Performance and Capabilities

The model was found to be capable of simulating 46 weeks of production (including 46 MRP runs) in 14 hours of elapsed time. This represented approximately 18 minutes per cycle of which two minutes was factory simulation, 6 minutes communications and interface programs and the remaining 10 minutes was MRP processing. It is ironic to note that the performance limiting element was the mainframe computer. It was noted that the model run time was strongly influenced by the numbers of orders and allocations in the system. For example, if a very smooth MPS was used which specified demand as a large number of small batches, the cycle time would increase to 45 minutes per simulated week.

The model was found to be capable of processing work loads in the range of zero to 150% of the current FCL work load. The upper bound was not a model constraint but a reflection of the true capacity limits of FCL. It was found that at MPS loads greater than 150%, the WIP and lead time measures became transient as work accumulated at the bottlenecks.

7.9 Model Validity

7.9.1 Overview of Validity Issues

The validity of any experimental facility must be addressed in the context of the use for which the facility has been designed. At the broadest level this work was intended to address the application and suitability of a policy design methodology. Consequently, the validity of this model could have been addressed at three conceptual levels:

1. A test of the functionality and utility of the recommended design methodology, required only that the model used correctly represented all of the elements existing within a manufacturing company.

2. A general test of the performance of policies generated using the recommended methodology compared to a more traditional approach, required that the model correctly represented a specific class of manufacturing company.

3. A specific test of the suitability of a given set of policies for use within a particular company, required that the model was a valid representation of that company.

This industrial case study presented the rare opportunity to compare the performance of policies designed, using the recommended methodology with those suggested by a more traditional approach in a live industrial environment. This was made possible by the existence of market and facility performance data relating to 12 months of production. Therefore, it was appropriate to test validity at the third and highest level, although a test of the underpinning philosophy could have been made at the second level.

The requirements of this model were to support the design of operating policies relevant to PCB manufacture at FCL. It would at first appear that a detailed analysis of validity could be confined to the PCB elements of the model. However, the arguments supporting the inclusion of; the sub-assembly and final assembly elements (within the market-MRP-supply model), and holistic performance measures, make it necessary to test the validity of the complete model.

It was argued that much of the traditional concern over model validity, stems from attempts to use simple models to represent complex systems. For example, the use of small numbers of typical parts to represent the complex multi-product interactions, and single level BOM MRP models to represent the multi-level environment. Such techniques raise validity problems of a philosophical nature not only in the immediate case, but in the bounds over which such models remain valid. These issues have been discussed in Chapter 5.

It is probable that such philosophical problems with validity will decrease as models grow to include more of the system under investigation. These may be expected to be replaced by tactical problems related to individual elements of the total model. In the environment of policy design, it is argued that the inclusion of the market, MRP and supply elements represents something of an upper limit to model completeness. As such the philosophical validity issues are greatly diminished. However as predicted, a number of tactical problems relating to the data required to drive and test the individual model elements became apparent. These were discussed in the previous sections on model data.

Much has been written on the topic of model validity and a number of criteria have been suggested. One approach has been that of addressing black box and white box validity. The white box view addresses the performance and behaviour of the separate model elements. It is assumed that the validity of the complete system can be assured by the validity of its constituent parts. The black box view addresses the performance of the model in relation to its external influences and ignores the performance of the constituent parts. Love (1980) working in a related area has argued that the black box view in isolation cannot establish confidence over areas of performance which lie outside the bounds of historical measures. Love examined this issue further and noted that in the majority of applications, models will be used to predict system performance beyond that which can be validated against historical data. It was concluded that under such conditions model validity cannot be tested to 100%, and that the validity of the internal mechanisms (logic, data etc) are of enhanced importance. It was considered that these arguments applied to this work, in that a model was required in the policy design environment, precisely because the real system could not be used for experimentation.

In addition to the above, two philosophical views exist (discussed in Emshoff & Sisson (1970)) on the test of truth. The first of these is described as the empiricist's view in which the inclusion of unproven elements (data, relationships, entities, behaviour, etc.) is proscribed. Under this philosophy the test of validity is made in absolute terms; any failures of such tests are excluded from the study. The second and alternative view to this is known as the rationalist's view. This recognizes the existence of system elements which cannot be fully defined or validated and accepts their inclusion in approximate terms rather than deny their effects. This view often finds favour in continuous modelling studies such as the application of "system dynamics" (Forrester (1961 & 1971)).

The above issues can be expressed as a two dimensional surface on which model validity can be mapped. On this surface, deficiencies in tactical validity (eg. concern over certain elements) could be offset by a generally high adherence to the empiricist's view. However tactical deficiencies and a high reliance on the rationalist's view would not be mutually supportive and would raise doubts over the applicability of results.

One view of validity which goes some way toward reconciling the above issues, is Herman's criteria (1967). These provide a structured multi-level approach to validity, combining black box and white box issues with both quantitative and subjective measures. Herman suggested the following five validity criteria.

1. Internal Validity.
2. Face Validity.
3. Variable Parameter Validity.
4. Event Validity.
5. Hypothesis Validity.

Descriptions and analyses of the above can be found in Herman (1967) and Emshoff & Sisson (1970).

One immediate problem with assessing the validity of the FCL model, is that of a paucity of data. This was limited to 12 months operational experience. The situation was aggravated by the fact that much of the performance data relating to the total system (eg. product due date accuracy, total inventory, etc.) had not been recorded against consistent measures.

This problem echoes that discussed by Love. It was therefore appropriate to adopt a similar strategy to achieve confidence in the total model. This relied on an examination of the model's sub-elements to establish "white box" validity. "Black box" validity was then established by comparing the model's performance to historical data. This then established a validity datum which together with the "white box" data provided confidence in the model's ability to test alternative policies for which there were no historical data. The following were evaluated as separate entities:-

1. The market model.
2. The MRP model.
3. The PCB simulator.
4. The assembly simulator.

The nature of these elements was such that each comprised a model in its own right with separate validity issues. Each was therefore tested against it's own requirements. These will now be discussed separately.

7.9.2 Validity of the Market Model

The data relating to the market model must be discussed on two levels. At the first level, the historical data gathered from FCL represented the actual market demands (firm sales orders) and actual demand forecasts. During the 12 months over which data had been recorded, the forecasting technique and the market segments had remained constant. All of the live products were modelled, with the exception of a small number of products representing 10% of the shop load. Therefore, validity was assured for the data relating to this portion of the market model.

At the second level, the market model data represented one of the primary control variables for the experiments. Therefore, a number of alternative data sets were generated to represent differing market and operational conditions. This included various load levels, smoothed demands and the removal of the forecast element. The only question of validity relating to this portion of the market model data was the validity of the assumptions behind these experimental parameters. This will be discussed with reference to experimental design in Chapters 8,9 and 10.

The operation of the market model has been discussed in 7.5 and has been shown to be a replication of actuality. On this basis the market model was considered to be valid.

7.9.3 Validity of the MRP Model Element

The use of TMS to represent the MRP elements ensured functional validity. The remaining issue concerned the validity of the data and policies. The data used within this element was a copy of the live database which had been edited to remove purchased parts and 10% of the live manufactured parts. On this basis it was considered that this data was of unquestionable validity.

The control policies and parameters again form part of the experimental parameters and thus will be discussed with reference to experimental design.

Operation of the MRP element was discussed in 7.4. It was shown that in the interactive mode this element functioned in exactly the same manner as FCL's live system. In consideration of these points the MRP element was accepted to be a valid model of FCL's live system.

7.9.4 Validity of the PCB and Assembly Manufacturing Models

The PCB and assembly manufacturing simulator represented the primary sources of uncertainty with respect to validity. Confidence in the simulator's ability to represent FCL's production facilities was therefore fundamental to the applicability of the policy recommendations to FCL.

The primary concern was recognized to be the manner in which the simulator reacted to changes in the size and timing of production orders, resulting from changes to the operational policies. It was considered that Herman's five criteria offered the most complete test of the PCB and assembly manufacturing model's validity. However, these criteria are traditionally associated with the assessment of the validity of a complete model and would therefore require some adjustment when applied to a sub-element. This adjustment was related to the analysis of event and hypothesis validity (criteria 4 and 5).

It was recognized that these two criteria were inextricably linked to the performance of the simulator with respect to its global environment. For example, an assessment of event validity in which simulation performance would be tested against historical data, could not be completed in isolation from the market MRP and production elements of the model. The performance of the three elements is interlinked in such a way that an assessment of event validity of one element would automatically constitute a test of event validity of the remaining two elements. To this extent an assessment of production simulator event validity could not be separated from an assessment of black box validity of the total model.

Similarly, hypothesis validity (in which the linkages between the system elements are investigated and tested) could not be performed on the production simulator in isolation. In view of these points, it was considered appropriate to apply the first three of Herman's criteria to the production simulator in isolation and to use criteria 4 and 5 as the basis of a validity analysis of the total model.

Herman's first criteria (internal validity) applies to the internal mechanisms and linkages of the model and is a test of both the model design (validity) and the execution of that design (verification). Internal validity tests are typically associated with multiple replications with the control parameters held constant. This provides a check of the interactions between the various stochastic elements contained within a traditional model. However, the deterministic nature of the internal elements of the production simulator removed the need for this approach. Thus, the remaining issues associated with this criteria were defined as; the validity of the model design and a verification of its implementation (ie the operation of the model logic).

Exhaustive discussions with, and involvement of, the manufacturing personnel during the model design were used to gain confidence in the first element of internal validity. This included a rigorous examination of the activity cycle diagram logic with the relevant personnel and separately with FCL management. Following these sessions, it was agreed that the model logic was a valid representation of the PCB manufacturing and product assembly operations.

The second part of internal validity testing involved a series of verification experiments to establish the representation of the ACD logic within the model coding. Full use was made of the graphical nature of the model and the standard verification utilities included in the Optick package. Additional test parts were created within the product databases to assist in these tests. For example, batches of a part which sequentially visited each work centre were used to test the transport, set and process logic routines.

Herman's second criteria (face validity) is a subjective test of the "look and feel" of the model surface (output). Again the graphical nature of the simulator considerably aided this assessment. Three tests were performed, each of which comprised the use of a separate group of operators, setters and supervisors. Each group assessed the "reality" of the model operating to a historical production plan. The subjective measurements used included; the length of input queues, the amount of idle time at each work centre and work centre load imbalances. The model passed each of the three independent test sessions.

It was found that the graphical nature of the model allowed a number of actual production problems to be identified and vocalized. One particular issue which the model demonstrated (and was immediately recognized to be valid by the production staff) was the different utilization levels of each work centre and the existence of flow bottlenecks. These sessions resulted in an additional and welcomed by-product in that those production personnel who had participated in the test sessions, became enthusiastic ambassadors for the model.

The third and final application of Herman's criteria (to the production simulator in isolation) was that of variable parameter validity. In essence this criterion is intended to test the validity of the model's reaction to changes in operational parameters. A purely quantitative analysis of variable parameter validity was made impossible by the complete lack of variable parameter performance data for FCL. This issue is closely related to those discussed with respect to the limitations of black box validity in isolation and again echoes those points made by Love. However, a qualitative appraisal was undertaken which did make a useful contribution to the assessment of validity. The first test was of the production hardware configuration. Alterations were made separately to the number of setters, operators and work centres. Assessments of simulated shop performance were then made. Again, three separate and mixed groups of production personnel were used to perform these qualitative assessments.

The second series of tests were of potentially greater importance in that the size and timing of WIP orders were chosen to be the varied parameters. Alternative production plans were generated with variations in mean order quantity and workload. The production simulator was then run against these in turn. The performance was assessed using the same assessment groups as for the test outlined above. The simulator was found to exhibit characteristics in line with those expected of the production facility.

On this basis the production simulator was accepted to be a valid representation of FCL's facilities, when viewed in isolation from the control elements. It is accepted that each of the tests outlined above include subjective elements. However it is argued that quantitative analyses would be of little value without historical data to underpin them. It will be shown that the tests involving the complete model further support validity and largely negate these limitations.

7.9.5 Hypothesis Validity of the Total Model

The interactions between the elements of the total model were discussed in detail (in 7.2 & 7.6) and were shown to be a replication of actuality. On this basis hypothesis validity was considered to have been achieved.

7.9.6 Black Box and Event Validity of the Total Model

Black box validity was addressed by comparing the performance of the FCL model to the historical performance of FCL. The recent changes and subsequent lack of data, posed a number of problems in this respect. Consequently, the following test was devised.

The only area of FCL which had been subjected to consistent measures of performance, was the PCB facility. Of these, WIP and flow time could be considered to be measures of total system performance, as these were dependent on the interactions between the market, production control and manufacturing elements. In the raw state, these data were biased by a large number of batches which had earlier been released as incomplete kits. However, with some care it was possible to determine the current level of WIP which corresponded to complete kits and which was flowing from work centre to work centre (fluid WIP). The current average fluid flow times were also determined. The fluid WIP and fluid flow times were found to be 3650 PCBs and 14 days respectively.

The control policies for the FCL model were made equivalent to those policies currently in force at FCL and the model was run against the previous 12 months MPS and sales data. The average PCB WIP and flow times were found to be 3450 PCBs and 12.5 days respectively. The WIP value was within 5% of the historical data, whilst the flow time data was within 11%. The model's under evaluation of flow time could be explained by late booking of closed WIP orders, which was known to have occurred at the time.

In addition, a comparison of the current status was made at which the WIP queues at each work centre within the model were found to correspond closely with those on the shopfloor. It is significant to note that during these tests the model correctly predicted a rare transient bottleneck (which was evidenced by a 1,000 PCB queue in front of the flow solder machine). This level of match is usually only associated with predictive on-line simulators such as those discussed in 7.7.

On this basis it was considered that the FCL model was a valid tool with which to evaluate alternative policy sets for use at FCL.

8. APPLYING THE METHODOLOGY TO FCL

8.1 Introduction

Chapter 5. introduced a structured policy design methodology based on a holistic view of policies and their effect on manufacturing system performance. This methodology was centred on utilizing the "low inertia" characteristics of AMT facilities and adapting a JIT configuration of MRP. A reduction in the level of MPS de-coupling was seen to be a fundamental goal of policy design.

This methodology adopted a three stage approach. Stage I was to determine the basic performance characteristics of the supply element of the system under investigation, with the inclusion of appropriate sensitivity tests.

Stage II was to derive core policies commensurate with the minimum inventory conditions. A combination of the "first principles" approach and appropriate experimentation was proposed for this stage.

Finally Stage III was to address any remaining mismatches in system performance, and the development of limited appropriate safety policies.

The primary requirements of this work are; the successful integration of MRP and the AMT based manufacturing facility, and the alignment of total system performance to the requirements of the marketplace.

This Chapter will discuss the application of Stage 1 *of the methodology* proposed in chapter 5 to policy design at FCL.

Successful integration is dependent on matching the performance of the system elements at their boundary interfaces. Within each element policy decisions were used to define system performance.

In terms of FCL's requirements, the boundaries of the problem related specifically to PCB manufacture. This included a detailed design of operational policies for both MRP and the PCB manufacturing facility. In Chapter 6. a typical bill of materials from an FCL product identified PCBs to be low level components (typically bill of material level 3, 4 or 5.) Following the arguments proposed in Chapters 2,3,4 and 5, consideration of PCB manufacture and policy design could not be viewed in isolation from parent items. Interactions between market place uncertainty and higher levels of BOM would invalidate any policy set designed in isolation of these issues. Therefore, it was determined that final assembly and sub-assembly operations must be included in the study.

At each BOM level the availability of purchase components was assumed (the justification for this assumption was discussed in Chapter 5.). The design and operation of the experimental facility on which this work is based was discussed in Chapter 7.

8.2 Identification of Operational Policies by Element

The goal of Stage I was to determine the performance characteristics of the separate elements of the total system and to identify those policies of interest.

The first action within Stage I of the policy design methodology was to identify those operational policies that were to be considered by all stages of the methodology and to group them by their appropriate system element. From the preceding work it was recognized that in the first instance policies for consideration would be restricted to those which offered potential support for, "low inertia" shopfloor characteristics and a JIT configuration of MRP. Consequently, the findings discussed in Chapters 2,3,4 and 5 were used to limit policy choices.

At the MPS level, policies considered by this work were as follows:

1. **The inclusion of a forecast element in the MPS demands.** The work of

De Bodt & Van Wassenhove (1980, 1982 and 1983) in the area of MPS uncertainty, identified the generally poor performance of a number of popular forecasting algorithms. They have reported a consistent 25% forecast error which is independent of the algorithm used. In view of this, selection of a particular forecasting algorithm was not included in this work. Effort was concentrated on the potential benefits of including a non-specific forecasting algorithm against a sales-only derived MPS.

2. The timing and grouping of MPS demands. FCL specified MPS demands in the time bucket closest to the beginning of the next financial period. An alternative to this, in which demands were staggered throughout each month, was evaluated.

3. The length of the MPS horizon. This is related to a number of important issues which include, MPS system performance (in terms of processing time) and WIP order instability and purchase order instability. For the orders generated by MPS processing to be relevant to all levels of bill of material, the MPS horizon must be greater than the longest composite lead time. Consideration of MPS horizon was in the first instance limited to investigations of composite lead time, resulting from alternative policy decisions.

The MRP policies considered by this work are as follows:

1. Lead time policy. FCL used a generic lead time policy in which all parts of a similar type were given a fixed generic lead time. There are a number of alternative policies, most notable of which are those known as linear lead times, in which a linear mathematical function is set to represent lead time. This work compared the effects of the current generic lead time policy with an alternative linear policy. Additional work addressed the parameter and constant values within the lead time policy.

2. Order Policy. TMS supported four alternative order policies. These were; make to order, variable length time bucket, synchronized time bucket, and MPS. Of these the fourth (MPS) was not of interest to this work as it related to an order policy which is reliant on the MRP II configuration and is confined to the bill of material level zero. Of the three remaining policies, it is interesting to note that none are particularly sophisticated and did not include any "optimising" functions. One consequence of this was the limited horizon sensitivity of WIP and purchase orders generated using any of these policies.

3. Pan size and minimum order quantity. In addition to the order quantity, TMS supported the use of pan size and minimum order quantities in the generation of WIP and purchase orders. These were applied to order processing after the order policy. The pan size related to a multiple value which was used to "round up" order quantity. The minimum order quantity was as its name implied.

4. Stock policy. The final component of the order quantity calculation related to a minimum or safety stock level. When a non-zero value was specified for the stock quantity, TMS generated orders to maintain the stock value above the specified lower limit.

5. MRP Time Bucket. TMS supported the use of a user defined time bucket length. The specification of this value is a complex issue and it is generally acknowledged that smaller time buckets result in more sensitive MRP systems. However, TMS supported a day dating facility under which individual WIP and purchase orders were related to the actual date of their requirements, rather than a less specific timing based on time buckets. In this situation, the length of the time bucket is of primary concern to the operation of the order policies (if a time bucket based order policy is used). It was considered that the duration of the time bucket should be related to the cyclical nature of management decision periods. This included such issues as the duration over which production plans were considered to apply and the frequency of reporting statistics. At FCL the time bucket was set at one working week. This was synchronized with the production planning period and the management reporting statistics. In addition, MRP regeneration was also run on a weekly basis. It was considered that the one week time bucket and weekly MRP regenerations represented a good working compromise between system sensitivity and data degeneration. Therefore in the first instance, time bucket duration was not considered until the implications of likely system performance under any recommended alternative policy was known.

Shop policies considered by this work were limited to the following:

1. **Priority and sequencing rule.** At the outset of this work a structured approach to priority rules and job sequencing had not been adopted. WIP tracking was performed on a "progress" basis. The current level of WIP order stability and order backlogs resulted in a "fire fighting" approach to WIP order progress. Typically the high level of late orders resulted in a loose and informal priority being applied to the latest job. An alternative flow based approach was evaluated.

2. **Batch Splitting.** WIP orders were released and maintained as complete batches of work, the size of which is dependent on the TMS order generation logic. An alternative approach using a transport batch technique, in which order quantities are broken down into smaller transport quantities, was assessed. This was closely linked to the flow based approach to work sequencing discussed above.

3. **Work Centre Utilization and Work in Progress levels.** These two are not necessarily shop policies, but are more correctly performance targets which affect operator and management priorities. Under the traditional approach work centre utilization is seen as a performance target to be achieved by individual work centres. When this approach is adopted a number of consequences for work flow result. For example, high levels of work centre utilization often result in

supervisors and operators assigning high priority to the achievement of standard hour targets, whilst transfer of work from one work centre to the next is seen as a relatively low priority. These effects can be viewed as a group which determines the shopfloor scenario. This was represented experimentally by a parameter set referring to the time taken to transfer work from work centre to work centre and the size of the transfer quantity. This was considered as an adjunct to the flow based parameter set discussed above.

The use of finite scheduling (and related techniques) for shop load balancing and priority assignment were excluded from this research because of serious doubts over their stability in the uncertain environment in Chapters 4. and 5.

8.3 Market Demand

The near "greenfield" nature of manufacturing operations at FCL resulted in a paucity of market data. The principal market in which FCL operated was new and, at the time of the research, was limited to 12 months operational experience of; customer demand uncertainty, delivery requirements, market segment growth, etc. Discussions with FCL management and a review of the limited data concluded that the product range would continue to diversify at the same rate and that the customer base would maintain the current level of uncertainty and delivery requirements.

The market model boundaries were defined as follows:

1. The study was limited to the current market environment as defined by data relating to the previous 12 month's operation.

2. Policy design work concentrated on the effects of lead time reduction and re-coupling within this environment.

It was considered that this approach would allow the current and future manufacturing capability to be defined. This would pave the way for a future re-assessment of FCL's strategic positioning in the market place. The historical data relating to FCL's market demands is contained in the MPSs shown in Appendix 3.

8.4 The Behaviour of Supply and Production Control Elements

A general application of this methodology would include relevant historical data on the performance of these elements. However, the paucity of data at FCL demanded a greater reliance on the use of the experimental facility.

The performance of the MRP and manufacturing elements was considered separately against performance criteria relevant to each element. In the first instance, a sensitivity analysis against MPS load and lumpiness was performed against the original policy set to determine the areas of highest potential. The objective was to determine the performance characteristics for each element against the current product mix (as defined by the historical MPS). This facilitated an analysis of the production interactions at the work centre level and the potential for adopting "flow based" shop policies. This analysis was limited to PCB manufacture.

For this Stage, the time efficient non-interactive mode of experimentation was used since total system performance was not under consideration. This precluded an analysis of the effects of demand uncertainty which will be considered in Stage II.

8.4.1 Performance Criteria for MRP and Manufacture

The performance criteria for MRP were defined as characteristic measures of the production plan for a given MPS and policy set. In the first instance, those characteristics which were considered most likely to offset manufacturing performance (in terms of flow characteristics), were load and lumpiness. Therefore, for this stage the measures were; average period input load in standard hours and production plan smoothness measured as the coefficient of variation.

It was recognized that the non-interactive experimental mode used for this Stage would invalidate measures such as due date performance and stock levels. Therefore, for this Stage the performance criteria for PCB manufacture were limited to measures of throughput. These measures were average PCB WIP and average PCB flow time.

8.4.2 General Performance Experiments

A static (deterministic) version of the historical MPS was generated. Then four additional MPSs were generated. The first two had identical product mix and demand timing to the original MPS but each had individual demands increased (or decreased) by 25%. These two formed the basis of a sensitivity analysis against load.

The second two MPSs were generated to form the basis of a sensitivity analysis against MPS lumpiness. Bobko and Whybark (1985) have discussed measures of MPS lumpiness and have highlighted some significant limitations of the most commonly used measure (coefficient of variation (cv)). They have demonstrated that cv alone is not sufficient to characterize an MPS and suggested that a measure of the spacing of MPS demand in time be included in the characterization of an MPS. In particular they recommend that the ratio of zero to non-zero demand periods be used to define spacing.

These deficiencies were recognized during the generation of the lumpy and less lumpy MPSs. The technique used to generate a plus 25% lumpy MPS, was designed to maintain product mix and overall load at the MPS level. This was as follows:

1. The average number of zero periods and cv was defined for each product line.

2. A plus 25% value of cv was then calculated for each product line.

3. Adjacent demands were then combined at random along the length of the MPS until the target cv value was met for that product line.

4. Individual demands were then moved in time such that a similar distribution of zero demands was maintained.

The original and modified MPSs are contained in Appendices 4 to 8. Each of these was then processed by TMS against the original policy set. The production plan loads so produced are shown in Tables 7. and 8.

Each of these production plans was then used to drive the factory simulator. The experimental data recording start point was determined from analysis of WIP accumulation. It was found that WIP levels reached stability in period seven. On this basis the start point for data collection was set at period 8 (this issue was discussed in section 7.9. The experimental run length for this series was set at three times the natural frequency of the variation in production plan load. From Tables 7. and 8. this was determined to be approximately four weeks. Therefore, a run length of 12 weeks was required giving an experiment duration of 20 simulated weeks.

In order to test the potential of "flow based" shop policies a range of transport batch sizes were evaluated. At the upper bound, a transport batch size of 999 was used to represent the existing practice of maintaining batches in their original order quantities. Since the largest order quantity was 650, no batch splitting would occur. At the lower bound, following discussions with shop management it was considered that transport batches smaller than 20 would present significant human resource problems. For this reason, it was decided to set a lower bound of 20. Analysis showed that the existing average batch size without batch splitting was 76.5 with a lower limit of 20 and an upper limit of 650.

Table 9. shows average PCB WIP level (measured in PCBs) against mean batch size for the original MPS +- 25% lumpiness. Table 10. shows average PCB flow time (in days) for the same MPSs. These results are plotted in Figures 18. & 19. for transport batch sizes 20, 50 and 999.

These results (Figures 18 and 19) reflect the way in which the output from a lumpy production plan is to some extent automatically smoothed by the capacity limitations of the production facility.

The smoothest production plan resulted from the smoothest MPS and was such that the production facility was maintained at an approximately constant load. Consequently work centre queuing had a minimal effect on WIP and flow time. However with the original MPS the production plan lumpiness was such that work centre queues formed during the periods of highest load. Consequently, average WIP levels and average flow times both suffered from the effects of increased work centre queuing.

At the highest level of MPS lumpiness, the production plan was such that the production facility alternated between severe overload and complete lack of work. During the periods of overload the flow times of the majority of batches suffered greatly from the effects of the large work centre queues. During periods of inactivity the batches that were launched were completed quickly, although the small number of such batches had a marginal effect on the measurement of average flow time. Thus the flow time statistic indicated a further deterioration of production shop performance. However, the cyclical nature of the shop load resulted in only a marginal change in average WIP levels, with the periods of heaviest load being offset by the periods of very low load.

An analysis of the effect of employing transport batches is shown in Figures 20. & 21. It is clear that there is significant potential for shop performance improvements by the use of transfer batches. It is particularly interesting to note that this improvement is maintained up to the lower bound (transport batch = 20). This suggests that the PCB facility is not particularly sensitive to the potential capacity loss, due to increased set up operations at the original load level.

The factory model was next run against the production plans generated against the original MPS +- 25% load. Table 11. shows the average PCB WIP and flow times associated with these production plans, for various transfer batch sizes. These results are plotted in Figures 22. & 23.

Again it is evident that the use of transfer batches yielded significant performance improvements throughout the range tested. In addition, average WIP and flow times are consistently higher with increasing MPS load.

Both of the flow time analyses (Figures 21. & 23.) indicated the existence of an element of bias at the higher values of transfer batch. It was suspected that the experimental run time was insufficient for the larger batches to be measured for flow time on their exit from the system. A review of the experiment duration was therefore required prior to the next series of experiments.

This concludes the application of Stage I of the policy design methodology to the FCL case.

Fig 18. Mean Flow Time (days) v MPS cv.

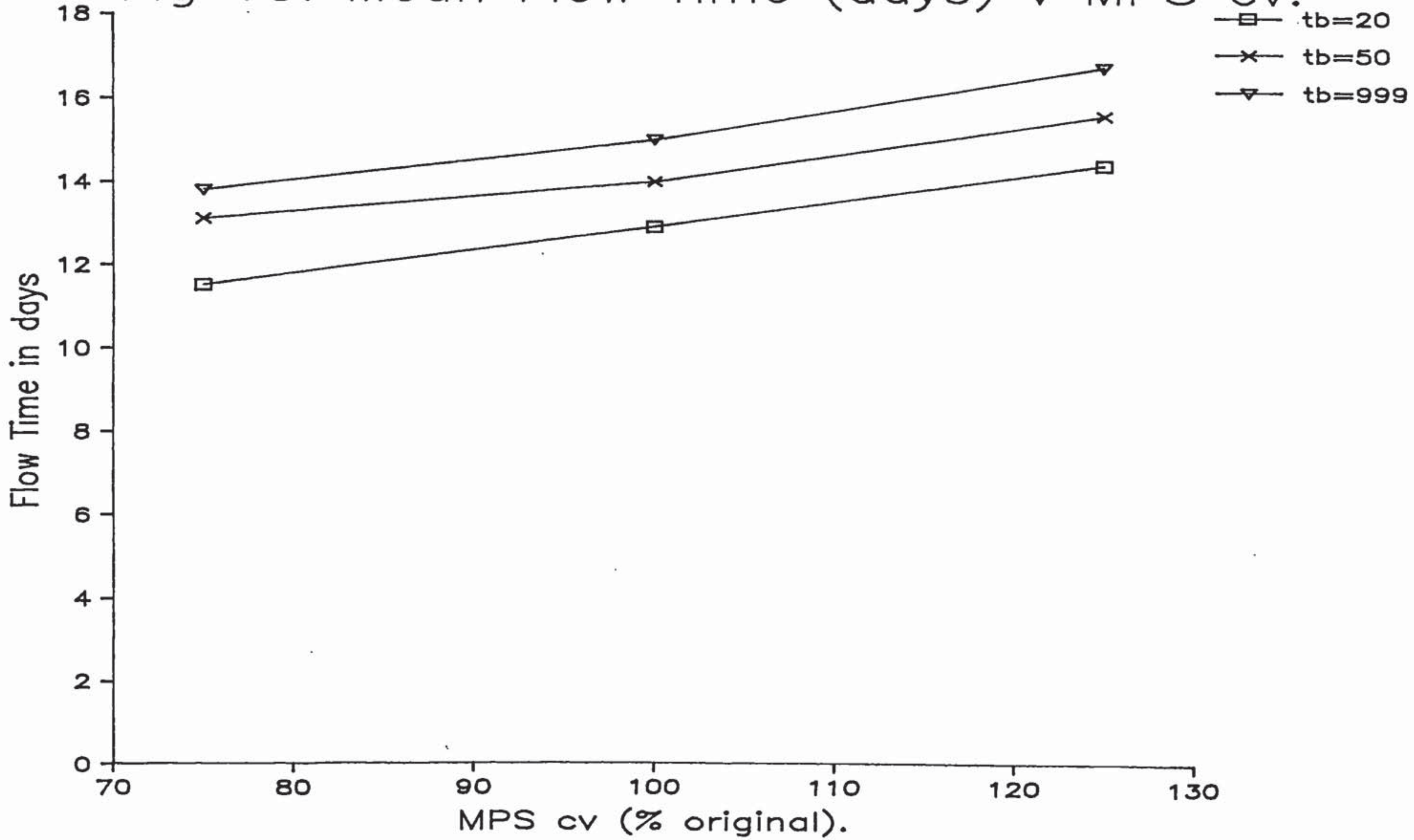
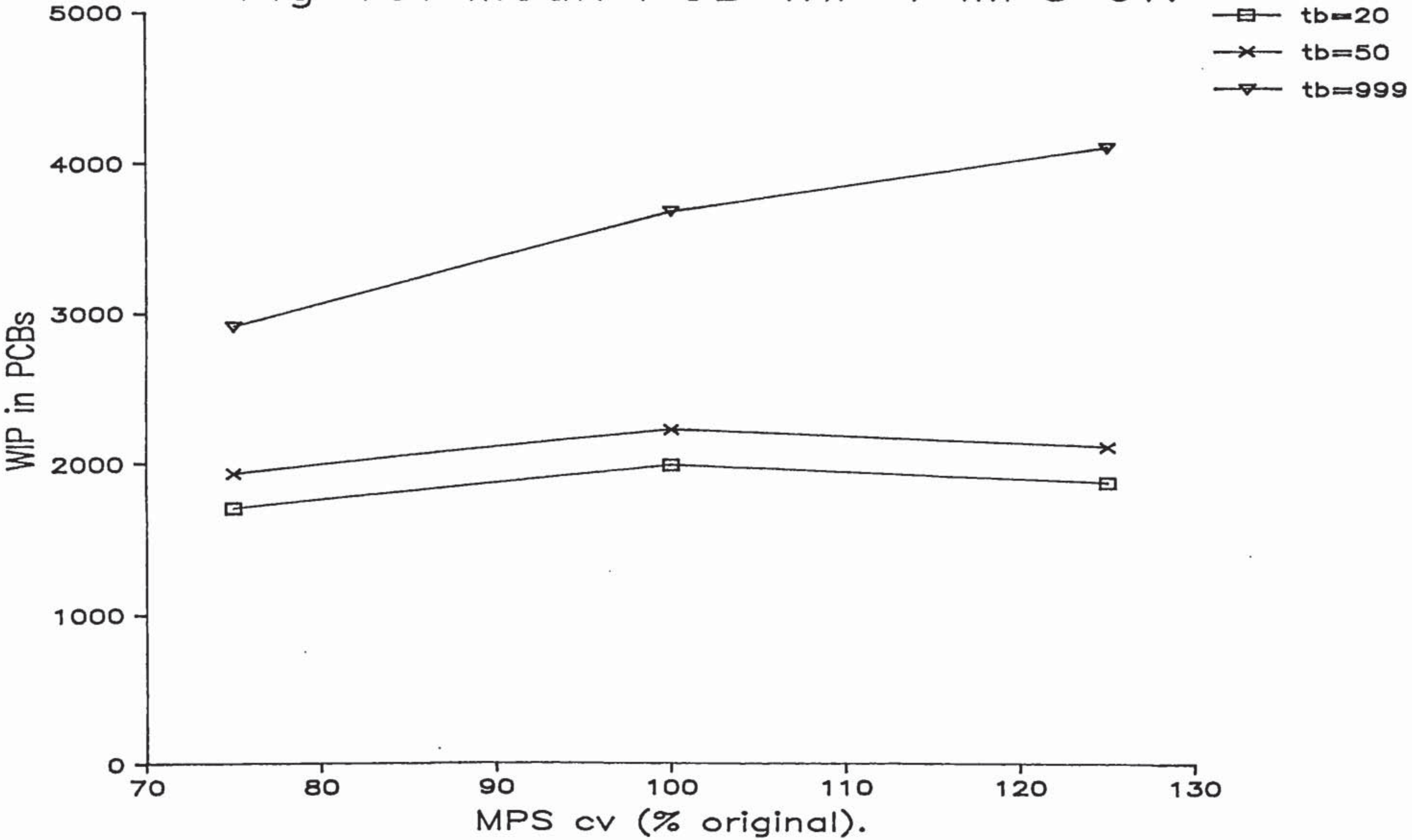


Fig 19. Mean PCB WIP v MPS cv.



Period no.	Period Load in st.h. MPS Load 75-125% (CV=100%) 75%	100%	125%
1	801.785	925.3279	1107.277
2	86.5853	92.0807	122.6138
3	1685.02	1999.377	2657.763
4	1029.914	1414.644	1802.102
5	136.9602	179.1158	230.6162
6	200.4988	331.5652	421.7796
7	2746.233	3289.133	4134.041
8	893.403	1195.266	1611.85
9	319.84	368.0088	455.1515
10	1806.711	2361.066	2818.134
11	1213.736	1490.712	1873.082
12	1057.944	1443.359	1869.685
13	281.3418	406.3011	481.4999
14	1418.692	1721.187	2243.197
15	1047.129	1103.37	1476.725
16	813.2369	1072.812	1395.5
17	577.2512	777.1858	965.147
18	2186.298	2772.609	3613.636
19	1072.527	1432.96	1756.792
20	1153.777	1534.759	1863.904
mean	1026.4442	1295.5420	1645.0248
st.d.	681.20304	833.53633	1059.3658
CV	.6637	.6434	.644

Table 7. Production plan load for MPS +- 25% Load

Period no.	Period Load in st.h. MPS CV 75-125% (load=100%) 75%	100%	125%
1	820.2542	925.3279	1169.456
2	130.413	92.0807	136.5849
3	119.531	1999.377	2629.341
4	1131.197	1414.644	2037.783
5	1248.175	179.1158	203.0491
6	1381.938	331.5652	427.4161
7	1260.612	3289.133	3119.349
8	2094.806	1195.266	2026.388
9	1796.988	368.0088	449.3864
10	1590.265	2361.066	2186.742
11	2148.982	1490.712	1004.36
12	1077.624	1443.359	691.7467
13	1299.492	406.3011	517.3036
14	990.778	1721.187	2088.534
15	1859.892	1103.37	1363.914
16	257.804	1072.812	998.1854
17	446.6284	777.1858	910.5548
18	2768.596	2772.609	3170.68
19	1361.774	1432.96	1249.729
20	1155.189	1534.759	713.9282
mean	1247.047	1295.542	1354.722
st.d.	675.0268	833.5363	914.2882
CV	.5413	.6434	.6749

Table 8. Production plan load for MPS +- 25% Lumpiness

Transport batch size	Mean PCB WIP (in PCBs) MPS cv=75%	MPS cv=100%	MPS cv=125%
20	1703.169	1988.890	1876.80
40	1933.276	2227.962	2111.52
80	2912.489	3684.558	4111.55

Table 9. Mean PCB WIP v Mean Batch & MPS cv.

Transport Size batch	Mean PCB flow time (days) MPS cv=75%	MPS cv=100%	MPS cv=125%
20	11.521	12.936	14.457
40	13.106	14.032	15.628
80	13.798	15.032	16.777

Table 10. Mean PCB Flow Time v Mean Batch & MPS cv

	WIP in PCBs MPS load (% original)			Flow Time in days MPS Load (% original)		
	75	100	125	75	100	125
tb=20	1338	1988	2955	10.9	12.93	14.43
tb=50	1523	2227	3232	13.58	14.03	14.62
tb=75	1778	2578	3629	14	14.81	16.89
tb=100	1875	2765	3984	14.7	15.21	16.96
tb=999	2508	3833	5698	13.3	13.8	16.13

Table 11. PCB WIP and Flow Time Against MPS Load and Transfer Quantity(tb).

Fig 20. PCB WIP v Mean Batch Size.

Original policies; MPS C.V's, 75 -125%

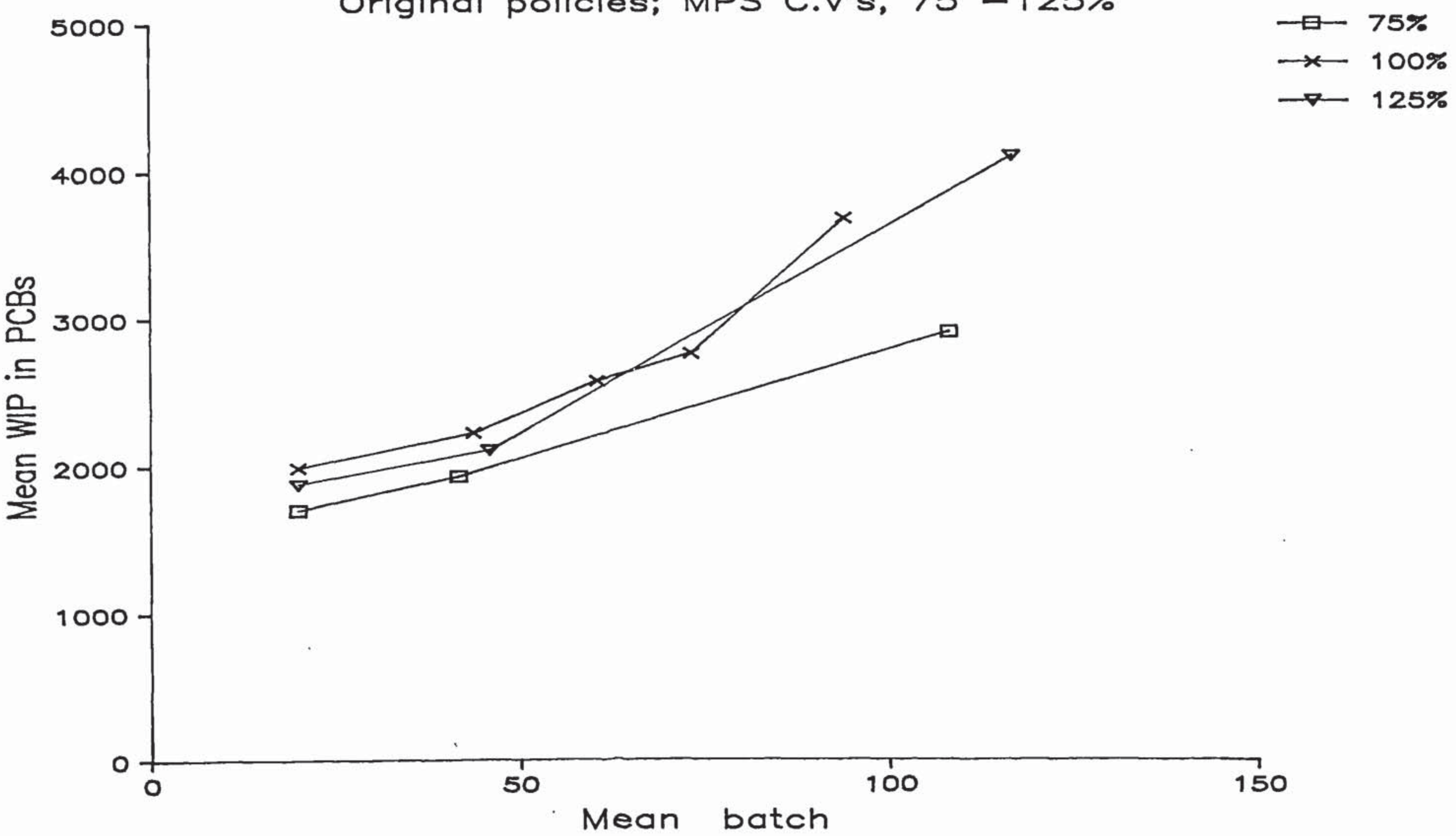


Fig 21. Flow Time (days) v Mean Batch Size.

Original policies; MPS C.V's, 75 -125%

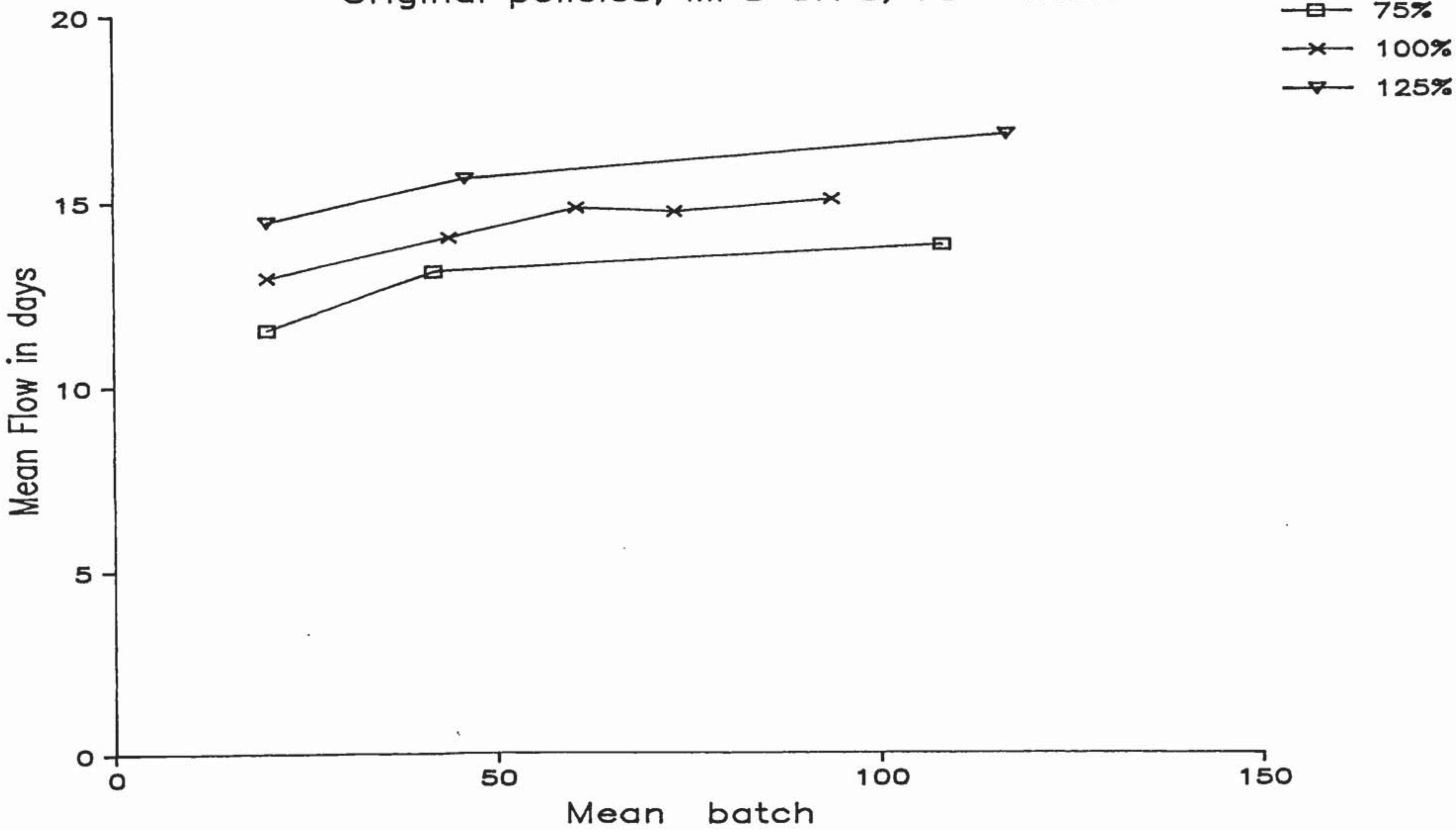


Fig 22. Flow Time (days) v MPS Load.

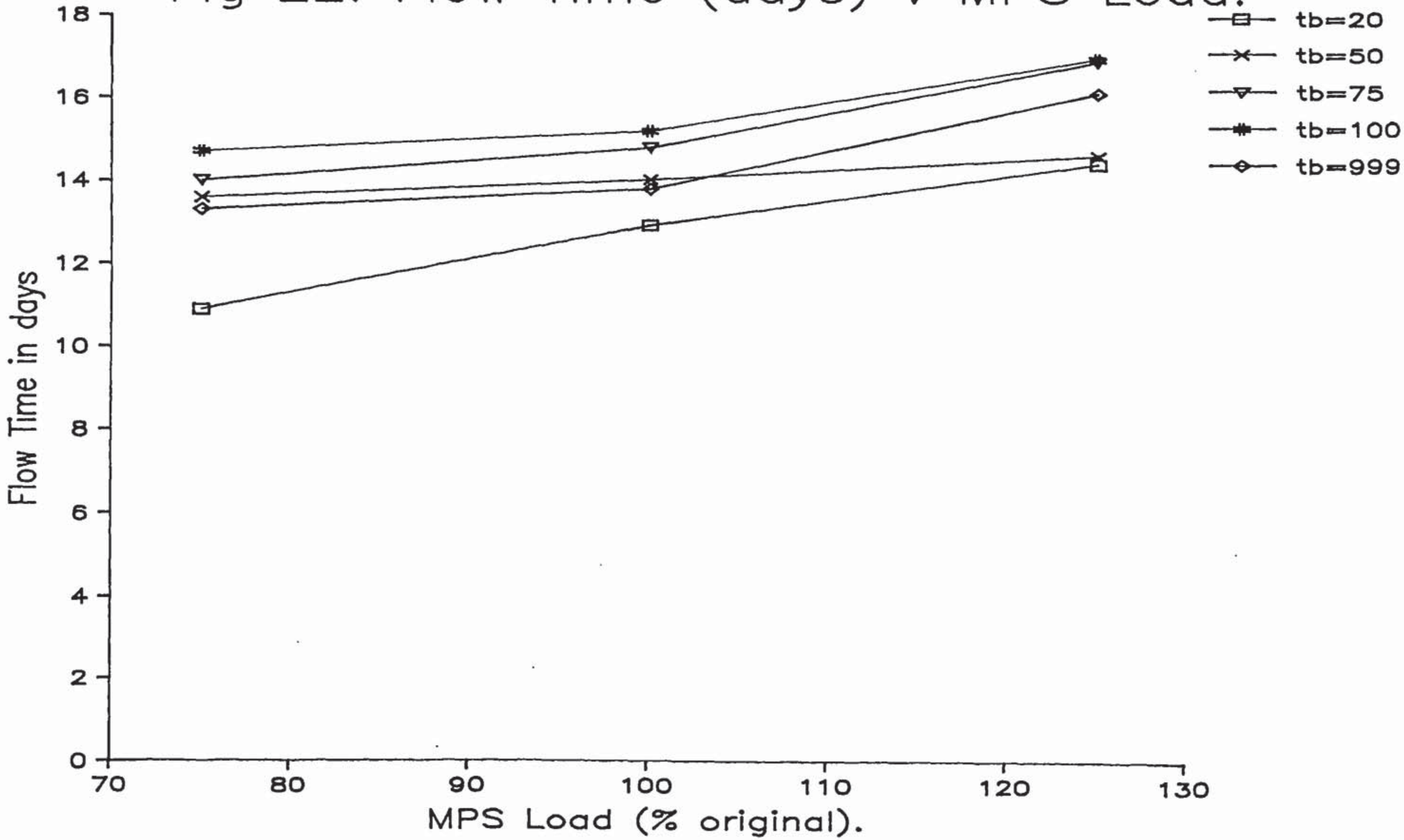
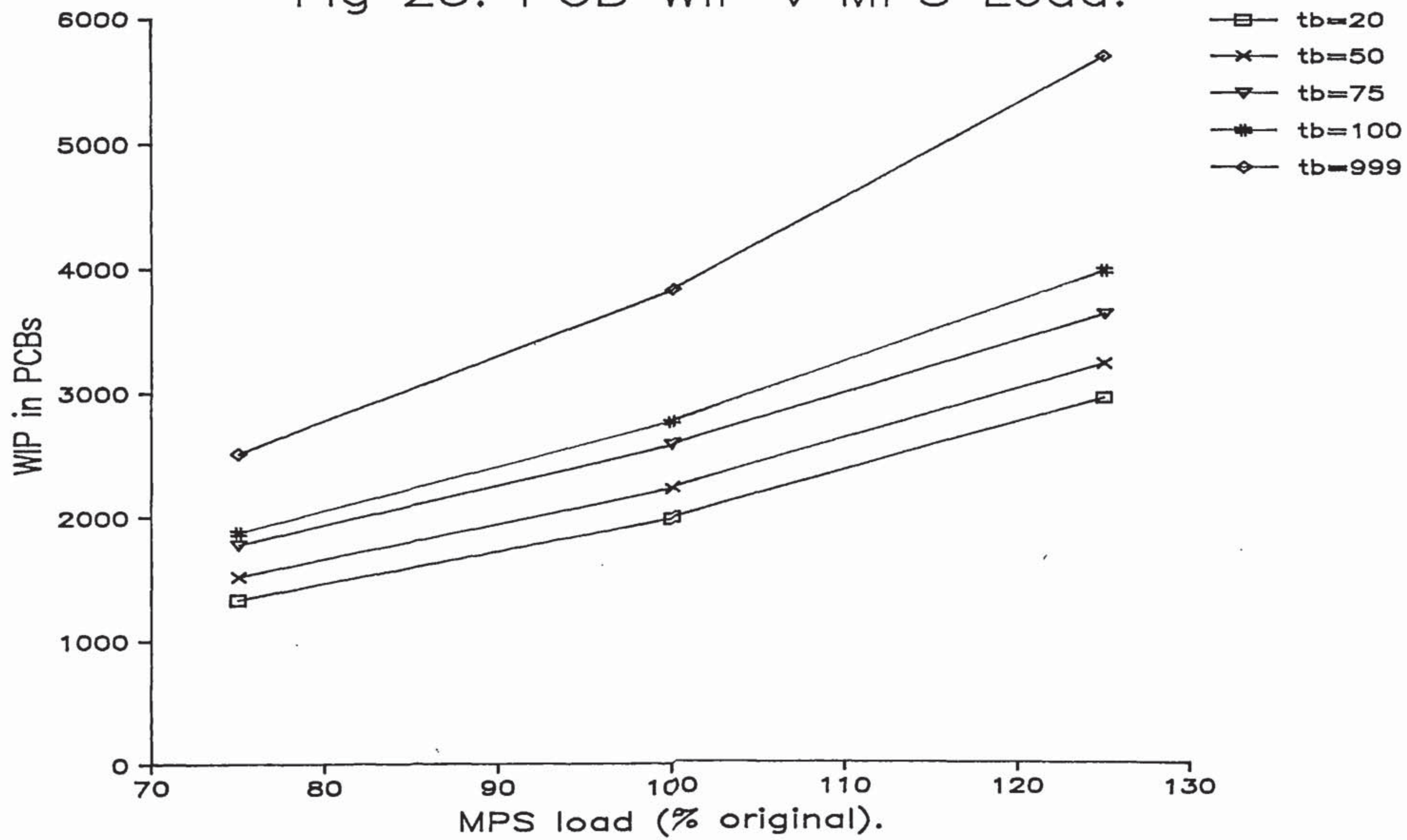


Fig 23. PCB WIP v MPS Load.



9. FORMULATING FLOW BASED POLICIES (STAGE II, PART I)

9.1 Introduction

The objective of Stage II of the methodology is to minimize the inertia of the manufacturing system, such that the need to de-couple manufacturing operations from the marketplace can be minimized. Stage II is in three parts; Part I covers the formulation of flow based policies, Part II covers the exposure of the supply and production control elements to the uncertainty of the market place ('re-coupling') and Part III covers the establishment of production flow times in the re-coupled environment. Stage II is presented in the following sequence:

1. **This chapter** will discuss the formulation of flow based policies **(Stage II Part I)** Data from Stage I was combined with those findings discussed in Chapters 2., 3., 4. and 5. which are relevant to reducing manufacturing inertia. The speed and convenience of the non-interactive experimental techniques used for Stage 1 was again used for this. However, the limitations imposed by the lack of interactions were considered in the design and scope of the experiments. Consequently, experimentation was confined to a "quick and dirty" approach. This was recognized in the scope of the findings produced by this section.

2. **Chapter 10** will discuss the exposure of the supply and production control elements to the uncertainty of the marketplace **(Stage II Part II)** and the determination of production flow times **(Stage II, Part III)**. Data from FCL's previous 12 months manufacturing history was used to generate a model of FCL's marketplace, against which the performance of the policies derived above were evaluated. Fully interactive experiments with MPS uncertainty were used for this work.

The static and interactive experimental results obtained from Parts I and II formed a useful basis of comparison between the two experimental techniques. The first of these (the static mode) is commonly used in MRP research, whilst the latter is proposed by the author to be mandatory for evaluating policies to be used in the environment of uncertainty.

9.2 Flow Based Policies

9.2.1 Overview

The approach adopted in the design of flow based policies can be stated as mission objectives for the MRP and supply elements of the total system. The mission of the production control element was to produce production plans which were based on accurate forecast and actual requirements with order sizing and timing representative of actuality.

From Chapter 8. a strong correlation can be seen between MPS and production plan smoothness and system performance in terms of WIP and lead time. A popular MRP technique is to manually reschedule groups of orders in time to increase production plan smoothness. However, it is considered that the effects of marketplace uncertainty would have unpredictable and potentially adverse consequences on this technique. Therefore in the first instance "artificial" means of achieving production plan smoothness were not included. However, this does not mean that production plan smoothness should be ignored. It was considered that wherever possible, policy decisions which can positively influence production plan smoothness, but which do not introduce artificial sizing and/or timing constraints, should be adopted. In addition, the production plan must assume throughput rates which were achievable by the supply elements. This is closely related to the assumption of infinite capacity by MRP.

The policy choices affecting the generation of the production plan and considered by this work included; MPS timing and grouping, MPS horizon, lead time policy, order policy (including minimum order quantity and pan size), and MRP run frequency.

The mission of the supply elements (PCB manufacture, sub-assembly and final assembly) was to achieve the order completion dates specified in the production plan. This required that the throughput rates assumed during the generation of the production plan could be achieved.

The policy choices affecting plan achievement and considered by this work were; WIP launching policy, operation sequencing, and inter-work centre work transfer policies.

In recognition of the limitations imposed by the static initial experiments, the performance measures used were limited to those reflecting the ability of the shopfloor to perform against the production plans. For this series of experiments, measures were limited to WIP and flow time. The level of WIP on the shopfloor reflected the relationship between load and effective capacity and thus by implication, the utility of the policies used. The average flow time can be used as a relative measure since one of the objectives is to achieve short throughput times.

In the uncertain MPS environment, changes in demand would influence due date performance and stock levels. Therefore measures designed to reflect the total system performance, such as order completion accuracy and total inventory costs, were restricted to the interactive experiments.

9.2.2 Lead Time Policy

The ultimate measure of the performance of a total system is its ability to supply the market with the right product at the right time, at the right cost and the right quality. Of these, timing is directly related to the choice of lead time policy.

In Chapter 2. it was noted that MRP logic assumes that the lead time offset for each part can be determined independently of the netting and offsetting process. This assumption has been shown to be invalid in Chapters 2. and 3. where actual lead time (flow time) has been shown to depend on a number of factors, including the size and timing of production plan orders and the relationship between load and manufacturing capacity.

Whilst ultimate truth may not be attainable within the limitations of

MRP processing logic, the author's contention is that a close and workable approximation is possible. This issue then poses a question over the level of independence which may be assumed during the netting and offsetting process.

Early workers such as Orlicky (1975) proposed that almost complete independence was possible and even desirable. It was recommended that generic lead times were assigned to groups of similar parts. This approach had been adopted by FCL and all PCBs had been given a generic lead time of 20 working days.

One obvious problem with this approach was that the flow time of each class member differed in reality, therefore the generic lead time never truly represented individual members of the class. In addition, the generic lead time must by necessity be set at a value equal to that of the longest lead time for the whole class. Consequently, the quantity of slack or safety in the lead time value will vary from member to member. This will significantly restrict the ability to prioritise work on the shopfloor and will have a deleterious effect on order completion accuracy and component availability for the parent item.

A further problem with this technique is that of aggravated production plan lumpiness. This results from the fact that all orders at each level tend to be offset by the same time. For example, an order for a sub-assembly consisting of seven different PCB types would result in each of those PCBs being released (as WIP) at the same time, since each would have the same generic lead time.

One alternative to the generic lead time, is that known as a linear lead time policy, in which a linear function of operations and batch size is set to represent lead time. An example of a linear lead time policy is shown below:

LT = (total set-up time) + (batch size x total process time)
+ (number of operations x (average transport time
+ average work centre queue time))

The effect of this policy on production plan characteristics was evaluated and full use was to be made of the data generated in Stage 1. In the first instance, the average work centre queue (E1/n) was calculated by comparing the actual lead times with values calculated using the above policy but ignoring the queue element ie:

$$E1 = (\text{actual lead time}) - (\text{calculated lead time})$$

Samples of average flow time and batch size were taken from 25 assemblies and 25 PCBs from each of the Stage 1 experiments. These were then used to calculate values of queue element per operation against the general classes of PCB and assembly for each specific MPS load and smoothness.

Tables 12. and 13. show sample results and calculations for assemblies and PCBs respectively. The decision to categorize the parts by groups (PCB or assembly) for the calculation of E1/n, whilst rejecting generic lead times was based on the following rationale:

1. E1 was a function of the flow characteristics of a particular shop.

2. Absolute accuracy in the calculation of the linear lead times was not as important as the effects of distributing launch and due dates in time, for these experiments.

3. The sample size of the flow time was insufficient to determine valid E1 values per part type.

These E1 values were then used against the original MPSs with plus and minus 25% increments in load and lumpiness; the *original policies and* the linear lead time policy. Sample calculation, E1 for assemblies:

Calculated L.T. = (mean batch size x total process time)
+ (mean transport time x number of ops)

$$\frac{E1}{n} = \frac{uLTa - (uB \times P) + (n \times uT)}{n}$$

Type	No Ops	Tran Time	Mean Batch	Total Process	Calc L.T.	Act L.T.	El	El/n
2	1	120	22.72	.1667	.72343	1	.2766	.2766
3	2	120	22.22	5	14.388	15.33	.9425	.4713
10	22	120	20.67	2.5821	12.172	12.36	.1885	.0086
11	4	120	20	.3483	1.8708	3	1.129	.2823
12	1	120	30	.0833	.56238	1	.4376	.4376
13	2	120	25.16	3.3333	10.983	11.59	.6068	.3034
15	3	120	20	.1983	1.2458	2	.7543	.2514
18	4	120	2	11.3	3.825	5.15	1.325	.3313
22	8	120	6.69	1.1245	2.9404	3.45	.5096	.0637
23	13	120	5.6	.8086	3.8160	4	.1840	.0142
24	15	120	5.58	2.1561	5.2539	5.74	.4861	.0324
28	1	120	3.86	.1667	.33043	1	.6696	.6696
33	2	120	20	.0814	.7035	1	.2965	.1483
47	5	120	2	17	5.5	6	.5	.1
48	11	120	4	.8245	3.1623	4	.8378	.0762
52	3	120	2	.1667	.79168	1	.2083	.0694
55	1	120	2	.1667	.29168	1	.7083	.7083
57	8	120	10	.69	2.8625	3	.1375	.0172
67	5	120	6	19	15.5	16	.5	.1
69	2	120	19.95	1.1	3.2431	3.99	.7469	.3734
78	12	120	13.08	.7394	4.2089	4.42	.2111	.0176
79	12	120	9.08	.7394	3.8392	4.42	.5808	.0484
96	10	120	6	8.66	8.995	9	.005	.0005
99	2	120	10	.7975	1.4969	2	.5031	.2516
							mean	.2105

Table 12. El/n for Assemblies

Type	No Ops	Tran Time	Mean Batch	Total Proc	Total Set	Calc L.T.	Act L.T.	El	El /n
102	2	10	20	.244	.1167	.66625	2	1.334	.4446
108	11	10	20	.4191	4.435	1.8313	16.33	14.50	1.208
110	12	10	20	.1939	6.6383	1.5645	12.55	10.99	.8450
113	11	10	20	.4191	4.435	1.8313	15.96	14.13	1.177
132	5	10	20	.4647	6.3683	2.0620	5.97	3.908	.6513
140	12	10	20	.8452	6.3683	3.1590	14.75	11.59	.8916
141	12	10	20	.9695	6.3683	3.4698	15.12	11.65	.8962
142	3	10	20	.4915	.4017	1.3415	3.75	2.409	.6021
145	9	10	20	.4199	2.9	1.5998	12.94	11.34	1.134
146	9	10	20	.7091	5.0667	2.5936	14.29	11.70	1.170
150	9	10	20	.4335	2.87	1.63	6.52	4.89	.489
154	10	10	20	.2918	3.0183	1.3151	11	9.685	.8804
155	8	10	20	.2608	1.7333	1.0353	6	4.965	.5516
168	12	10	20	.7641	3.6533	2.6169	9	6.383	.4910
170	3	10	20	.7568	.3333	1.9962	4	2.004	.5010
178	15	10	20	.897	6.7017	3.3927	17	13.61	.8505
179	13	10	20	1.0414	6.4517	3.6808	15	11.32	.8085
186	14	10	20	1.8917	6.5867	5.8443	22	16.16	1.077
201	11	10	20	1.6982	5.4	5.1497	16.03	10.88	.9067
213	4	10	20	.1633	.3333	.53325	3	2.467	.4934
214	5	10	20	.2935	.3833	.88583	4	3.114	.5190
220	13	10	20	1.163	4.2033	3.7037	15.44	11.74	.8383
224	7	10	20	.228	1.1167	.85542	5	4.145	.5181
239	15	10	20	1.4593	3.2583	4.3680	15.98	11.61	.7257
242	12	10	20	.7717	3.5033	2.6172	14	11.38	.8756
								mean	.7818

Table 13. El/n for PCB´s

where; El = work centre queue element
uLT_a = mean actual lead time for the part
uB = mean batch size for the part
P = total process time for the part
S = total set time for the part
uT = average inter wc transport time
n = number of operations for the part

Sample calculation: El for PCBs.

Calculated L.T. = total set up time.
+ mean batch size x total process time
+ mean transport time x number of ops

$$\frac{El}{n} = \frac{uLT_a - (S + uB \times P + n \times uT)}{n}$$

The 20 week production plans resulting are shown below (Table 16). Tables 14. and 15. show a comparison between linear and generic lead times in terms of the production plan smoothness (measured as coefficient of variation) for constant MPS smoothness and load respectively.

These results show an obvious increase in production plan smoothness (for each MPS) with the adoption of the linear lead times (with the exception of constant load and cv = 125%). From this, it would appear that FCL's product structures are unsuited to the use of generic lead times.

9.2.3 MPS Grouping

A further method of addressing production plan smoothness is to smooth MPS demands. The benefits of this were observed in the Stage I experiments. However, this policy design methodology argues against the application of load smoothing MPS techniques as the movement of MPS demands in time (away from the customer requirement dates) amounts to de-coupling.

Fortunately, this does not exclude all techniques for MPS smoothing. The possibility exists for improvements to the scheduling of the

MPS Load	Production plan cv Constant MPS cv 75%	100%	125%
Generic Policy.	.6637	.6434	.644
Linear Policy.	.4448	.4659	.4679

Table 14. Comparison of Production Plan cv

MPS cv	Production plan cv Constant MPS Load. 75%	100%	125%
Generic Policy.	.5413	.6434	.6749
Linear Policy.	.4545	.4659	.704

Table 15. Comparison of Production Plan cv

Per no.	Load 75-125% (cv=100%) 75%	100%	125%	MPS CV 75-125% (load=100%) 75%	100%	125%
1	817.687	1226.53	1226.53	817.687	1226.53	1226.53
2	497.445	548.490	789.34	867.878	548.490	889.762
3	1125.38	897.372	1568.81	1004.63	897.372	1331.37
4	260.932	270.988	300.818	425.076	270.988	304.67
5	466.371	526.038	626.275	774.370	526.038	676.579
6	978.019	1241.16	1529.35	1013.8	1241.16	1406.08
7	1539.02	1988.33	2533.77	1333.71	1988.33	1874.49
8	1264.07	1736.86	2241.57	1585.18	1736.86	2501.53
9	510.371	738.170	910.186	1563.41	738.170	599.258
10	667.585	984.922	1212.33	1848.60	984.922	456.086
11	844.652	1152.55	1479.60	1037.76	1152.55	884.270
12	1234.74	1630.35	2118.1	1027.78	1630.35	1200.82
13	642.713	710.089	950.62	1823.14	710.089	1020.7
14	1157.05	1190.47	1400.61	1149.48	1190.47	1655.6
15	1288.50	1658.14	2083.96	775.825	1658.14	2972.99
16	915.494	1128.01	1415.48	390.465	1128.01	272.826
17	261.356	285.615	330.850	1341.87	285.615	241.428
18	414.738	584.017	781.907	651.086	584.017	274.839
19	498.730	655.345	860.500	2682.28	655.345	550.35
20	1047.34	1288.64	1705.00	1183.99	1288.64	61.1
mean	821.612	1022.11	1303.29	1164.91	1022.11	1050.07
st.d.	365.426	476.169	609.841	529.447	476.169	739.248
CV	.4448	.4659	.4679	.4545	.4659	.704

Table 16. Period Load in st.h. With Linear Policy Lead Times

customer requirement dates. For example, FCL had initially adopted the common technique of placing all MPS demands in the last time bucket of each monthly financial period. This approach is illustrated in Figure 24. The reasoning behind this was based on the fact that delivery contracts were initially timed from the month end. This timing was a hangover from the pre-privatisation working relationships with FCL's main customers (BT districts). It was anticipated that as the relationship with FCL's current customers developed, the timing of deliveries would become based on the customer's operational requirements rather than arbitrary commercial arrangements. It was agreed that this could lead to MPS demands being staggered throughout the month, with the size of each demand remaining similar to that already found. This is illustrated in Figure 24.

A new MPS was created to model the effects of MPS demand "staggering". At this time, the opportunity was taken to generate a number of longer MPSs to overcome the experiment run length bias identified in Stage I. The new experimental length was calculated from the longer of:

1. 10 x the natural frequency of production plan load variation.
2. 10 x average flow time.

The purpose of this work was to identify policies conducive to short flow times. Therefore, the new MPS's were designed to be used in this area. From Stage I, production plan variability was found to have a periodicity of four weeks. An average of 8 days was considered to represent the upper bound of flow time. Consequently, the experiment duration was set at 40 weeks. The MPS length was then set at 50 weeks giving a 10 week stabilization period at the start of each experiment. A longer original MPS was then generated, together with a staggered version. In addition, smooth, moderate and lumpy MPSs were generated. These are included in Appendices 9 to 13.

1. MPS demands timed at month end.

Period (week) & Quantity: →

Type:	1	2	3	4	5	6	7	8	9	10	11	12
AA	10			20				30				10
BB	12			12				13				12
CC	5			5				10				5
DD	1			1				1				2
EE	50			50				50				50
FF	33			28				17				37

2. MPS demands staggered throughout the month.

Period (week) & Quantity: →

Type:	1	2	3	4	5	6	7	8	9	10	11	12
AA	10			20				30				10
BB		12			12				13			
CC			5			5				10		
DD	1			1			1				2	
EE		50			50			50			50	
FF			33			28			17			

Fig 24. MPS Demand Timing.

Table 17. shows the production plan loads in standard hours generated against the original and grouped MPSs. In addition, an evaluation of the linear lead time policy has been included. It can be seen that with generic lead times a significant increase in production plan smoothness results from the staggering of MPS demands. The linear policy lead time was again seen to improve production plan smoothness. When comparing the effect of staggering in conjunction with the linear lead time policy, the increase in smoothness was less appreciable.

It could be argued that the grouping of WIP orders can be reduced by the adoption of a linear policy or MPS shuffling. However, there appears to be a natural limit to the level of production plan smoothness, indicated by the small increase achieved when the two techniques are combined. It must be noted that these results apply to static MPS experiments and must be re-validated in the uncertain environment.

The ultimate test of production plan characteristics must be the performance of the supply elements against the plan. Therefore, the factory model was run against each of the above production plans.

The length of the experiments was increased to overcome the bias indicated in Chapter 8. The end point for this series of experiments was determined by monitoring the stability of two key measures; WIP and flow time. Measurements were taken at periods 24, 29, 34, 39 & 42 and plotted. These are shown in Figures 25 to 29. From these it was found that the measurements stabilized between periods 34 and 39. A reduction in all measures at period 42 was evident. This was identified to be the result of a reduction in production plan load as the end of the MPS was approached. This evaluation justified an experiment duration of 32 weeks, with data recording commencing in period 7 and ending in period 39.

In addition to the four production plans, a number of different

period	Original MPS Linear L/T	Gen L/T	Staggered MPS Linear L/T	Gen L/T
1	1226.531	925.3279	1099.828	855.1093
2	548.4905	92.0807	1322.38	513.6325
3	897.3727	1999.377	287.1546	1082.953
4	270.9888	1414.644	302.0542	794.3701
5	526.0381	179.1158	709.5835	1533.854
6	1241.163	331.5652	1242.001	1377.54
7	1988.339	3289.133	1741.117	1553.473
8	1736.863	1195.626	904.2361	581.3843
9	738.1709	368.008	1073.635	1697.034
10	984.9229	3350.903	1404.467	1935.916
11	1152.554	1490.712	890.2258	1239.828
12	2620.191	1443.359	2032.092	1870.324
13	710.0896	406.3011	546.8973	1008.241
14	1190.475	1721.187	1805.12	1442.327
15	1658.149	1103.37	847.713	1754.425
16	1128.011	1072.812	1256.549	96.565
17	285.6154	777.1858	1399.968	1685.939
18	584.0178	1060.899	613.5658	1040.522
19	655.3458	1432.96	1138.15	2294.068
20	1288.642	1534.759	378.5761	893.284
21	1154.805	0	853.3577	0
22	825.5401	663.1226	1617.654	268.5184
23	702.8087	1232.883	1276.524	1165.588
24	1396.395	1134.641	508.8541	1540.239
25	1398.533	867.372	1329.286	661.4011
26	940.5931	222.1722	1125.785	638.3793
27	634.0887	665.249	656.8969	673.4318
28	1496.866	936.9818	829.1202	661.4141
29	805.443	900.3004	368.9446	802.4762
30	773.116	1180.487	1745.772	355.3685
31	254.6913	242.7601	529.002	1272.041
32	448.7412	700.8746	393.1518	230.8545
33	477.7945	1271.35	1144.492	2415.849
34	1332.293	1021.721	167.978	463.1133
35	591.0944	653.3853	1164.774	493.453
36	971.2509	1230.424	1993.943	1226.031
37	1503.994	2015.913	776.4005	1987.498
38	1561.893	1204.711	1400.763	1109.51
39	504.7901	629.1561	540.3284	1069.554
40	767.535	643.1841	755.0183	1092
41	1529.576	1425.719	1124.471	1260.8
42	1072.206	687.5368	581.6387	1537.922
Mean	1021.7971	1017.3410	1031.4996	1032.5344
st.d.	511.61814	700.67973	489.63764	617.52681
c.v	.50070422	.68873632	.47468526	.59806897

Table 17. Evaluation of Grouping on Production Plan Smoothness.

transport batch sizes were included in the experiments. This continued investigation into the potential benefits of breaking down order quantities into smaller units.

It was considered that if the shopfloor ethos was to be directed toward achieving throughput, then it would be probable that a significant reduction in inter-work centre transport time could be achieved. Previous experiments had assumed that the current inter-work centre transport time of 2 hours would be maintained. Investigation revealed that this time was a result of the low priority assigned to work movement under the existing management philosophy. Further investigation and discussions with operators and management resulted in agreement that, with the new approach, inter-work centre transport time could be reduced to 10 minutes for PCBs and 20 minutes for assemblies. These new values were built into all future experiments which included transport batches.

The result of these experiments, in terms of PCB WIP and flow time, are plotted in Figures 30. & 31. These graphs again show the considerable potential for WIP and flow time reduction by adopting small inter-work centre transfer batches. From both graphs the curves representing the original MPS with linear policy lead time (Org/L) and the staggered MPS with linear policy lead time (Stg/L), almost exactly coincide. Similarly, the curves representing the original MPS with generic lead times (Org/G) and the staggered MPS with generic lead times (Stg/G), are equivalent. This suggested that MPS grouping did not have any significant effect on the performance of the PCB manufacturing facility in the static MPS environment. However, the linear lead time policy did produce consistent WIP and flow time reductions in this environment.

Whilst these results offered some encouragement, it was considered that static experiments could not be used to define the most effective queue element to be used with the linear lead time policy. This belief is based on the relationships between composite lead times, exposure

Fig 25. Mean Batch Size v Run Length.

Original MPS & MRP pol's.

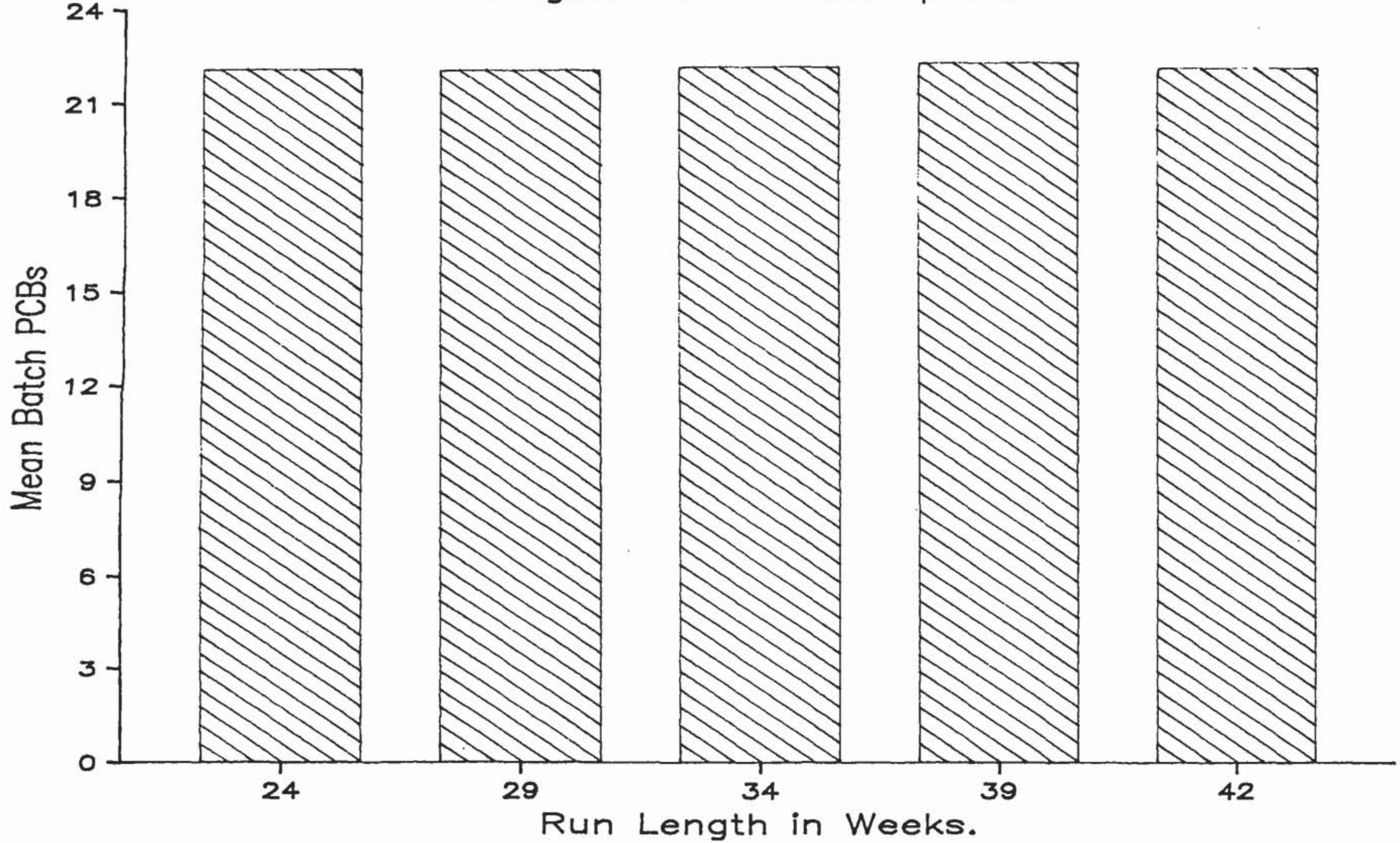


Fig 26. Mean PCB WIP v Run Length.

Original MPS & MRP pol's.

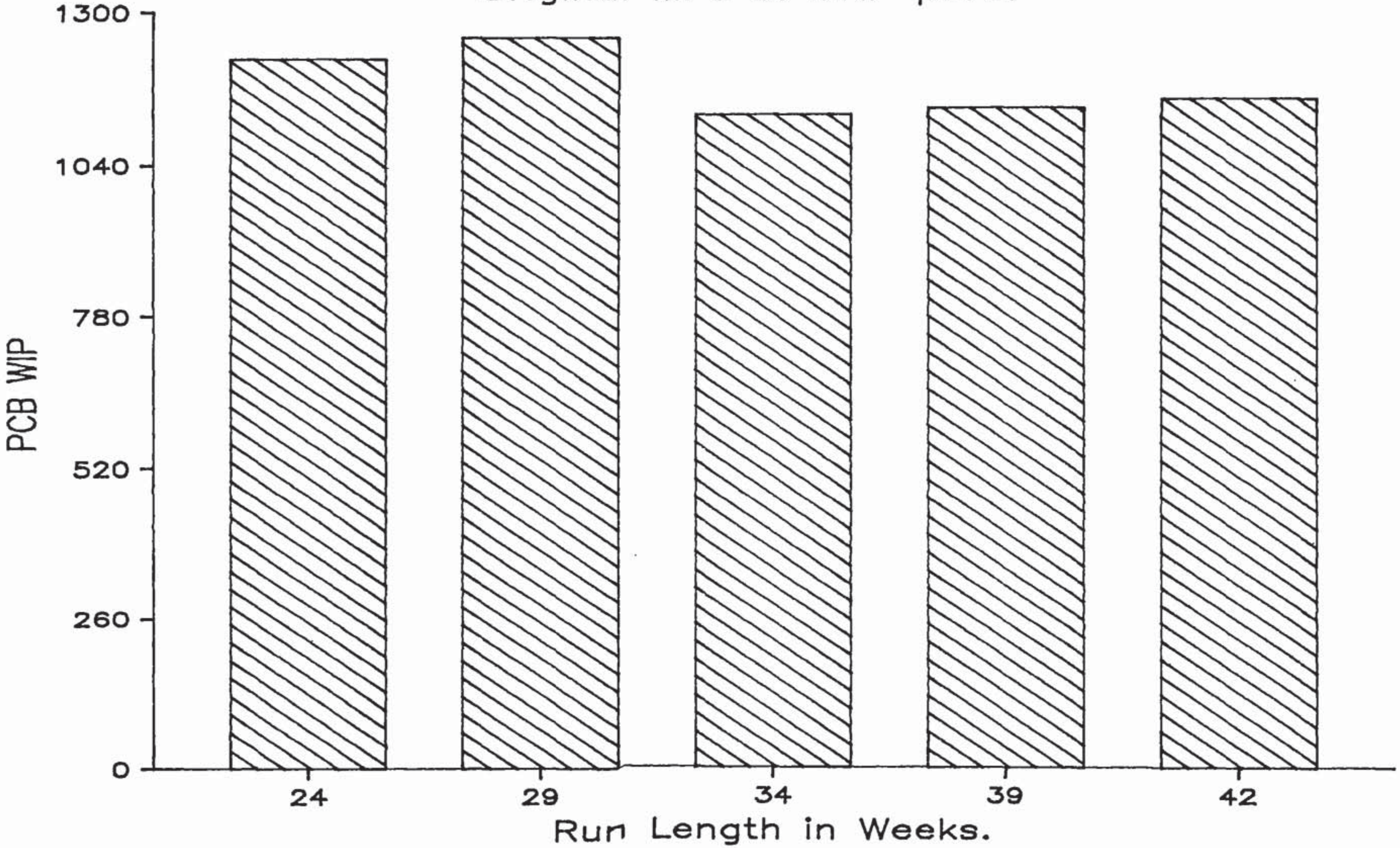


Fig 27. Assembly WIP v Run Length.
Original MPS & MRP pol's.

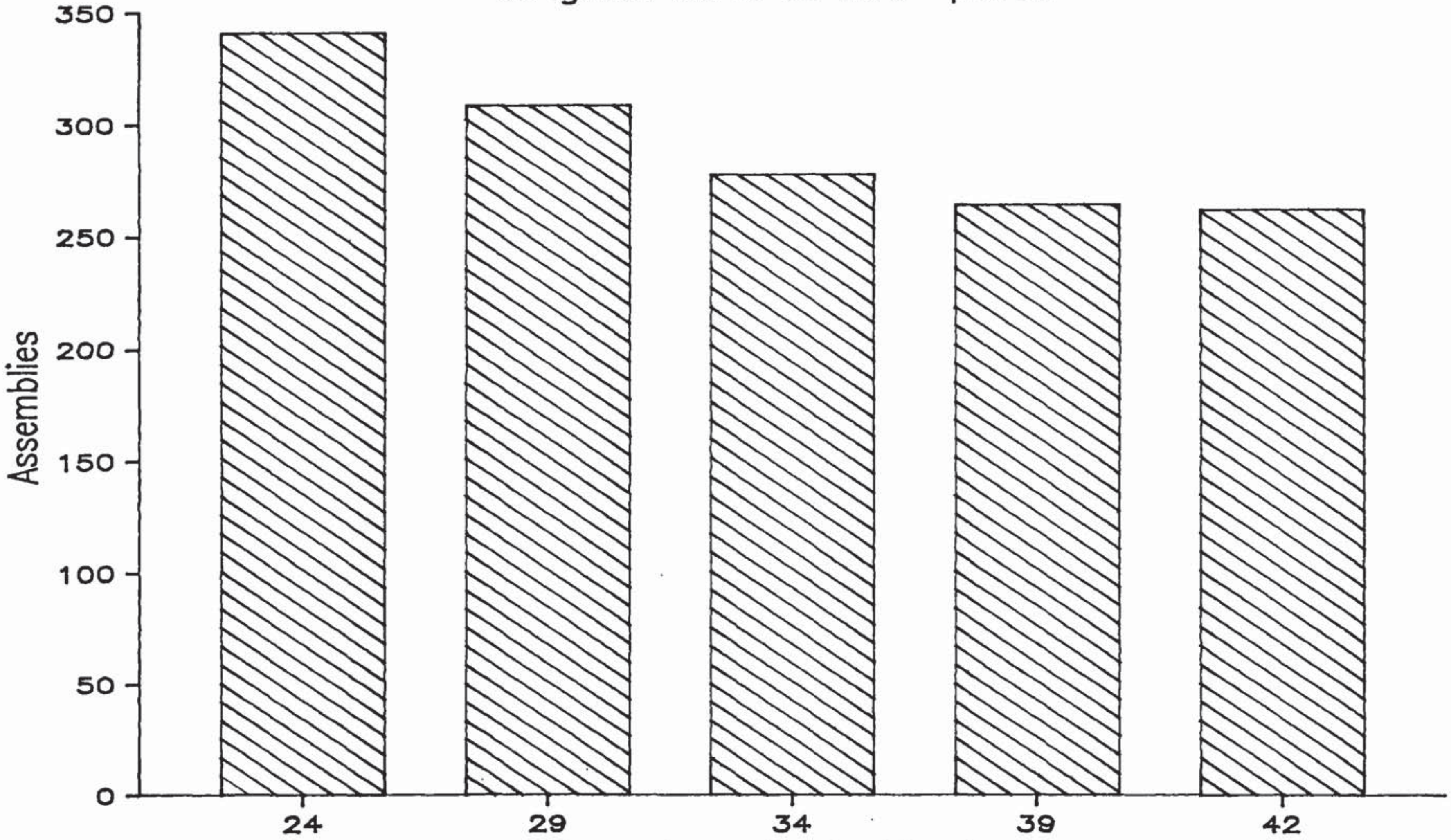


Fig 28. PCB Flow Time vs Run Length.

Original MPS & MRP pol's.

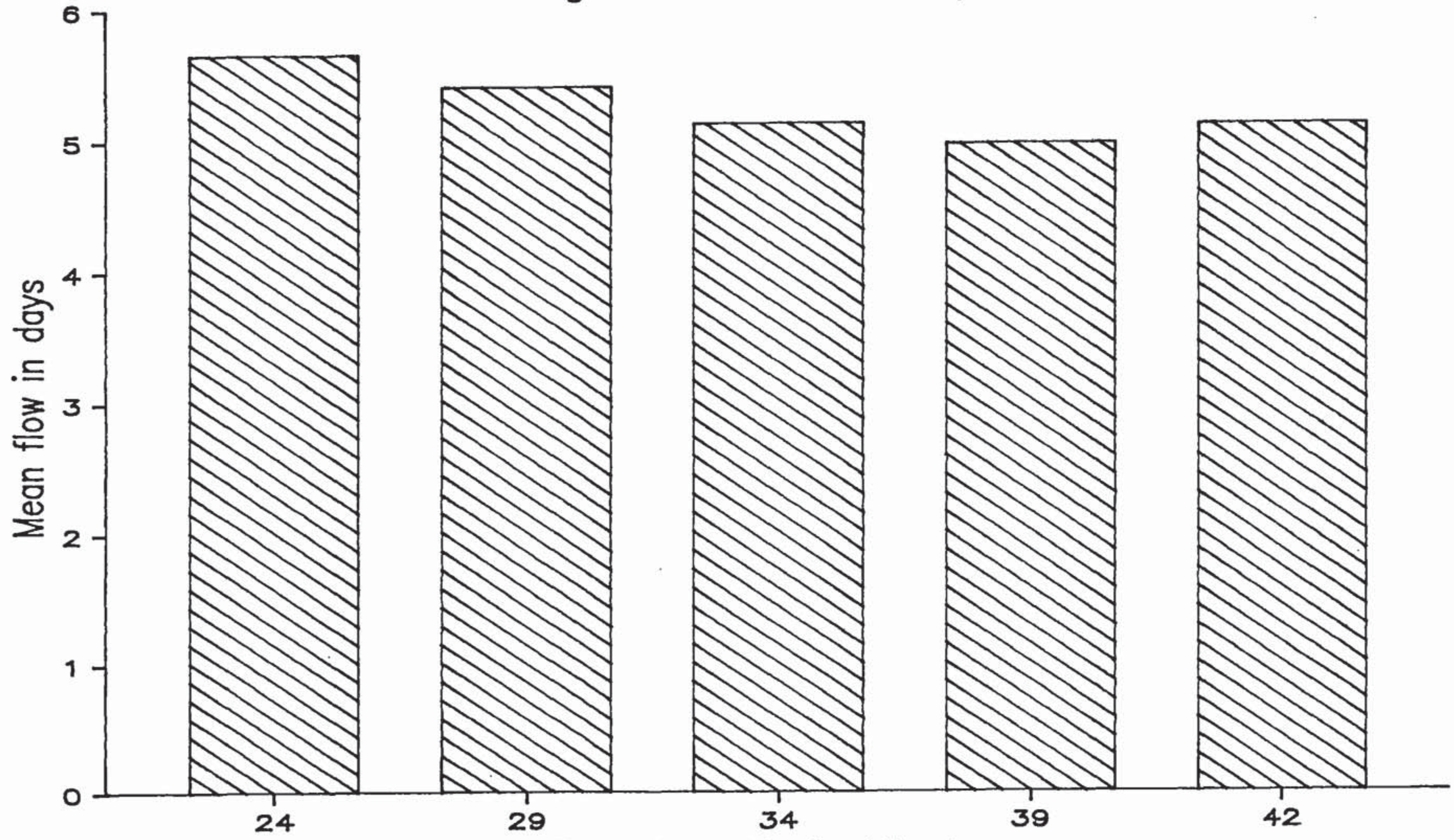


Fig 29. PCB Flow cv. v Run Length.
Original MPS & MRP pol's.

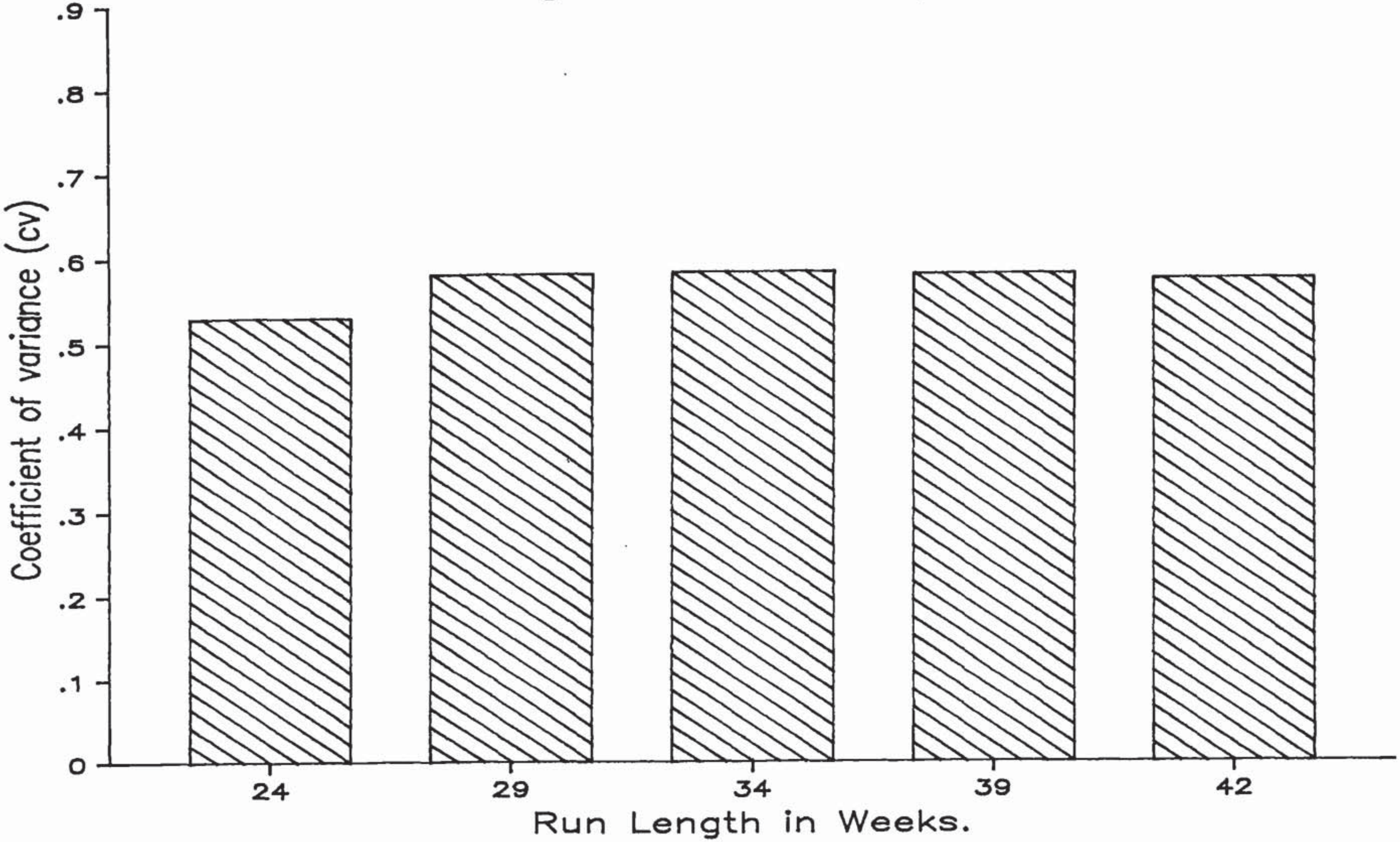


Fig 30. WIP (PCB's) v Transfer Quantity.

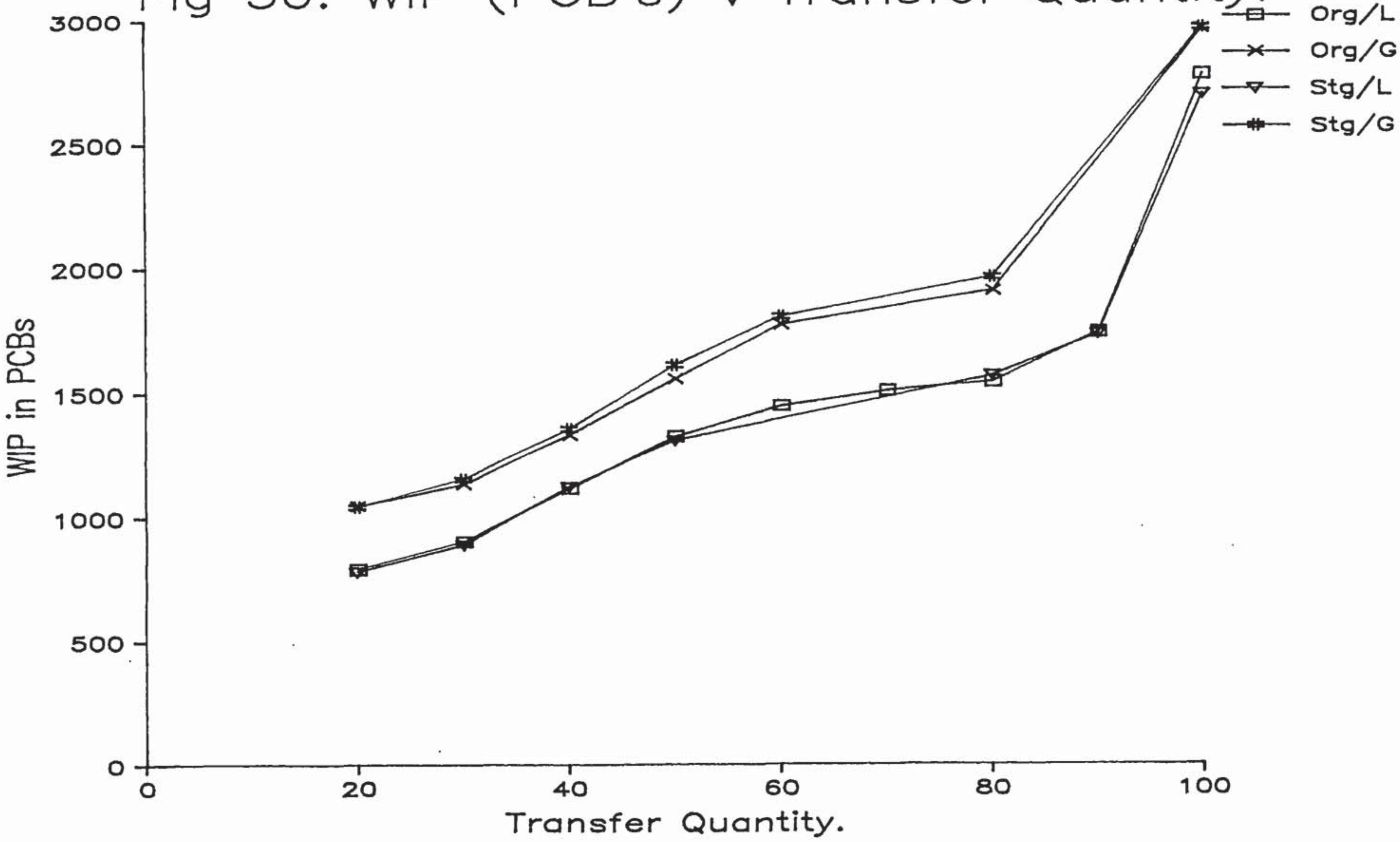
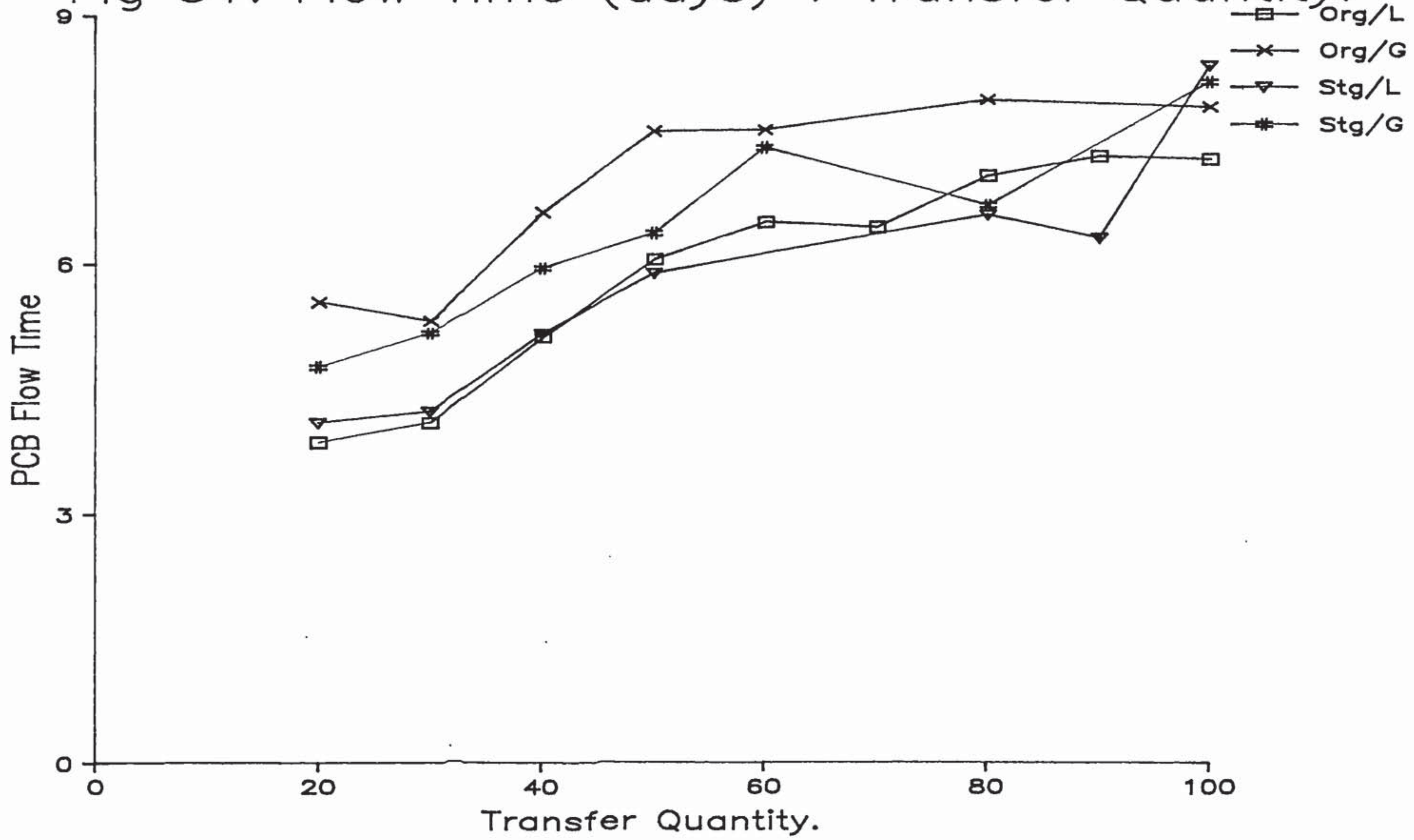


Fig 31. Flow Time (days) v Transfer Quantity.



to MPS uncertainty, queue element and the load/effective capacity balance. Therefore it was decided to include a more complete appraisal in the interactive experiments. This will be discussed in Chapter 10.

9.2.4 Order Policy

Chapter 3. has discussed Order Policy in detail and many of the assumptions underpinning the recommendation of "optimal" techniques have been shown to be invalid in the case of MPS uncertainty. In view of this questionable validity, it was decided not to include such techniques in this work.

The philosophy behind order policy choice, at this stage of the methodology, was to develop policies which would result in demand driven production plans consistent with a JIT configuration of MRP. The author's re-analysis of De Bodt and Van Wassenhove's ranking of order policy performance, indicated that lot for lot and period order quantity offered significant performance potential. Analysis of the historical order profile, determined that a lot for lot policy would result in severe practical difficulties at FCL, due to the likely number of orders that would result. This included a significant increase in MRP processing time. However, the practical implications of a period order policy were considered to be in line with the capabilities of FCL.

TMS offers two alternative methods of specifying period order quantities. The first (known to TMS as order policy 3) synchronizes the period for which orders are to be aggregated to the MRP time buckets. Under this policy all orders within a given time bucket were aggregated and planned for release at the time associated with the first of these orders. The second policy, (known to TMS as order policy 2) uses a variable length unsynchronised time bucket. Under this policy, during MRP processing, an order for a particular part would cause TMS to look forward for a variable time period and include any additional requirements in the initial order. Table 18. below shows typical order quantities against; lot for lot, POQ synchronised to the planning time buckets (op 3), POQ with an independent bucket size of 5 days (op2/5) and POQ with an independent bucket size of 10 days (op2/10).

The Order policy initially used by FCL was based on a derivative of POQ and was designed to batch numerous small demands into larger orders. This was underpinned by traditional thinking on the benefits of large batches. Standard TMS features were used; a 2 bucket (10 working days) POQ with the addition of a minimum order quantity of twenty and a pan size of ten. Table 19. illustrates the action of this policy.

The first order for AA123 occurs in period 1 (5) and the second in period 2 (12) etc. The order policy combines the requirements for periods 1 and 2, 4 and 5 and 6 and 7. The totals for periods 1 and 4 are then made up to 20. This results in excess orders with the consequence that the requirement for 27 in period 6 is reduced to 20 (leaving 13 on hand).

One effect of this order policy is to increase the lumpiness of the orders for AA123. On a global scale, this policy was likely to increase the lumpiness of the whole production plan for PCBs.

It was decided to compare the performance of the two period batching function against the two possible single period POQ techniques offered by TMS (op 3 and op 2/5 days). This was to determine whether the small differences in timing would influence the selection of one against the other.

Production plans were developed against the moderate MPS and original MPS (Appendix 14.); these were then run against the factory model. The previous experimental success of the transport batch technique suggested that an analysis should be made of shopfloor performance with and without the use of transport batches (TrB). Previous results

work day	1	2	3	4	5	6	7	8	9	10
demand for part AAA	0	0	4	6	5	0	0	12	1	7
lot for lot	-	0	4	6	5	-	0	12	1	7
Sync POQ (op3)	-	15	-	-	-	-	20	-	-	-
POQ (op2/5)	-	-	15	-	-	-	-	20	-	-
POQ (op2/10)	-	-	35	-	-	-	-	-	-	-

Table 18. Lot for Lot, Synchronized POQ, POQ(5 days) and POQ(10 days)

period	1	2	3	4	5	6	7
PCB type AA123							
Period Order	5	12	0	13	0	15	12
POQ (2/10)	17	0	0	13	0	27	0
Order (inc min & pan)	20	0	0	20	0	20	0
Excess	3	3	3	10	10	13	13

Table 19. Operation of Initial FCL Order Policy

supported the use of a transport batch size of 20 for the TRB case. The null case was modelled by setting the TRB parameter to 999 (ie. in excess of the largest order quantity). Experiment start and end points were set identical to 9.2.3.

The resultant average PCB WIP and lead time levels are presented in Figures 32. & 33. together with the results of the original order policy. It is clear from these results that the performance of the shop was insensitive to the use of the form of POQ used, as each of the POQ policies was found to produce equivalent shop performance. The potential for WIP and flow time reduction offered by splitting order quantities into transport quantities further suggested that the batching of orders effected by the initial order policy was unnecessary.

The insignificance of the 2 period batching function was probably the result of the spacing of requirements (allocations) in time. The ability of a manufacturing facility to process small batches is influenced by the reduction of effective capacity due to setting operations. This is influenced by the proportion of small batches and the variety of part types on the shopfloor at any given time. This in turn is influenced by the manner in which orders are specified in the MPS. In the example below (Table 20.) it can be seen that the smooth MPS resulted in a larger variety of part types (of reduced mean order quantity) on the shop-floor at any given time. Furthermore, a 10 day POQ would possibly have a more significant effect than with the lumpy MPS.

Therefore, it was decided to investigate the removal of the batching functions within the order policy against four levels of MPS smoothness; smooth (cv=.35), moderate (cv=1.19), original (cv=1.91) and lumpy (cv=2.76), each of these were maintained at the same load and product mix as the original. Changes were made by splitting individual MPS demands to increase smoothness and combining MPS demands to decrease

Smooth MPS

Period	1	2	3	4	5	6	7	8	9	10
Period Demand										
AA123	5	5	5	6	6	6	7	7	5	5
BB345	5	5	5	2	2	2	2	4	4	4
CC678	10	5	5	7	7	9	9	2	2	2

Lumpy MPS

Period	1	2	3	4	5	6	7	8	9	10
Period Demand										
AA123			15			18			31	
BB345		15			6			14		
CC679	20			23			13			2

Table 20. Smooth and Lumpy MPSs

Minimum order	0	10	20	30
Original MPS Prod Plan cv	.5611	.5489	.5671	.5730
Smooth MPS Prod Plan cv	.2358	.2814	.2734	.2839

Table 21. Production Plan cv v Minimum Order Quantity

Fig 32. Mean PCB WIP v Policy.
Original MPS.

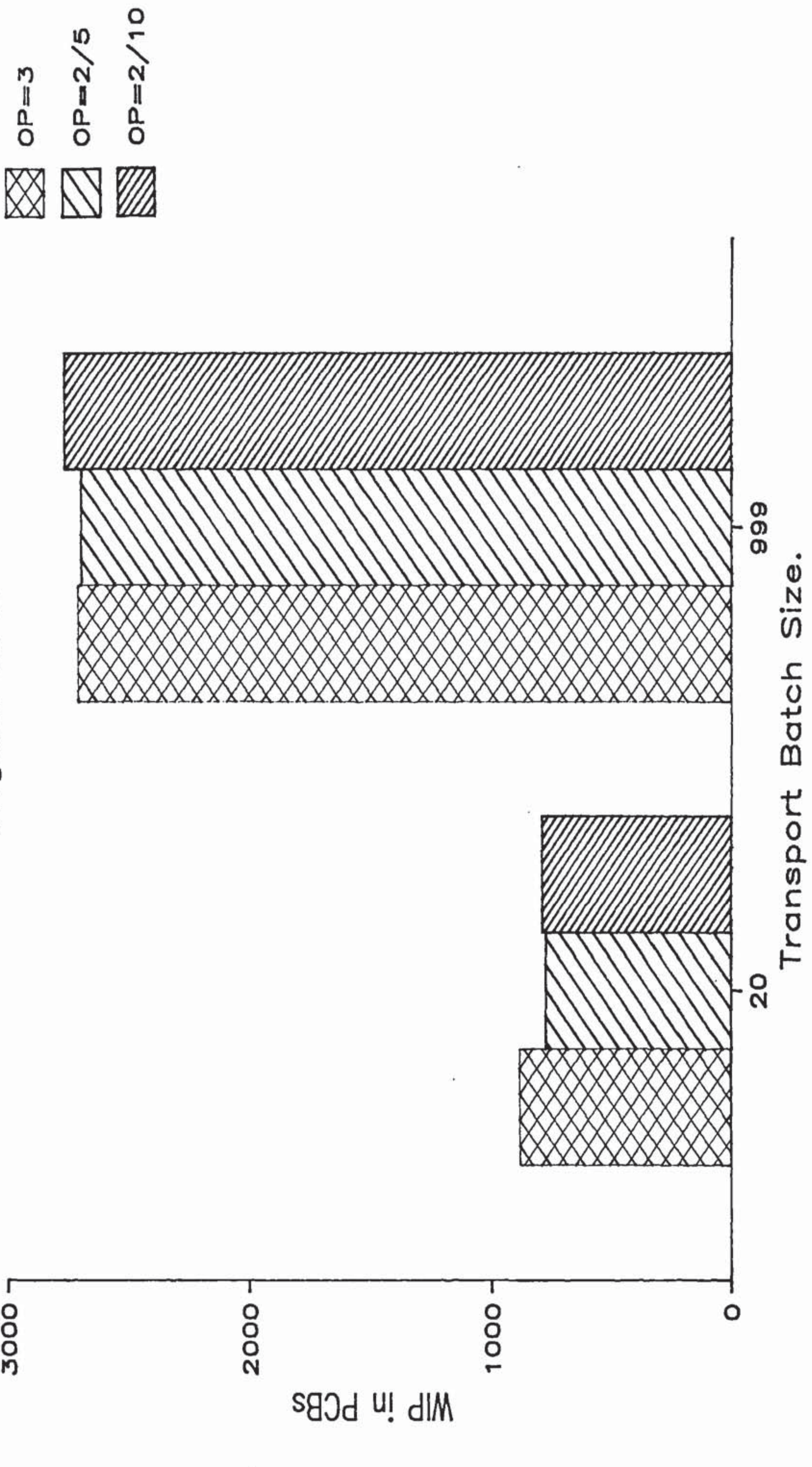


Fig 33. Mean PCB WIP v Policy.

Moderate MPS.

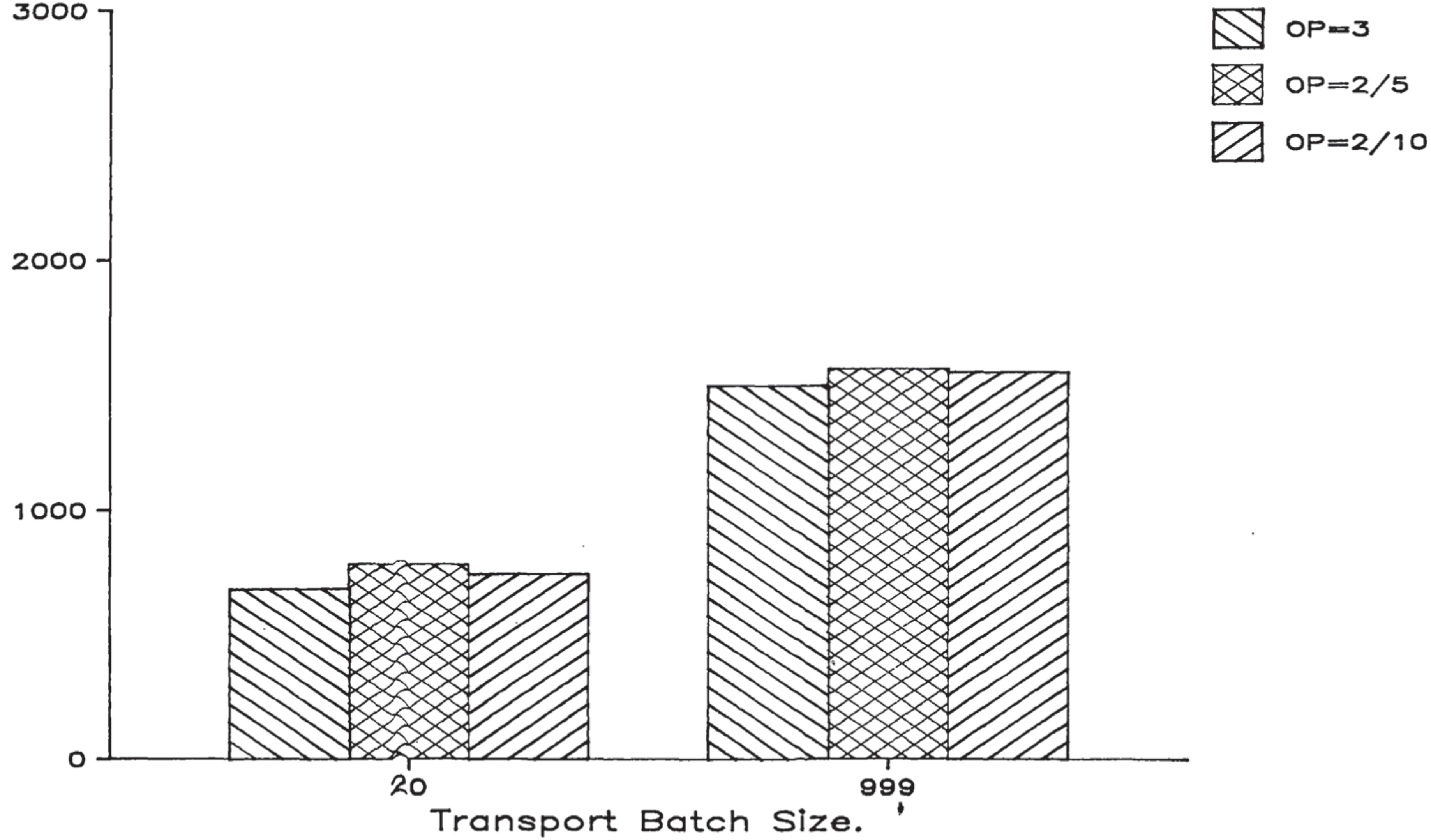
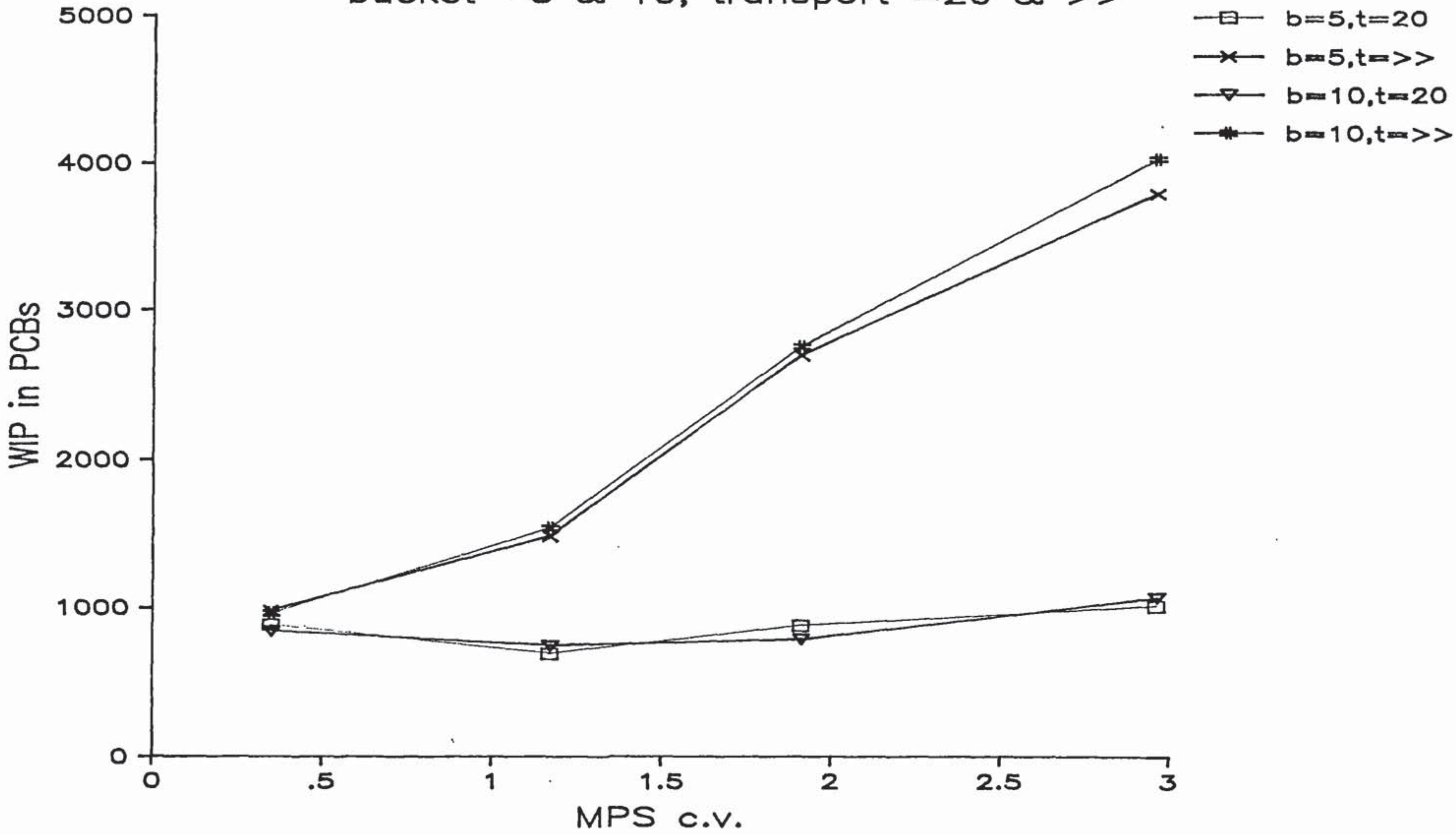


Fig 34. PCB WIP v MPS cv

bucket =5 & 10, transport =20 & >>



smoothness. These MPSs can be found in Appendices 9, 11, 12 and 13.

Each of the above MPSs were used to generate production plans using a single period order policy (op 3) with the minimum order and pan size remaining at 20 & 10 respectively. These are shown in Appendix 14.

The factory model was then run against each of these plans. The experiment start point and duration remained as for the previous experiment. Again, resultant average PCB WIP levels are plotted for transport quantities of 20 and 999 in Figure 34.

It can be seen that the removal of the two period batching function (bucket=10 days) does not have any detrimental effect on average WIP levels, as the two curves with transport batch on (t=20) and off (t=>>) are almost identical over the MPS cv range. It is interesting to note that the correlation between MPS smoothness and reduced WIP levels is strongest when the transport batches are not used (the curve of WIP against MPS cv for transport batches of mean size 20 approaches the horizontal). This would suggest that some of the adverse effects of lumpy production plans are negated by using transport batches. These results support the use of order policy 3 (synchronized time bucket). Again these results are limited to the static MPS case and this policy must be evaluated in the dynamic case.

9.2.5 Minimum Order Quantity and Pan Size

A further element of the order policy is the minimum order quantity and the pan size. In 9.2.4, FCL's policy was to use a minimum of 20 and a pan size of 10. The success of the previous experiments pointed to the PCB shop having the ability to cope with small batches. Therefore, it was decided to evaluate the effects of removing the minimum and pan parameters. In addition, it was considered worthwhile to conduct a general evaluation of the effect of 3 further levels of minimum order quantity (10, 20 & 30) on production plan characteristics and shop performance. Two MPS smoothness levels were chosen; the original (cv =

1.91) to represent the FCL case and smooth (cv =.35) to represent the worst case, in which pan and minimum were equal to zero and would coincide with the smallest average batch sizes.

Production plans were produced against the above combinations of MPS and policy; these are contained in Appendix 14. Table 21. above summarizes production plan cv against minimum order quantity.

For each MPS group, three of the four data values show an increasing trend of production plan lumpiness with increasing minimum batch size. This is in line with the effects of order batching illustrated in Table 19. above. The anomalous data points (min = 0, original MPS and min = 10, smooth MPS) are of interest in that they demonstrate the subtle effects resulting from the complex interactions occurring during MRP processing. This serves to underline the importance of the holistic approach to policy design.

The factory model was run against each of the above production plans. Data collection periods remained as with the previous experiments.

The opportunity was taken to evaluate several transport batch sizes in this environment to ascertain a definitive value. A range of transport batch sizes were used with 999 (representing no batch splitting) as the upper limit and 20 (representing the potential minimum) as the lower limit.

The results of PCB WIP are plotted in Figures 35. & 36. For the original MPS, the shop performance was similar for each of the minimum batch size values with all transport batch sizes. At larger mean batch sizes, the WIP level remained broadly similar; however the mean batch size (for a given transport batch size) increased with minimum order quantity. This resulted in a higher curve gradient with decreasing minimum order quantity. These results indicated that for the original MPS, average WIP (for a given transport batch size) was independent of minimum order quantity.

Fig 35. WIP (PCB's) v Mean Batch.

Original MPS (cv=1.91)

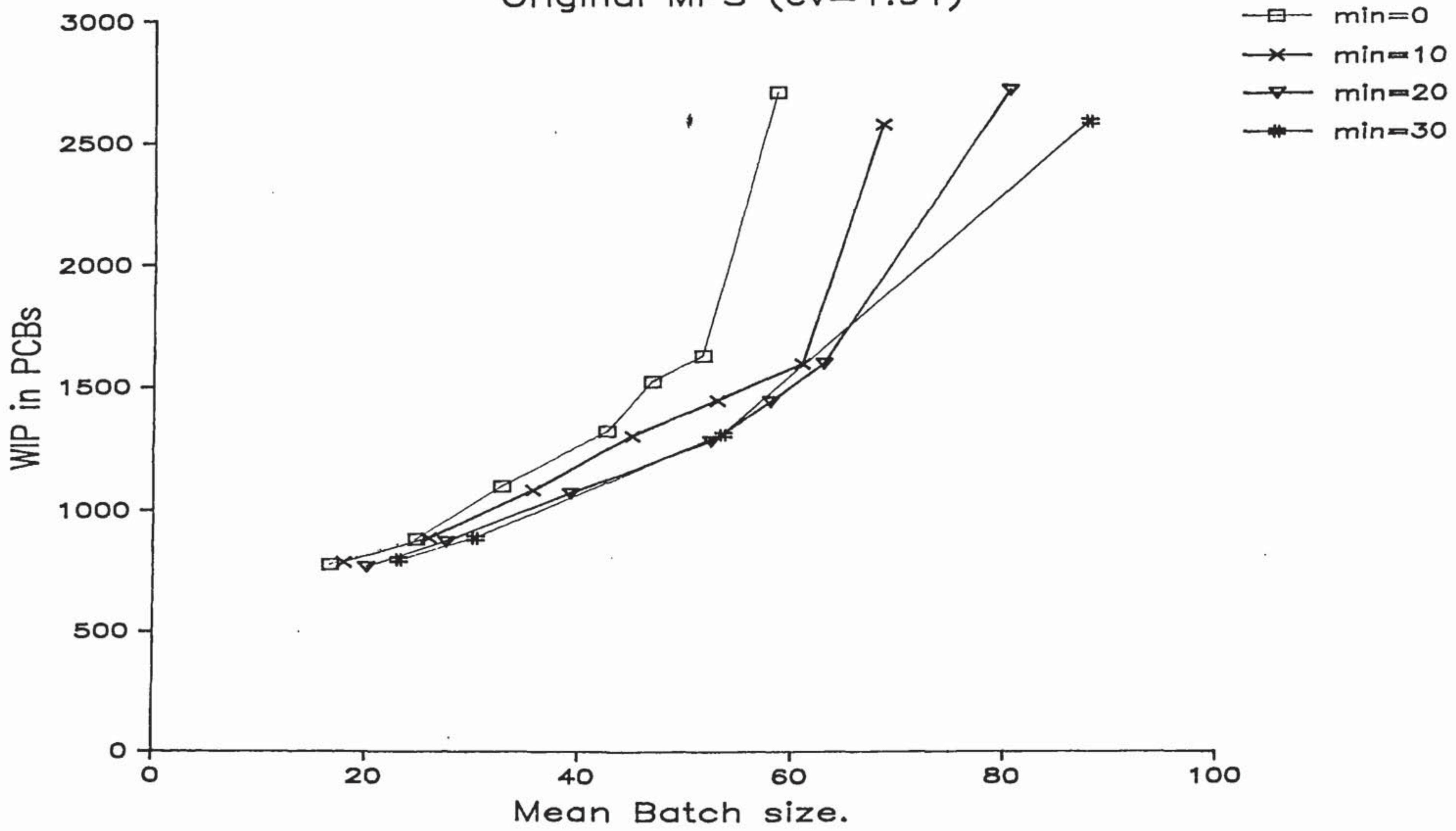
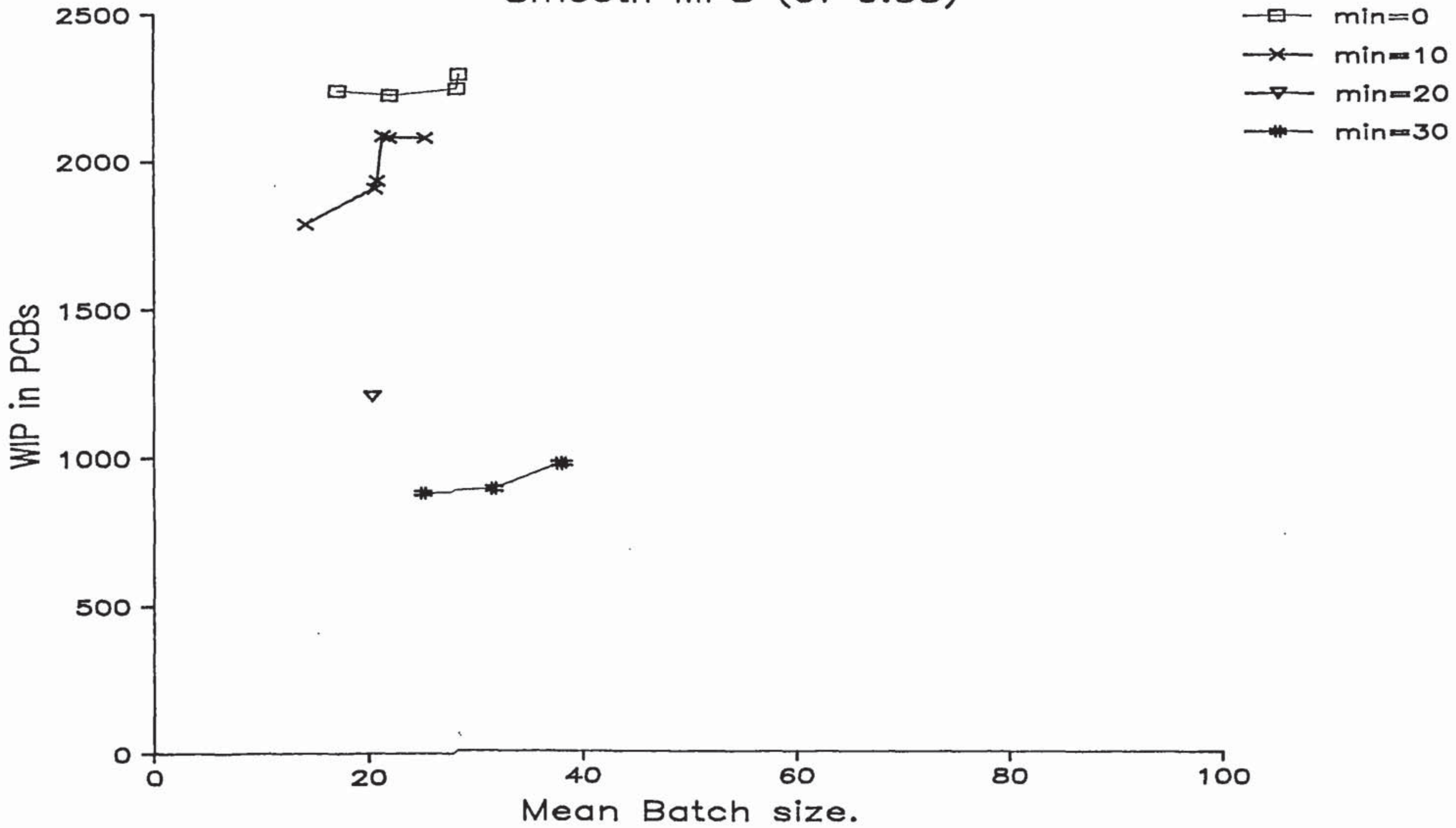


Fig 36. WIP (PCB's) v Mean Batch.
Smooth MPS (cv 0.35)



For the smooth MPS the most obvious change was the narrow range of average batch sizes against transport batch size. This indicated that a low proportion of large batches (ie.> 50) was generated by the smooth MPS. In addition, average WIP was heavily influenced by the minimum batch size. The highest average WIP levels were experienced with the minimum batch size set at zero. This suggests that at this condition the effective capacity of the PCB shop was severely restricted by the large number of set ups associated with the predominantly small batches. With the smooth MPS, a minimum order quantity of 30 was required to produce acceptable levels of WIP.

The "smooth MPS + minimum batch = 0" result reversed the correlation between MPS and production plan lumpiness and average WIP levels. Again this emphasized the importance of the holistic approach.

9.2.6 Summary of MRP Policy Findings

The purpose of the above experiments was to determine a workable group of "core" MRP policies which support the re-coupling of the manufacturing systems with market demand. To this end, the following policies have shown potential against the original MPS:

1. Linear policy lead time.
2. POQ order policy, with min order quantity = 0, and pan size = 0

Distributing MPS demands throughout the monthly period (whilst maintaining the cv value) produced a small additional increase in production plan smoothness over that achieved by using a linear lead time. However, shop performance was not significantly improved by this technique.

The measures used in this analysis were chosen to reflect shop performance against MRP generated production plans such that policies supportive of "low inertia" manufacture may be determined. However, it was recognized that WIP and lead time were not sufficient to evaluate total system performance. A more complete set of measures would be required for the evaluation of these and other policies in the interactive and uncertain MPS stage of this work.

9.2.7 Shop Policies

The preceding work, whilst concentrating on MRP policies has included an analysis of the use of batch splitting techniques. It has been shown that considerable potential is offered by breaking down TMS generated order quantities into smaller "transfer batches". Transfer quantities as low as 20 (considered to be the practical lower limit) have shown significant reductions in PCB WIP and lead time. The improvements indicated resulted from improvements to the flow of work in the shop.

In Chapters 2. and 5., the work of Goldratt (1981 & 1984), Kanet (1981 & 1984) and Fox (1982 & 1983) was discussed and it was noted that shop capacity was limited by the capacity of the bottleneck, and that bottlenecks and non-bottlenecks present different aspects of the shop flow problem. Table 22. gives the average utilization and input queue values for each PCB work centre, from a sample of three of the preceding experiments.

From the above table it is evident that queue size and utilization for each work centre is insensitive to MPS and MRP policy changes. The most highly loaded work centres are associated with the highest average input queues and utilization levels. From this, it can be seen that work centres 1 and 2 are likely to become bottlenecks first as load is increased.

The average measures used above, suggested that none of the work centres were capacity bottlenecks at the measured load and product mix. However, the load variations inherent in the production plan resulted in transient overloads. This was evidenced by the achievement of utilization levels in excess of 80% over short durations. Therefore, it was considered relevant to formulate shop policies based on bottleneck concepts.

Work Centre	Orig MPS Orig Pols Util %	Queue PCBs	Orig MPS Lin L.T. Util %	Queue PCBs	Smooth MPS Lin LT + min=10 Util %	Queue PCBs
1	42	177.32	41.5	179.84	44.3	293.28
2	33.5	83.94	32.7	55.00	34.9	85.48
3	9.4	16.24	7.6	17.14	8.5	24.74
4	14.9	5.48	15.4	.18	15.4	.64
5	27.5	30.21	27.9	19.46	27.6	13.38
6	19.4	9.86	19.6	.36	19.4	.00
7	23.1	.86	23.4	1.92	24.6	4.08
8	6.0	.00	5.4	.00	5.7	.08
9	27.4	1.52	28.4	.32	28.5	.00
10	28.3	5.68	28.1	3.92	28.6	2.20
11	17.3	.20	17.3	.00	17.5	.00

Table 22. Sample Utilization and Mean Queue Values for each PCB Work Centre

The philosophy proposed by Goldratt was to maximize the throughput of bottlenecks by seeking to minimize set up operations and thus maximizing effective capacity. At non-bottlenecks spare capacity is used to support additional set-ups and smaller batch sizes. One practical technique for implementing this philosophy was to combine transfer batches with a bottleneck shop sequencing rule. Figure 37. represents a typical work centre at which an input queue is shown as several transport batches. If the example work centre was a bottleneck, the input queue would be sequenced so as to minimize the number of set ups. If the work centre was not a bottleneck, then a secondary sequencing rule would be used such as FIFO.

Whilst maintaining this view, bottlenecks would be assigned the goal of defining capacity, whilst the non-bottlenecks would address the twin issues of achieving throughput and maintaining due date performance. Under these circumstances, it would be appropriate to use a due date performance related secondary sequencing rule. Additionally, the bottleneck input queue would not always contain members which can be sequenced to save set ups under these circumstances. It would then be appropriate to use the same rule as for non-bottlenecks in a secondary capacity. From Goldratt's work and the findings shown in Table 22. it was probable that the majority of work centres would be non-bottlenecks and as such would be working toward achieving flow time and due date targets.

In Chapter 5. it was noted that finite scheduling techniques suffer instability at significant levels of MPS uncertainty. Consequently, in the dynamic environment of the medium batch production shop (such as PCB manufacture at FCL) it often proves ineffectual to attempt to produce and achieve complex sequenced production plans. The addition of bottleneck sequencing rules to this problem decreases the probability of successfully applying these techniques to an MRP produced production plan.

The solution offered by Goldratt (OPT), replaces the MRP processing with a proprietary goal seeking mathematical modelling algorithm. OPT seeks to produce a production plan in which the bottleneck operations are finitely scheduled. Consequently, doubts are raised over its stability in the uncertain MPS environment. This work adopted an alternative approach in which the "top down" production schedule was replaced by localized batch sequencing using bottleneck and flow based rules. These operated in conjunction with the MRP produced period order plan (production plan).

At FCL each work centre or group of work centres was under the control of a supervisor. It was proposed to evaluate the potential offered by allowing these personnel to sequence work through their areas of responsibility using bottleneck and flow based rules.

Work centre supervisors would identify the existence of a bottleneck by the existence of an input queue. It was recognized that " non-bottlenecks" do occasionally suffer transient overload ie., several transfer batches may arrive from separate feeder work centres simultaneously. This could result in a deterioration of due date performance if the bottleneck rule were to be invoked under these circumstances. Following discussions with production personnel, it was considered prudent to set an indicator limit of five transport batches in the input queue. Above this limit a work centre would be considered to be a bottleneck.

Recognizing the potential correlation between simplicity and success, the secondary sequencing rule must be within the understanding of the supervisors. Numerous rules exist and this subject was discussed in Chapter 4. It was considered that in the first instance, due date based rules such as "earliest due date first (EDDF)" or "least slack per operation remaining (LSOR)", were in sympathy with our requirements. Of these, EDDF offered the most straightforward implementation as TMS automatically produced due date stamped operation lists. The potential

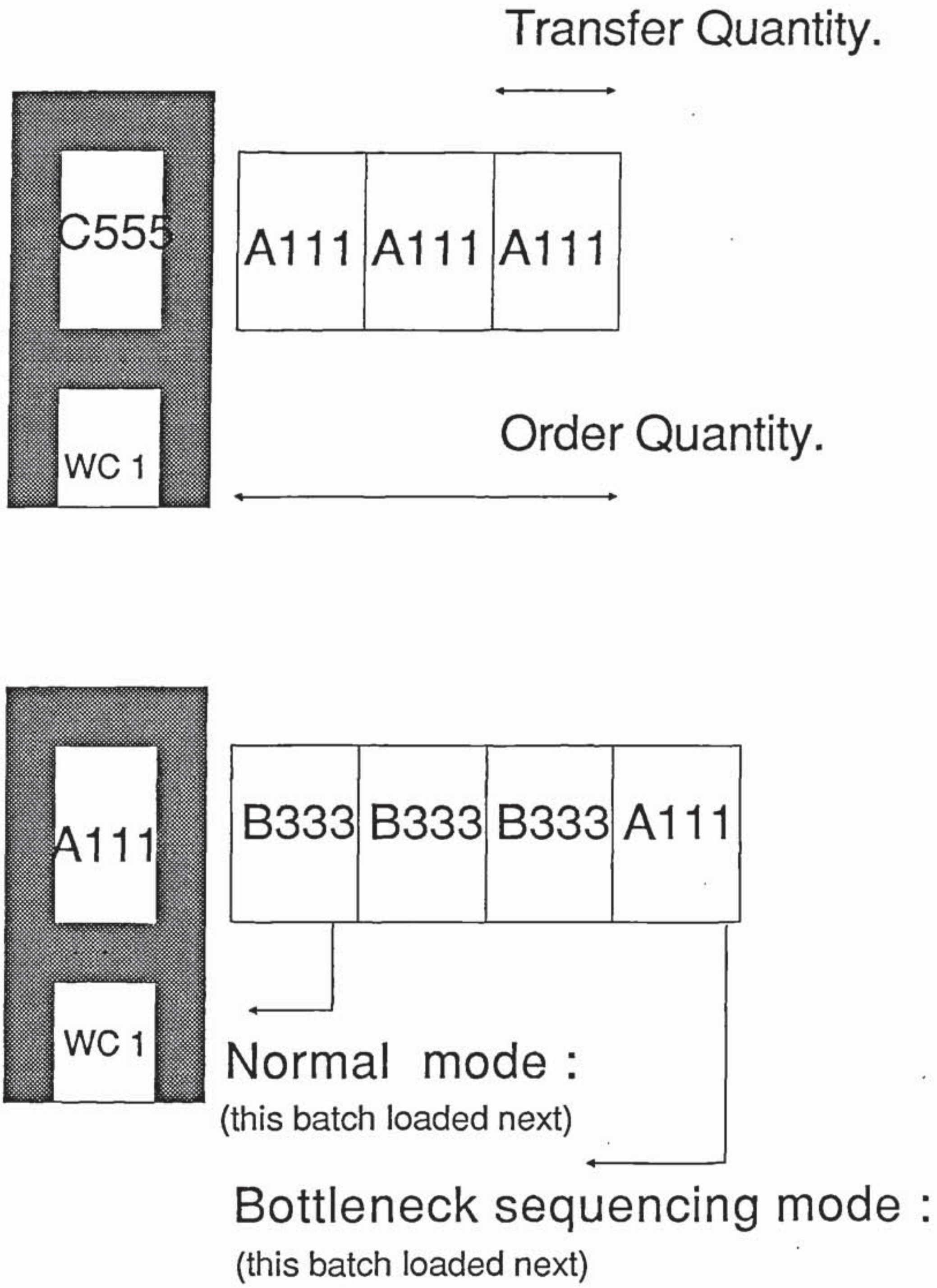


Fig 37. Bottleneck Sequencing at a Work Centre.

shortcomings of this rule were reduced by the similarity of PCBs as a group. It was therefore proposed to evaluate this rule initially.

The above rules can be summarized as follows:

1. Work will be transported between work centres in transport batches of 20. Transfer will occur immediately on completion of each operation.

2. Bottleneck work centres will be identified by the presence of an input queue exceeding 5 transport batches.

3. The input queue of a bottleneck will be sequenced so as to minimize set ups by combining transport quantities and placing batches of the type for which the machine is currently set to the front of the queue.

4. EDDF will operate as the priority rule at non-bottlenecks and as a secondary rule at bottlenecks.

Whilst the above policies are likely to have a positive influence on shop measures such as WIP and flow time, it is more appropriate to consider these policies in terms of total system performance using measures of total inventory, due date performance etc. Therefore, a static MPS assessment of these policies will not be attempted since these measures (due date in particular) are likely to be influenced by MPS uncertainty.

9.3 Summary

This chapter has discussed Part I of Stage II of the policy design methodology. MPS, MRP and shop policies have been developed which are compatible with a JIT configuration of MRP and "low inertia" capabilities of the AMT based PCB shop. A combination of "first principles" based research and experimentation have been used to achieve this. The experimental techniques used for this work (static MPS) were selected primarily for their efficiency in evaluating a wide range of alternatives. However, the omission of MPS uncertainty and rolling schedule calculations introduced some limitations to the application of system measures, such as due date accuracy and stock levels. Chapter 10. will address Part 2 of Stage II. This covers the exposure of the manufacturing element to market uncertainty (re-coupling at MPS level) and will therefore address these shortcomings.

10. EXPOSING MANUFACTURE TO MARKET UNCERTAINTY (STAGE II, PARTS II & III)

10.1 Introduction and Measures of Performance

The preceding chapter addressed Part I of Stage II of the policy design methodology (the formulation of flow based policies). MPS, MRP and shop policies consistent with low system inertia and MPS re-coupling were discussed. These were then tested (with the exception of bottleneck sequencing) in the static MPS environment to provide a "rough cut" assessment of their performance.

This chapter will discuss Parts II and III of Stage II of the policy design methodology. Part II covers the exposure of the supply and production control elements to the uncertainty of the market place (re-coupling), whilst Part III covers the determination of production flow times.

Those policies which showed potential in Part I were selected for testing in the more rigorous "fully interactive with MPS uncertainty" experimentation mode. In addition, those policies which could not be assessed in the static mode, or produced results which were influenced by this mode, were included. Specifically, this related to bottleneck sequencing and MPS grouping.

Data from FCL's previous 12 months manufacturing history was used to generate a model of FCL's market place, against which the performance of the above policies was evaluated. Fully interactive experiments with MPS uncertainty were used for this work.

In Chapters 8. & 9. the limitations in assessing total system performance, imposed by the static environment were recognized. Consequently performance measures were limited to the flow characteristics of the PCB manufacturing facility (PCB flow time and WIP). This chapter will assess the performance of alternative policies in the uncertain interactive environment. Under these circumstances it was appropriate to adopt measures which correspond to total system performance.

System performance measures can be placed into two groups. The first relates to the timing of order completion. At the PCB level flow time, due date accuracy (planned due date - actual completion date measured in days) and the standard deviation of due date accuracy, were chosen to represent the ability of the shop to meet its commitments. As such, these measures are both a test of production plan validity and an indication of production shop inertia. At the assembly and product levels the same measures were employed and provided a measure of the ability of the supply and production control groups to meet the requirements of the marketplace.

The second group contains measures which relate to the cost and "efficiency" of production. It is traditional in manufacturing research to employ standard cost based measures for this second group. However, in Chapter 3. a number of problems associated with using such measures were discussed. Principal among these, was the recognition that the changes in WIP and stock levels resulting from alternative policy choices would invalidate the use of a fixed overhead cost rate within comparative measures. This objection effectively rules out all of the standard cost based measures. Consequently, the case for a marginalist view was argued.

At FCL these issues are compounded by the paucity of relevant cost data resulting from recent changes to the business environment. The approach adopted during this research was to address these shortfalls within the context of requirements for total system measures.

In the case of FCL it was considered that the development and implementation of operational policies would not result in any immediate strategic repositioning of FCL in the marketplace. Therefore absolute cost measures (with which a comparison of FCL against its competitors could be made) would not be required to determine the utility of alternative policy sets. Comparative cost measures would therefore suffice.

It was recognized that in the first instance policy decisions would be implemented without any changes to existing manpower or capital equipment levels. Under these circumstances the capital assets and the labour costs can be considered to be fixed. Therefore, cost variations resulting from changes to operational policies will be confined to changes in working capital requirements resulting from movements in WIP and stock levels. It was therefore considered that measures of WIP and stock would form an appropriate basis for comparative study.

In the absence of reliable cost data, it was decided to group the manufactured parts by family and to use units of component type (PCB or assembly) for these comparative measures. In terms of cash flow requirements it can be seen that WIP and stock items of the same type are equivalent (ie. a PCB requires the same working capital support regardless of whether it is a WIP or stock item). Therefore, measures of total inventory cost were based on the sum of WIP and stock levels against the component family.

From the above, three comparative measures of PCB manufacturing cost were developed these were; average PCB WIP, average PCB stock and average PCB total inventory (stock + WIP) measured in PCBs. In addition, a measure of the effect of policy decisions on the total system required that assembly total inventory (measured as the average number of assemblies) be included in the analysis.

10.2 Experimental Design

The experiments for this phase of work were designed around three levels of MPS, three levels of shop policy and four levels of MRP policy, giving a total of 36 experiments. The fully interactive experimental mode (discussed in Chapter 7.) was used for this work. The purpose of these experiments was twofold. First to establish the utility of the policies developed in Chapter 9. and to compare their performance with the original traditionally *based reference set.* Secondly, to establish the performance of the supply and production control elements in the raw market environment, in line with the requirements of Stage II of the policy *design methodology proposed in* Chapter 5.

10.2.1 Uncertain MPSs

At the MPS level, FCL's historical MPS data formed the first experimental condition. Two data bases were compiled, the first containing weekly manifestations of FCL's historical MPS and the second containing weekly sales. The data for these is shown in Appendix 3. This condition represented the actual market demand in that it was constructed from actual sales orders and forecasts of market demand. Throughout the data collection period, no attempt was made to smooth the MPS and both actual and forecast demands were subjected to regular weekly revisions. In the interactive mode each weekly MRP regeneration was preceded by an upload of the MPS as specified during that week and the sales corresponding to that week.

For the second interactive MPS it was decided to include a reappraisal of the effects of MPS grouping in the uncertain environment. In section 9.2.3 the benefits of scheduling MPS demands in periods other than the month end were discussed. Subsequent testing in the static MPS environment indicated that such an approach was of limited value. However, it was considered probable that the interactions resulting from the uncertain environment would influence the performance of this approach to Master Production Scheduling.

A grouped version of the original uncertain MPS was generated by the following technique:

1. An analysis of the total standard hour content of each MPS product was made (Table 23.).

2. Four product groups were then generated which had roughly equivalent standard hour content (Table 24.).

3. Each of these groups was assigned to one of the weeks in the MPS time buckets (Figure 38.).

4. Each of the sales relating to an individual product was assigned to that product's period.

5. Finally, the MPS level demand uncertainty resulting from marketplace uncertainty and the monthly MPS reviews were adjusted in time to a review period corresponding to the relevant product group's MPS time bucket.

Product	Std. Hrs. each.	MPS demand	Total Std. Hr. Load.
10	5.7	1420	8094
1	10.4134	580	6039.772
18	147.28	36	5302.08
12	7.144	665	4750.76
16	4.2613	810	3451.653
41	57.38	60	3442.8
47	173.1017	19	3288.9323
201	1.6982	1560	2649.192
67	63.39	35	2218.65
5	12.741	156	1987.596
68	15.744	109	1716.096
70	15.744	95	1495.68
37	4.4703	245	1095.2235
202	.7471	1410	1053.411
56	4.554	165	751.41
226	.5372	1300	698.36
225	1.4612	200	292.24
Total	526.3674	8865	48327.8558

Table 23. Total Standard Hour Load Per Product

	Product type & Total MPS Load (in st.h.)					Total st.h. per group.
Group 1	10	201	202	–	–	
	8094	2649	1053	0	0	11796
Group 2	1	47	68	56	226	
	6039	3288	1716	751	698	12492
Group 3	18	41	5	70	–	
	5302	3442	1987	1495	0	12226
Group 4	12	16	67	37	225	
	4750	3451	2218	1095	292	11806

Table 24. MPS Product Groups of Equivalent Standard Hour Load

Group Number:	1	2	3	4	1	2	3	4	1	2	3	4
	Period (week) & Quantity: →											
Type:	1	2	3	4	5	6	7	8	9	10	11	12
10	12				24				13			
201	34				34				36			
202	24				8				8			
1		16				12				4		
47		34				34				34		
68		11				13				12		
18			30				31				21	
41			5				5				6	
5			80				75				80	
12				60				70				75
16				22				38				43
67				90				90				80

The first three members of each group are shown.

Fig 38. MPS Demand Timing Groups 1,2,3 & 4..

Two model databases were compiled containing MPS and sales data. These are shown in Appendix 15.

The final manifestation of interactive MPS was again based on the grouping technique outlined above, but in this case all MPS forecasting was removed. MPS demands were therefore limited to known customer sales orders. This differed from the static MPS in that the sales orders were timed to occur (as in reality) close to the requirement dates with customer order lead times averaging 12 to 16 weeks. Data was collected by determining the time and quantity of the last change to each MPS demand. This was taken to represent true "firm sales orders". Only one additional database was required to hold MPS data, as the sales timing remained the same as that for the grouped MPS with forecast. This myopic MPS represented a rigorous test of the supply and production control elements inertia and their ability to meet market requirements.

10.2.2 Shop Policies

Shop policies cover a range of issues such as; priority rule, work scheduling, batch splitting and WIP launching. The policy issues discussed in Chapter 9. were tested as three groups of policies representing alternative operating scenarios.

The first policy group represented the original operating conditions. WIP orders were released on their suggested launch date, batch integrity was maintained for order quantities less than 120; set-ups were minimized wherever possible and inter-work centre transport set to take two hours. In addition, a FIFO sequencing rule operated whenever conflict occurred at a work centre.

The second group of policies represented a test of transport batches in isolation. Within the shop model the batch splitting algorithm was enabled and all PCB orders were broken down into transport quantities of average size 20. Inter-work centre transport time was given a high priority and set to take an average time of 10 minutes. In addition, WIP launching and priority rules remained as for the above set.

The final group of policies were designed to represent the full transport batch and bottleneck sequencing rules formulated in section 9.2.7. Again the batch splitting algorithm was enabled and a mean value of 20 was assigned to all PCB orders. Inter-work centre transport time was set to average 10 minutes and in addition, a bottleneck sequencing algorithm was enabled. This algorithm allowed each work centre to determine its status by counting the length of its input queue. A limit of 5 transport batches resident in the input queue was set to indicate whether a work centre was behaving as a bottleneck or not. In the case of the former, each bottleneck work centre re-sequenced its input queue to minimize the number of set-up operations. Transport batches of equivalent type were processed sequentially, such that one set operation would service the group. In addition, work was prioritised using the EDDF rule. In the case of non-bottleneck work centres, transport batch quantities were maintained and excess capacity was used to support additional set-up operations. In this condition the EDDF priority rule was used in isolation.

10.2.3 MRP Policies

At the MRP level decisions with respect to; order policy, stock policy and lead time were required. Of these, stock policies were maintained at the zero safety stock level in keeping with Stage II of the methodology. Component and finished goods stock was therefore the result of mismatches between lead time and flow time, forecast errors and order cancellations.

One of the primary influences of the order policy on system performance is through the interaction of production plan characteristics and shop performance. In Chapter 9. order policy 3 (POQ), with pan and minimum set to zero, was shown to offer "low inertia" performance potential. That the alternatives offered by TMS (for example a two period POQ and larger pan sizes) did not offer any potential benefits in terms of reduced inertia. It was shown that within a 50% variation of MPS smoothness the support offered by these alternatives was of insignificant value.

It was considered that the static MPS investigation of these issues (discussed in Chapter 9.) provided sufficient support for setting the order policy to 3 (POQ) and setting pan and minimum values to zero in the first instance.

In view of the above points, at the MRP level comparison between alternative policies was confined to the performance of the linear lead time policy in the first instance. In Chapters 8. and 9. this policy was shown to have a beneficial effect on production plan smoothness and WIP levels.

Lead time policies were also expected to have a significant effect on order completion accuracy, with increases in lead time tending toward increased order completion earliness. Within the linear lead time policy the queue time per operation element can be adjusted to increase or decrease average lead times.

In Chapters 8. and 9., the queue time per operation was determined empirically and as such was set to equal the experimentally determined queue time. In the uncertain MPS experiments it was recognized that some benefits may accrue from increasing the queue element beyond this value. Five levels of queue element were chosen; 0.15, 0.5, 1, 1.5 and 2 days per operation. The first of these was equal to the calculated value determined in Chapter 9. The latter corresponded to an average lead time of 20 days for PCBs and assemblies, which was equivalent to

Fig 39. Lead Time v Queue Element.
Linear Lead Time Policy.

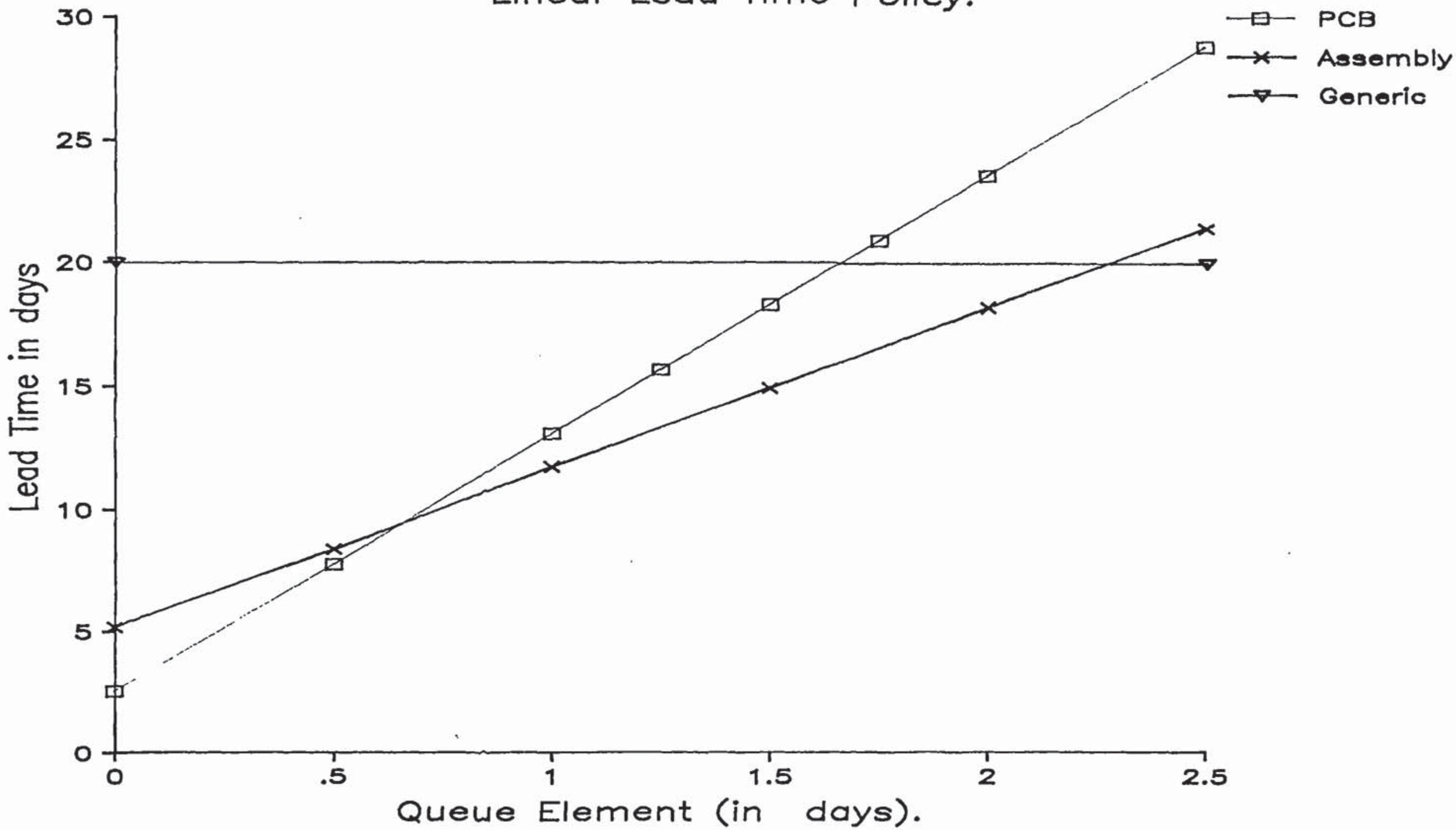


Fig 40. Mean PCB WIP v Run Length.

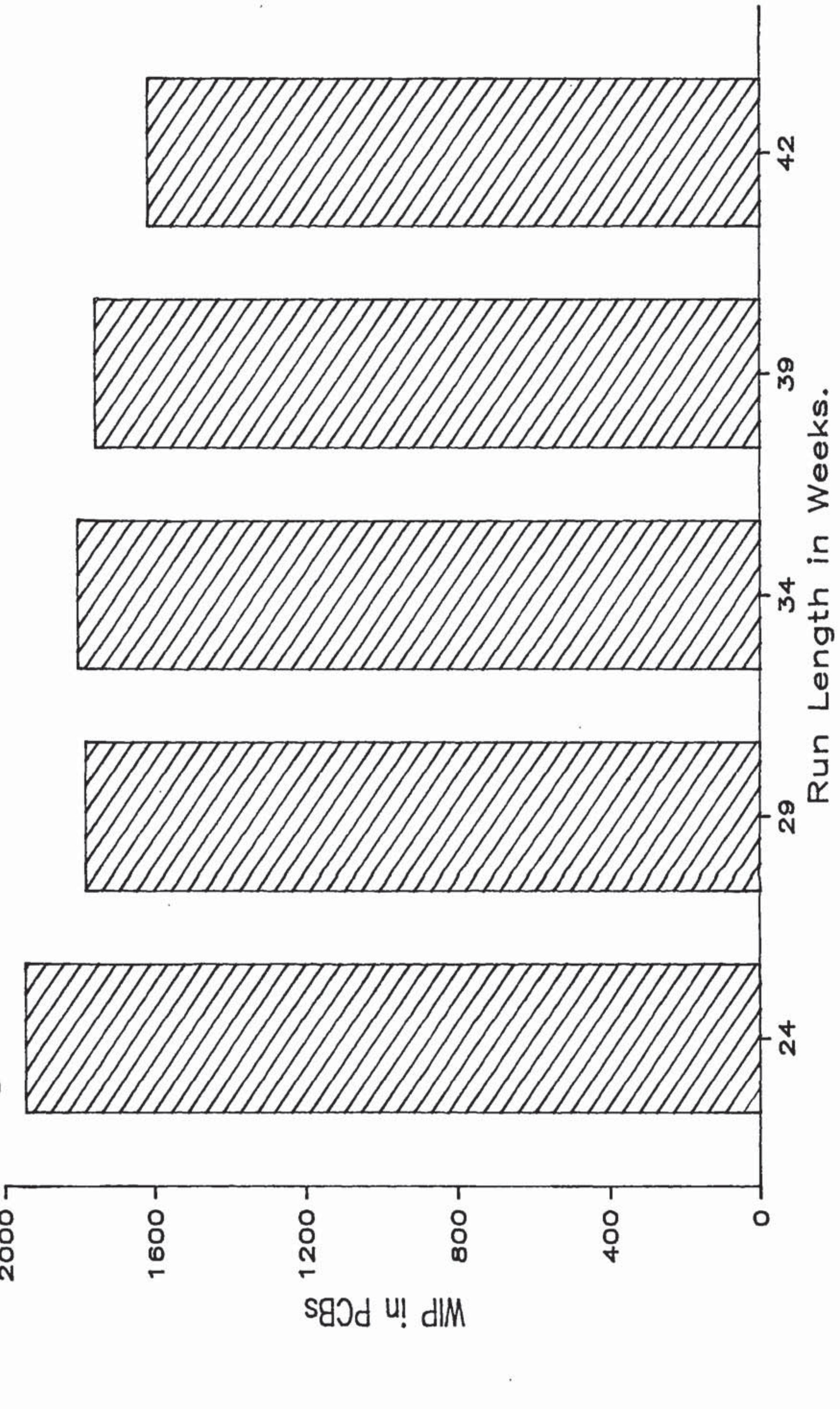


Fig 41. Mean Ass'y WIP v Run Length.

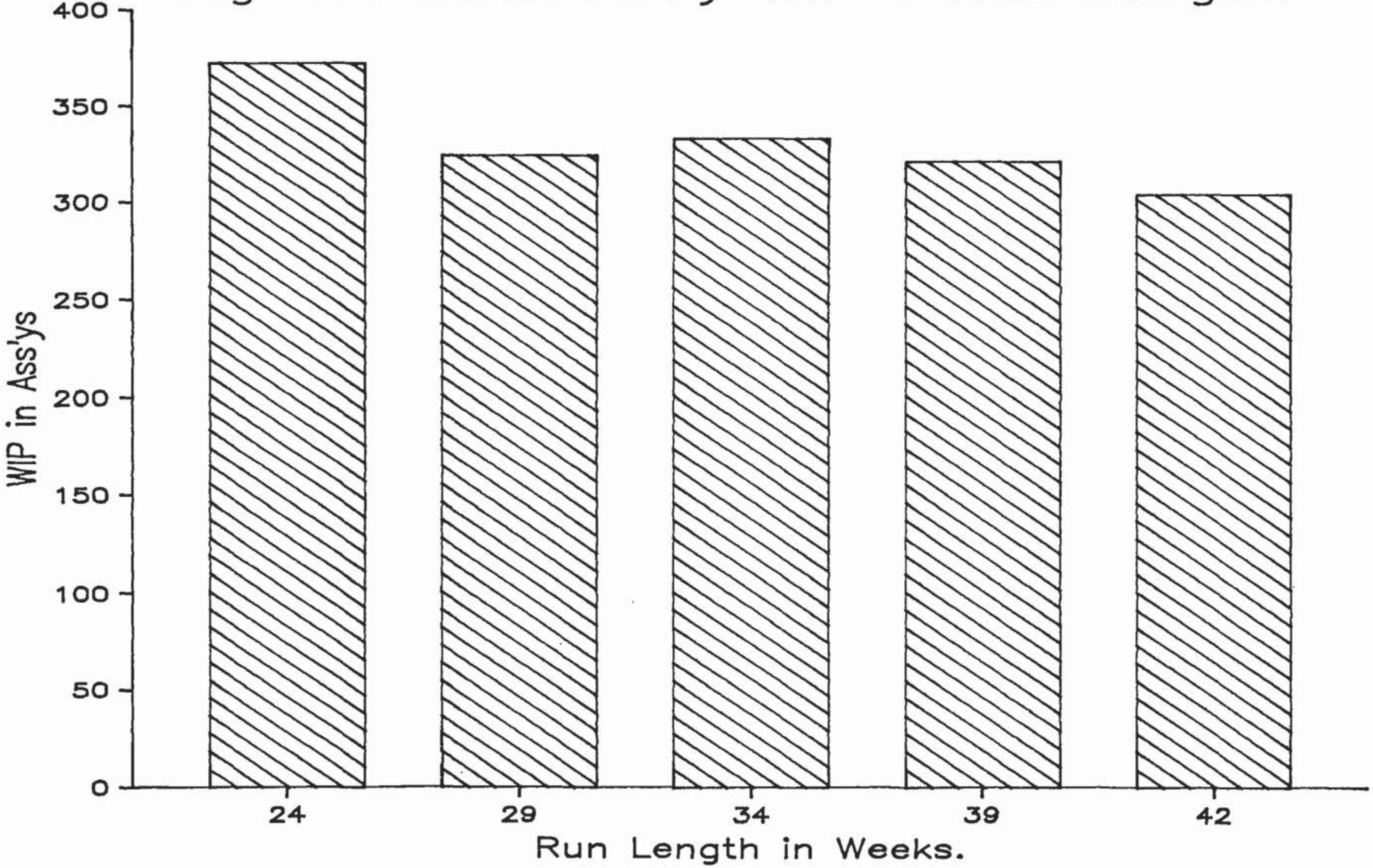


Fig 42. Mean PCB Flow v Run Length.

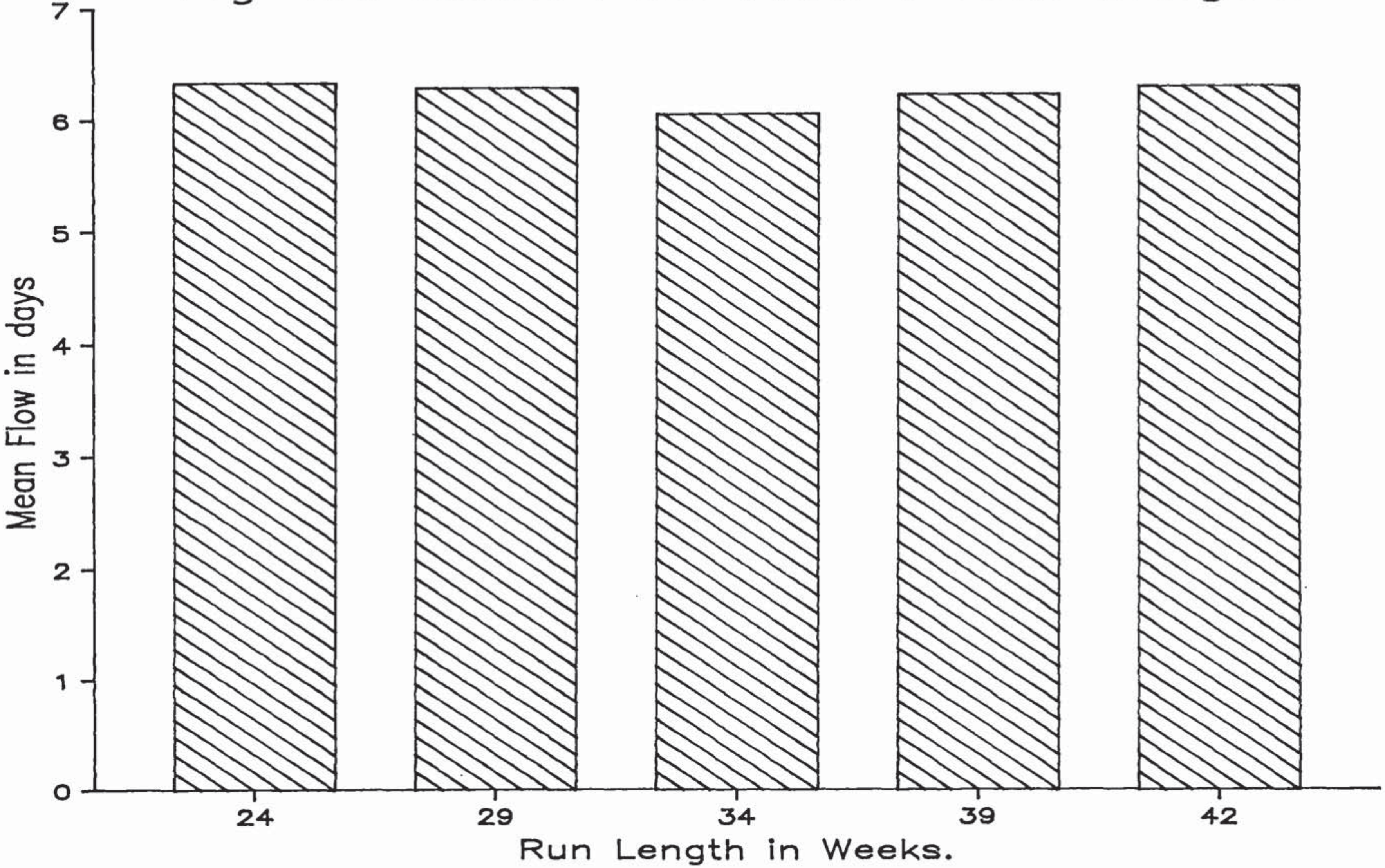


Fig 43. PCB Flow cv v Run Length.

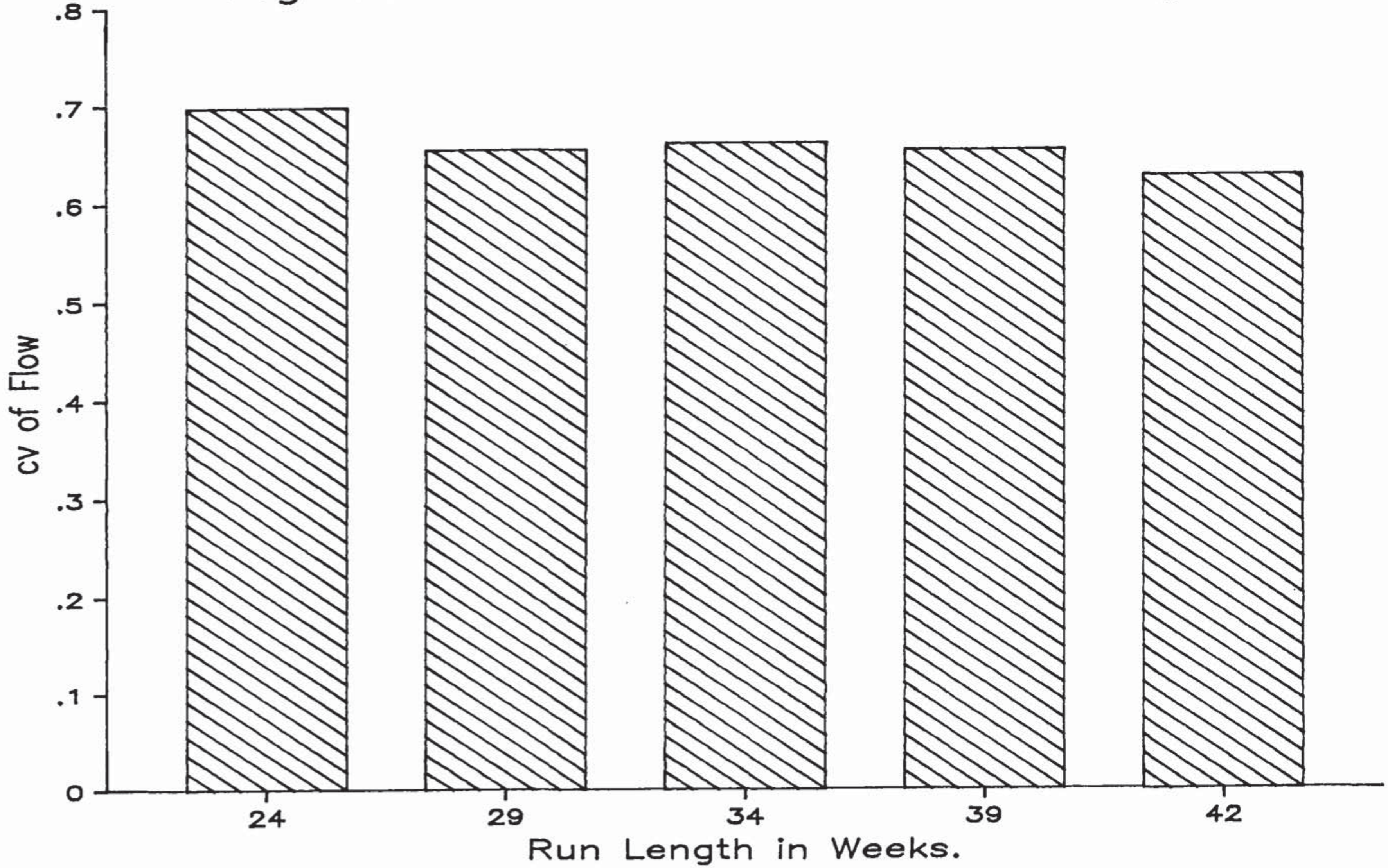
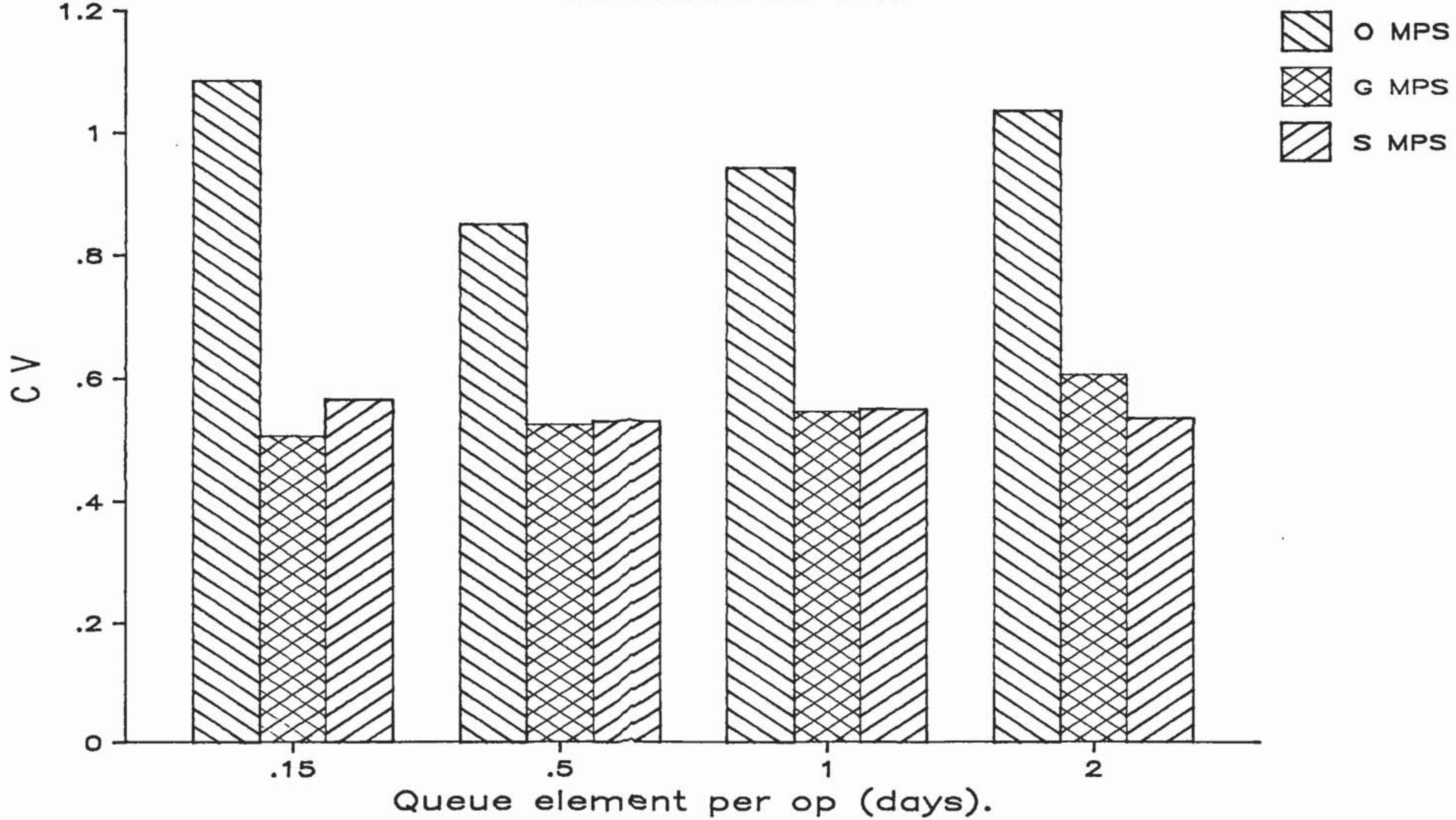


Fig 44. Production Plan Smoothness.

Measured as C.V.



the generic value used by FCL. This is illustrated in Figure 39. Therefore the production plans generated using this value can be viewed as the linear equivalent of the original generic lead time. The middle values were included to complete the analysis.

In addition to the experiment series outlined above, the validation run was included in the analysis to facilitate a comparison with the performance using the original MPS, Shop and MRP policies.

The data recording start points and experimental duration were determined in an identical manner to the experiments outlined in Chapter 9. Data recording was started at period 9 and ended at period 39. Figures 40, 41, 42 and 43 show result stability at periods 24, 29, 34, 39 & 42 and support the use of the period 39 end point.

10.3. Interactive Production Plan Characteristics

Tables 25, 26 and 27 show the weekly production plans for each of the MPS and lead time combinations. It is interesting to compare these with the plans produced by the static MPS (Tables 7. & 8.).

Two important differences exist between these sets of plans. The first is that the interactive plans exhibit a 30-40% increase in standard hour work load. It is probable that a significant portion of this increase is due to MPS demands being omitted during the preparation of the static MPS. The technique used relied on five sample manifestations of the historic MPS taken sequentially in time. These were then assembled into a static MPS. It is possible that some orders were absent from the sample MPSs. It is also probable that some of this increase was due to order cancellations resulting from uncertainty.

The second effect resulting from the introduction of uncertainty is a 40-50% increase in production plan cv.

period	Original MPS & MRP	Original MPS Order Policy = POQ min stock = min order = pan = 0 Linear Lead Time, Queue element = .15	.5	1	2
7	376.25	252.3	1909.113	2219.9	1096.253
8	2881.6	1813.85	1820.318	1276.7	556.969
9	1683.89	2795.82	1025.174	539.4	313.604
10	328.96	888.74	1081.827	504.3	666.36
11	1953.39	196.347	1748.262	1404.1	1137.717
12	5402.34	4547.148	4207.705	4316.8	4453.187
13	1178.24	1024.54	550.395	640.8	710.74
14	454.35	168.3	527.564	602.4	1074.407
15	972.12	282.9	1042.019	1050.8	1247.214
16	2608.78	3137.513	2304.349	2630.6	2440.311
17	1593.14	1488.109	452.655	1020.4	43.49
18	1587.52	814.639	811.562	775.4	1113.107
19	571.81	240	568.333	883.5	1892.367
20	4206.81	3654.8	4559.628	4041.2	4672.207
21	1846.46	2589.8	1871.5	1659.4	605.636
22	0	1490.7	1217.527	310.4	295.823
23	827.98	408.78	941.27	786.3	515.704
24	1475.92	660.9	999.546	1109	1550.196
25	427.72	1760.5	965.147	1570.1	829.012
26	3360.07	3210.82	3235.306	3076.5	2497.174
27	672.73	1307.14	1576.348	736.8	1254.992
28	1366.19	385.07	2025.911	962.6	804.485
29	358.49	6215.04	1209.62	824.3	274.091
30	4042.18	1451.88	2669.505	3270.9	2227.206
31	637.76	730.415	1485.011	614.5	1207.141
32	442.32	80.34	20.309	82	345.095
33	179.7	5531.18	303.977	72	281.097
34	6055.41	416.12	5132.516	5261.8	5752.432
35	44.18	269.27	393.081	265.2	174.337
36	226.71	322.06	648.713	429.9	564.163
37	102.19	6.01	9.628	366.9	325.89
38	528.71	65.6	246.232	382.8	471.1764
39	1123.017	601.39	804.038	1006	869.86
Periods 9-39					
Mean	1500.513	1479.031	1465.578	1354.355	1280.710
cv	1.024310	1.086165	.8514271	.9430304	1.038343

Table 25. Interactive Production Plans (Original MPS) In Standard Hours Per Week

period	Grouped MPS Order Policy = POQ min stock = min order = pan = 0 Linear Lead Time, Queue element = .15	.5	1	2
7	1042.125	695.077	696.923	944.984
8	834.114	1009.564	1275.9	1169.62
9	1004.263	1349.441	2185.401	352.6
10	853.917	2016.095	792.422	516.85
11	1833.034	963.041	864.473	693.92
12	1716.15	1217.608	519.744	266.24
13	1600.984	2056.245	1957.732	1926.02
14	2352.685	2812.224	2827.198	3274.33
15	1731.636	1273.844	1297.431	1886.63
16	904.866	760.505	1051.222	1635.39
17	1388.128	753.625	1762.539	438.4
18	1751.416	1932.326	1634.302	1465.3
19	897.648	1212.012	1018.11	924.1
20	1935.626	2115.531	1434.914	2537.54
21	2623.722	2545.437	2398.607	1838.64
22	2584.286	1826.448	2287.923	2258.24
23	885.68	1010.124	992.568	1172.33
24	546.918	566.558	890.515	625.8
25	3326.532	3558.98	3544.183	3258.33
26	2471.106	2905.647	2900.001	2240.55
27	1604.048	1409.086	1385.221	1008.534
28	1870.969	1527.242	1888.603	1856.96
29	1318.463	1319.507	662.712	656.02
30	1441.43	2328.311	1503.974	918.96
31	1597.147	1971.286	1697.304	1028.5
32	2715.082	1909.056	2122.611	1784.788
33	2378.547	1917.299	1141.135	1740.93
34	674.874	759.151	886.122	1392.68
35	1380.74	1297.862	982.944	1079.66
36	1784.546	1562.503	1593.021	1439.64
37	414.061	467.646	331.298	343.45
38	2.712	94.368	76.177	172
39	340.22	273.858	535.365	534.6
Periods 9-39.				
Mean	1509.323	1497.500	1428.442	1314.622
cv	.5058018	.5242189	.5448802	.6065021

Table 26. Interactive Production Plans (Grouped MPS) In Standard Hours Per Week

period	Grouped Sales Only MPS. Order Policy = POQ min stock = min order = pan = 0 Linear Lead Time, Queue element = .15	.5	1	2
7	960.747	695.007	504.02	493.16
8	834.1135	1008.581	783.74	954.1
9	999.415	1346.186	1190.14	295.97
10	721.698	1962.799	493.24	453.66
11	1711.759	833.896	1029.62	1482.73
12	2940.412	2434.437	1995.74	2307.12
13	1987.238	1869.942	2730.56	2148.14
14	3058.094	3678.025	3297.74	3318.91
15	2406.115	1826.545	1984.07	1903.68
16	1090.842	924.166	977.37	1682.62
17	1279.3	849.7739	1582.85	652.36
18	810.0428	1161.843	1006.09	988.402
19	409.3651	912.8965	759.54	673.54
20	859.6387	1384.306	724.87	1811.05
21	2891.905	2634.226	2481.9	1969.48
22	2757.703	2136.668	2288.94	2111.74
23	1001.879	900.9599	1232.54	1360.1
24	311.6079	292.2948	582.64	763.9
25	2261.068	2861.534	2686.4	2459.65
26	2240.912	2203.175	2110.77	1615.2
27	1581.183	1628.928	1838.99	1753.8
28	1472.66	1093.308	1778.01	1782.16
29	975.5525	1224.887	327.49	260.1
30	1795.949	2062.392	1806.05	1172.3
31	2267.553	2627.608	1459.33	1685.1
32	2606.387	2014.767	2111.47	2123.5
33	2245.058	1853.78	1361.79	1571.33
34	669.4331	949.0607	769.2	1097.5
35	1889.752	1364.783	1886.35	2018.24
36	1761.804	1542.604	1876.11	1622.23
37	578.714	603.9499	624.22	788.85
38	64.3723	365.4422	264.8	253.8
39	276.1679	214.0212	386.4	217.3
Periods 9-39.				
Mean	1506.619	1498.872	1422.212	1387.628
cv	.5642714	.5299155	.5505052	.5356697

Table 27. Interactive Production Plans (Grouped with sales only MPS) In Standard Hours Per Week

Figure 44. shows the production plan smoothness measured as the coefficient of variation for each of the uncertain production plans. From this plot it is clear that MPS grouping has a substantial positive effect on smoothness. The cvs for both of the grouped MPSs (grouped with forecast (G MPS) and grouped sales only (S MPS)) are approaching 50% of the non-grouped original MPS.

It is probable that this is related to the staggering of MPS reviews. In the original MPS format each product was reviewed monthly and the forecast adjusted accordingly. Thus, the effect of this monthly review was translated into WIP actions in one period. In the grouped format each product group was reviewed monthly but one group was reviewed each week. Thus the disruptive effects of MPS rescheduling were smoothed over the entire month.

10.4 Supply Performance in the Interactive Environment

10.4.1 PCB Manufacturing Facility

Figure 45. shows the PCB WIP levels for each of the interactive experiments. The original MPS, MRP and Shop policy datum is shown at the furthest left. The three groups of MPS policies are arranged from left to right with the first representing the original MPS configuration, the second representing the grouped MPS and the last representing the grouped sales only MPS. The results for each set of shop policies is shown against each combination of lead time queue element and MPS configuration (B = full bottleneck sequencing, T = transport batching, and O = original shop policies). This presentation format will be maintained for all of the interactive results.

There are two interesting features of the PCB WIP results. The first is the considerable reduction in average WIP resulting from the introduction of transport batch based shop policies (transport batch alone and bottleneck scheduling). It is apparent that with many of the policy combinations, the introduction of transport batches alone, achieves the major portion of the WIP savings with bottleneck scheduling producing a moderate further reduction.

The second interesting feature is the variation in average WIP with changes in lead time queue element. For each of the MPS configurations the shortest lead times (queue = .15 days per operation) produce the greatest WIP levels. From this point, a general reduction in average WIP followed by a gradual increase is observed as the queue element is increased. This could be related to a shift in the level of "shuffling" of order timing, as the average lead time is extended (by the action of the linear policy with increasing queue values). In addition bottleneck scheduling appears to offer the greatest improvement over transport batching at the .15 day queue element level. This result is consistent across each of the MPS configurations, and could indicate that this technique has most to offer WIP reduction when the safety element in the lead time is at a minimum.

Figure 46. shows the average PCB stock levels for each of the policy combinations. There are two points of interest in these results. The first concerns the increase in average stock levels with increasing lead time (represented by increasing queue element). This is consistent for each MPS and shop policy configuration and shows that any safety elements built into the lead time, result in increased stock holding costs. In addition, the original MPS and grouped original MPS are equivalent in terms of average stock, whereas the grouped sales only MPS results in stock levels which are consistently lower for each lead time queue element value. It is probable that this results from a lower rate of "false orders", and cancellations resulting from the omission of the forecast element. This implies that the inclusion of a forecast element and its attendant forecast error will tend to increase stock levels.

The second point of interest concerns the reduction in average stock in relation to the original policies. It has been shown above that a queue element of 2 days per operation produces a linear equivalent to the original generic lead time of 20 days. Therefore, it is possible to compare the stock levels produced by the original policies with those produced by the original MPS, original shop policies and the linear equivalent of 20 days. It is probable that the reduction from an average of 4042 PCBs (original) to an average of 2323 PCBs (Figure 46.) is attributable to the removal of the two period batching function and the minimum batch and pan size parameters. It is probable that much of the additional stock attributable to the original policies, is redundant to requirements and results from the rounding up of PCB order quantities. This stock would be exposed to the risk of obsolescence due to engineering change.

Figure 47. shows the average total PCB inventory levels for each of the policy combinations. These results reinforce those of PCB WIP and stock. A strong and consistent trend of increased total inventory levels associated with increasing lead time queue element, is exhibited. The only minor exception to this, are the results for the original MPS configuration with a queue element of .15 days per operation. It is apparent that in this case the high WIP level overpowers the increasing stock trend.

The performance of the transport batch based shop policies is consistently better than the original policies. However, the bottleneck scheduling rules appear to offer only marginal further reductions in inventory, with the greatest benefits occurring at the .15 day per operation queue element. From this, it would appear that bottleneck sequencing plays a minor role in reducing inventory for a given lead time queue element, particularly when sizeable safety elements are included in the queue allowance. This minor increase in performance is surprising and will be discussed in more detail at the end of this section.

Each of the results offered potential inventory savings over the original policies. The greatest potential being offered by the "grouped sales only" MPS, bottleneck sequencing and a queue element of .15 days per operation (average PCB inventory = 3028 PCBs). The original policies resulted in average inventory levels of 7428 PCBs, therefore the above policies represented a potential saving of 59% in PCB inventory.

Figure 48. shows the results for PCB flow time against each policy combination. These results mirror those for PCB WIP and all of the above comments apply. The differences between the flow time results and the WIP results are limited to consistently greater spacing between the bottleneck sequencing, transport batch and original shop policy results. This is a function of the measured statistic. The inventory measures such as WIP and stock were measured in absolute terms. However, the timing measures such as flow time and due date accuracy were recorded against each completed batch (ie flow time per batch), so as to mirror the measures used at FCL. Thus the flow time measure, will be influenced by the number of completed batches and not their size. Consequently any change in the distribution of batch size will effect these measures. With the transport batch based policies, the batch size distributions were found to be equivalent across the policy combinations. However, with the original shop policies, the absence of batch splitting tends to increase the variance in the distribution of batch sizes. The larger batches found in the tail of the distribution will have a greater impact on the inventory measures than on the timing measures such as lead time. Thus, there is a greater increase in inventory levels attributable to the use of the original shop policies, than is the case with the lead time measures.

Figure 49. shows the results for PCB average order due date accuracy measured as the arithmetic average of the planned due date, minus the

Fig 45. PCB WIP v Policy.

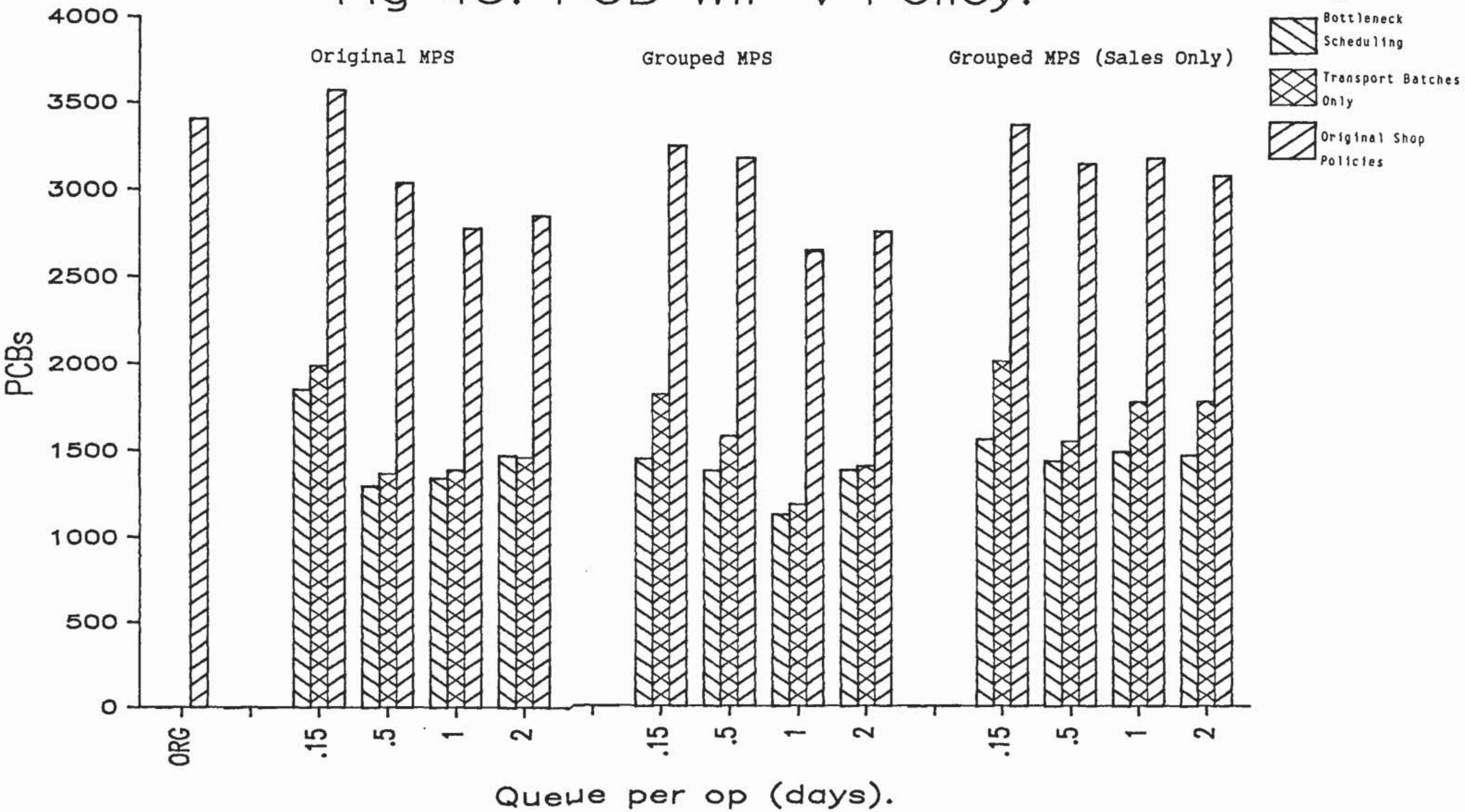


Fig 46. PCB Stock v Policy.

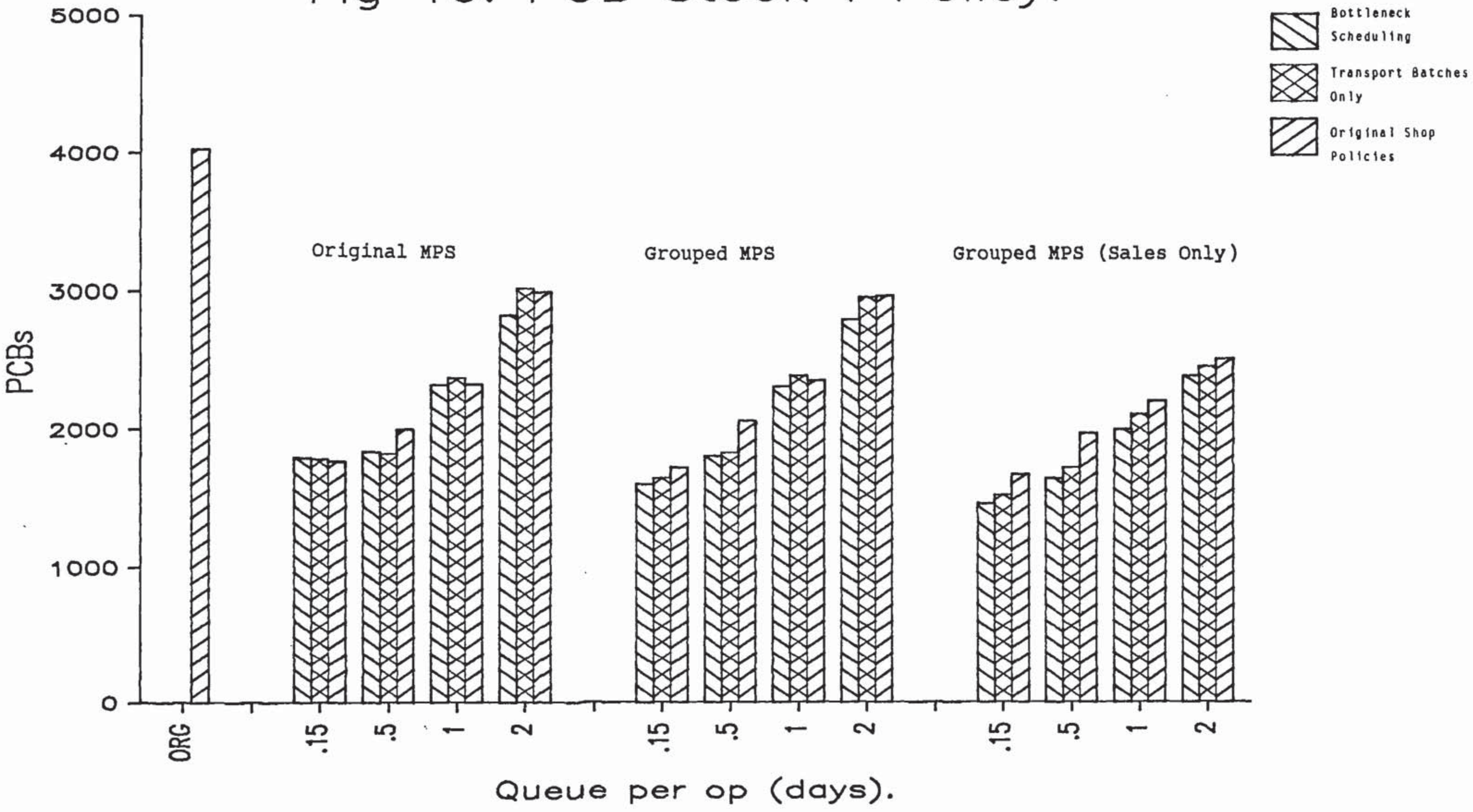


Fig 47. PCB Inventory v Policy.

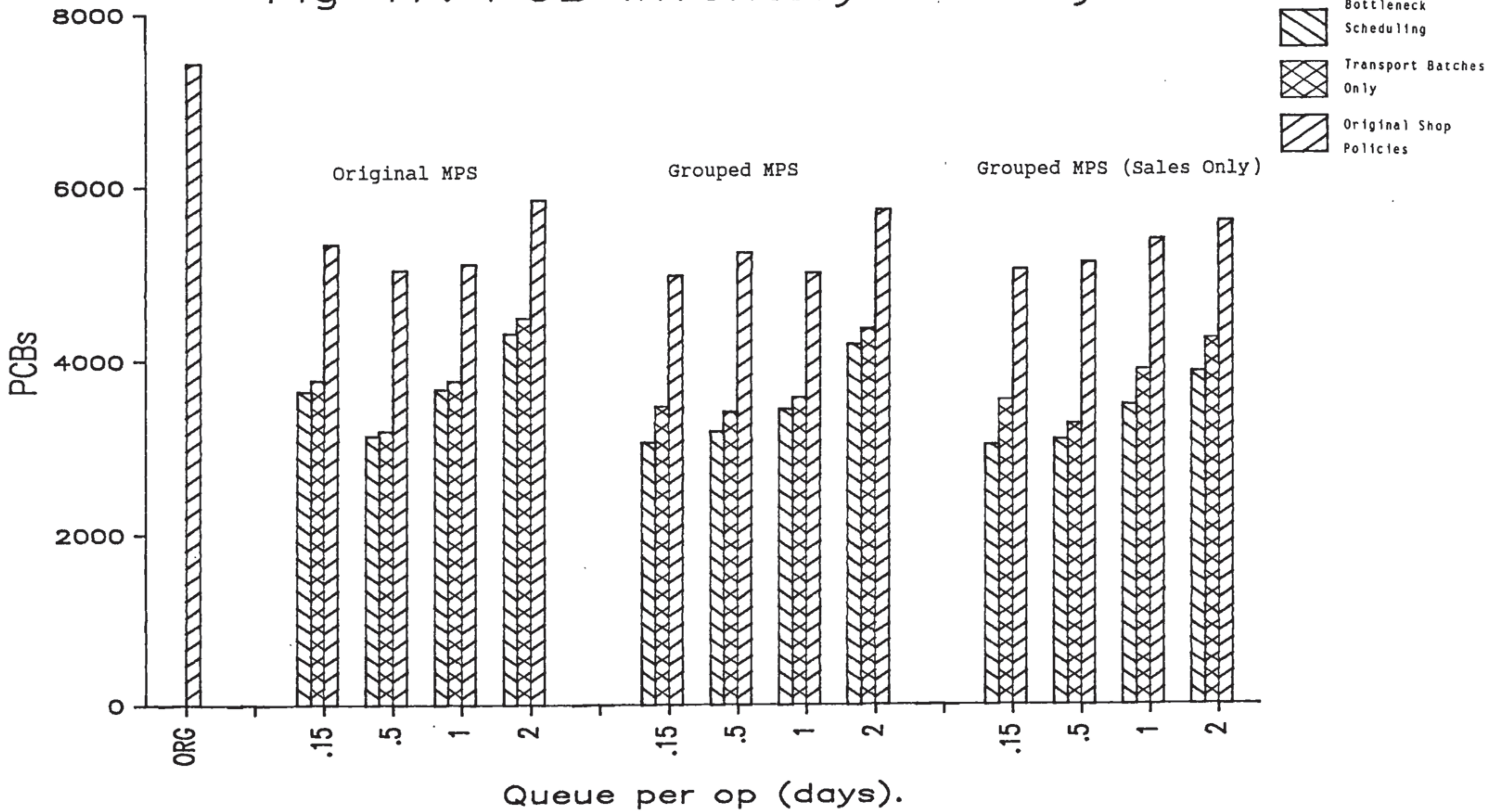


Fig 48. PCB Flow Time v Policy.

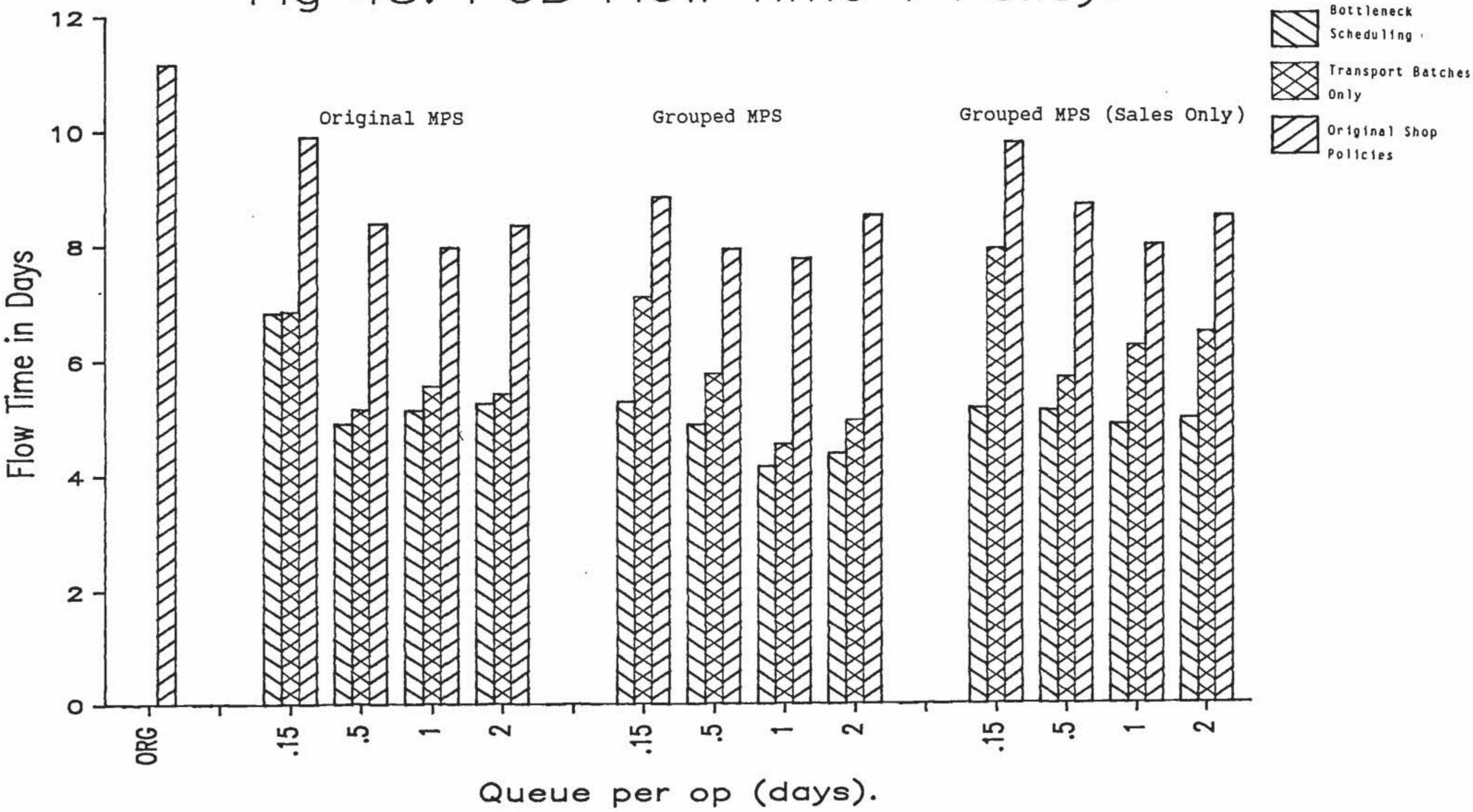


Fig 49. PCB Due Date Accuracy v Policy.

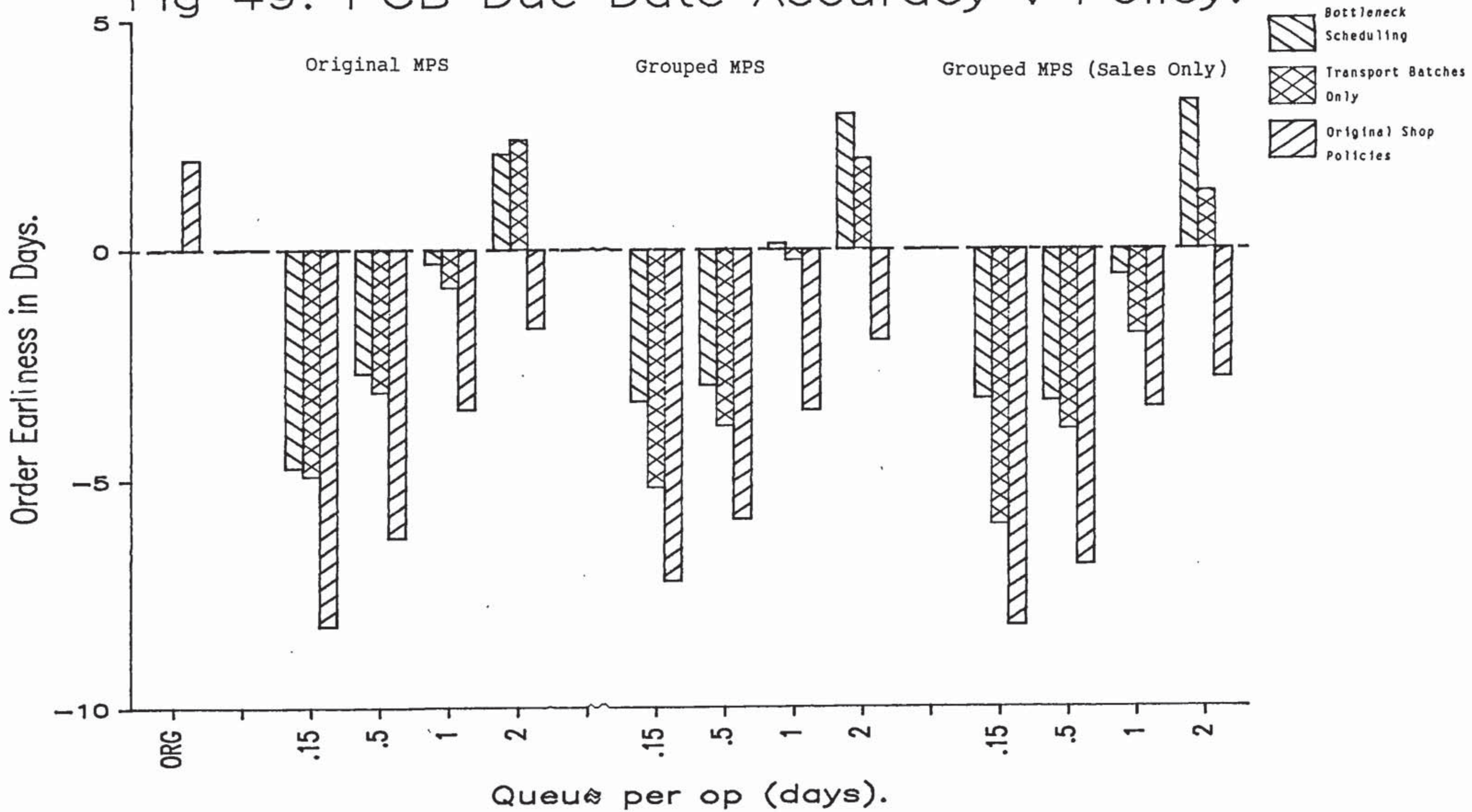


Fig 50. PCB Due Date sd v Policy.

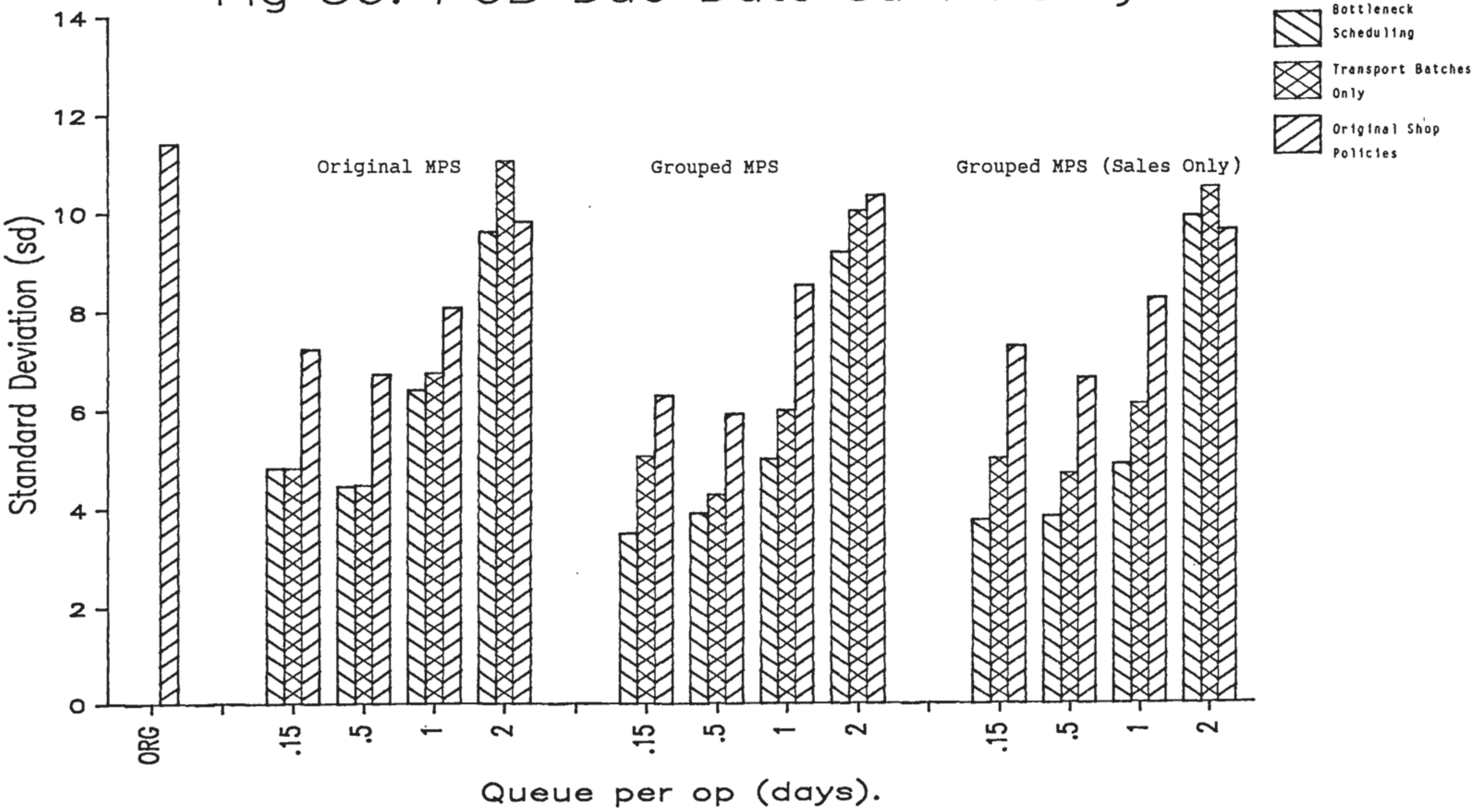


Fig 51. PCB Due Date Spread.

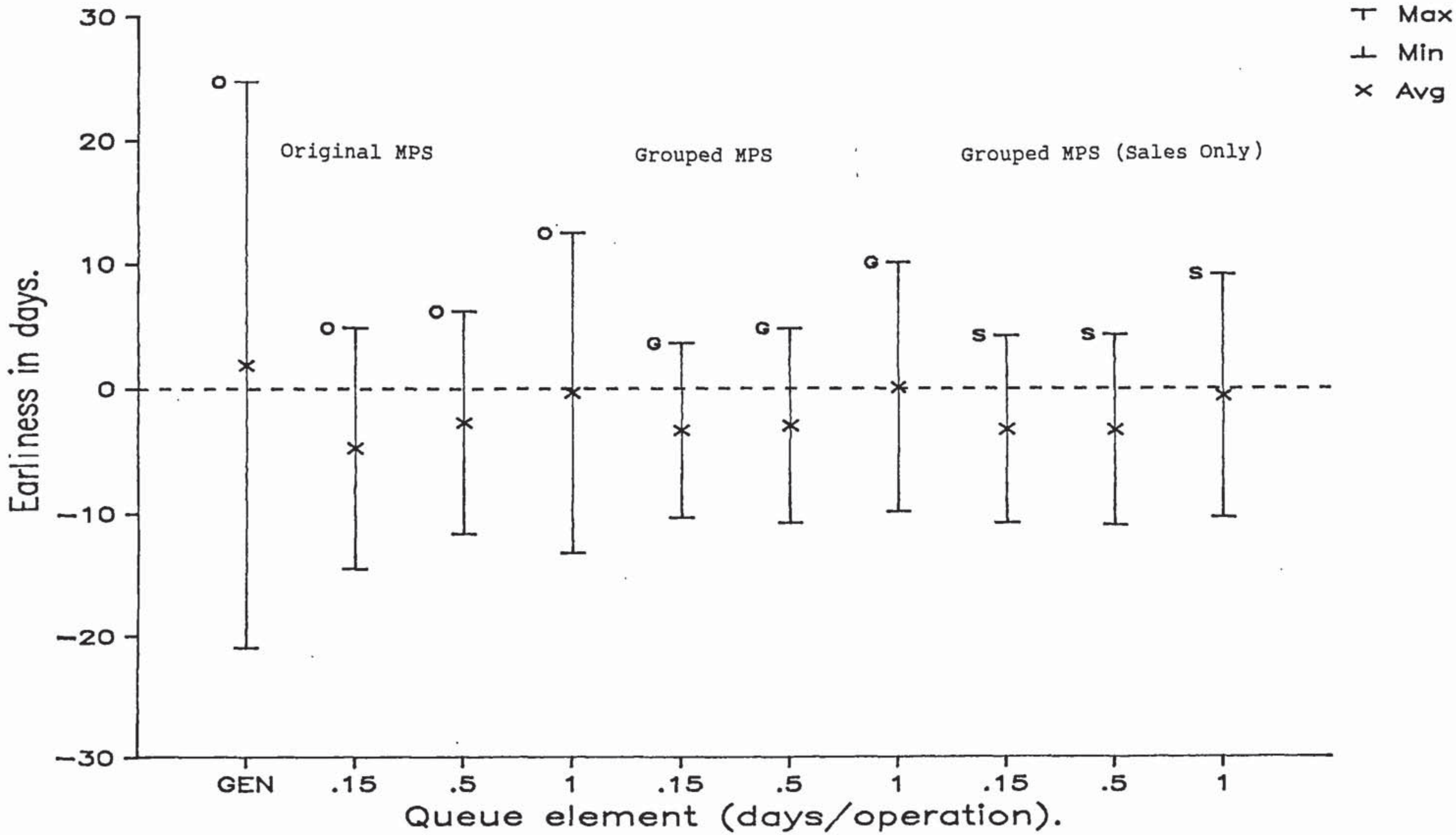


Fig 52. Assembly Inventory v Policy.

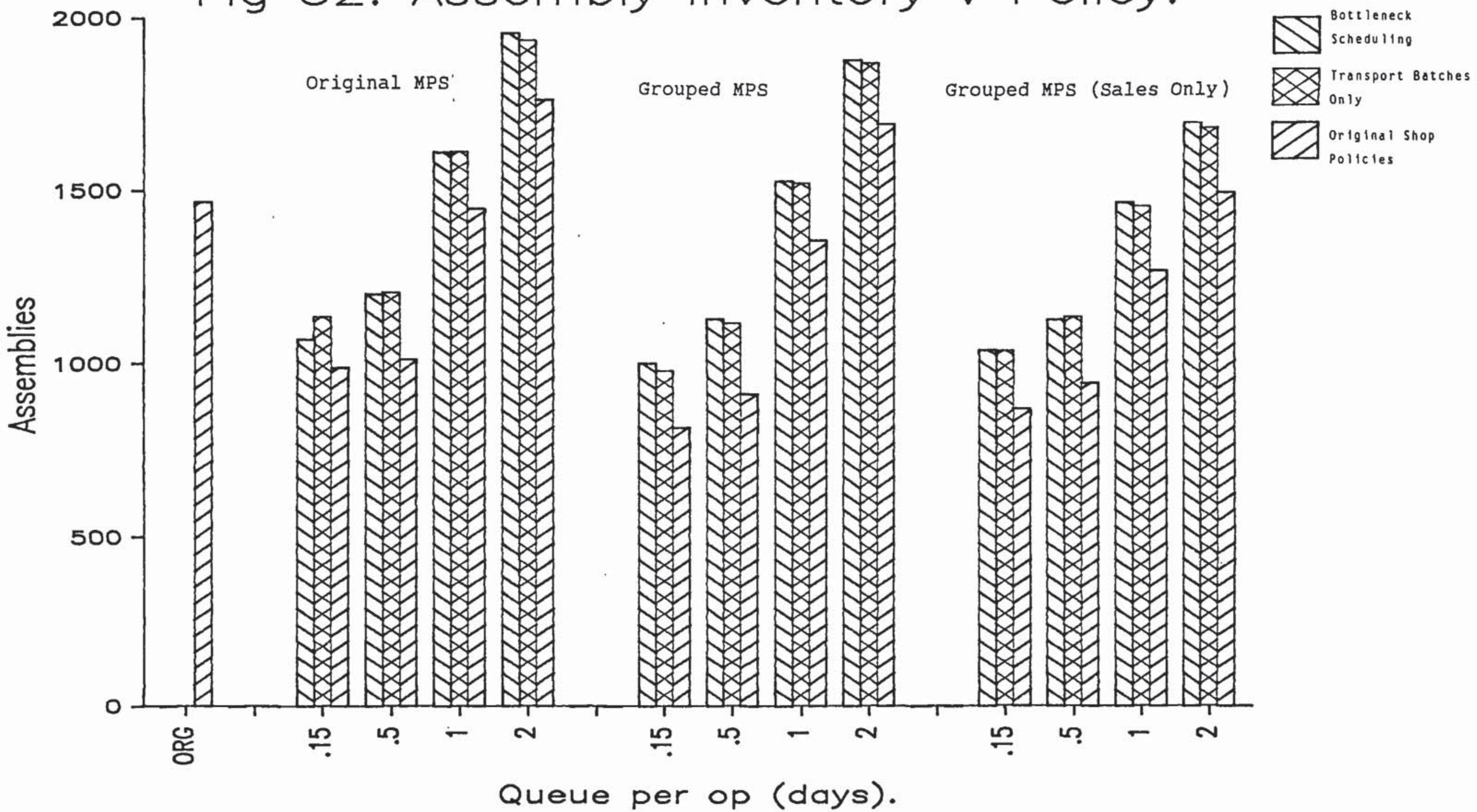


Fig 53. Assembly Due Date v Policy.

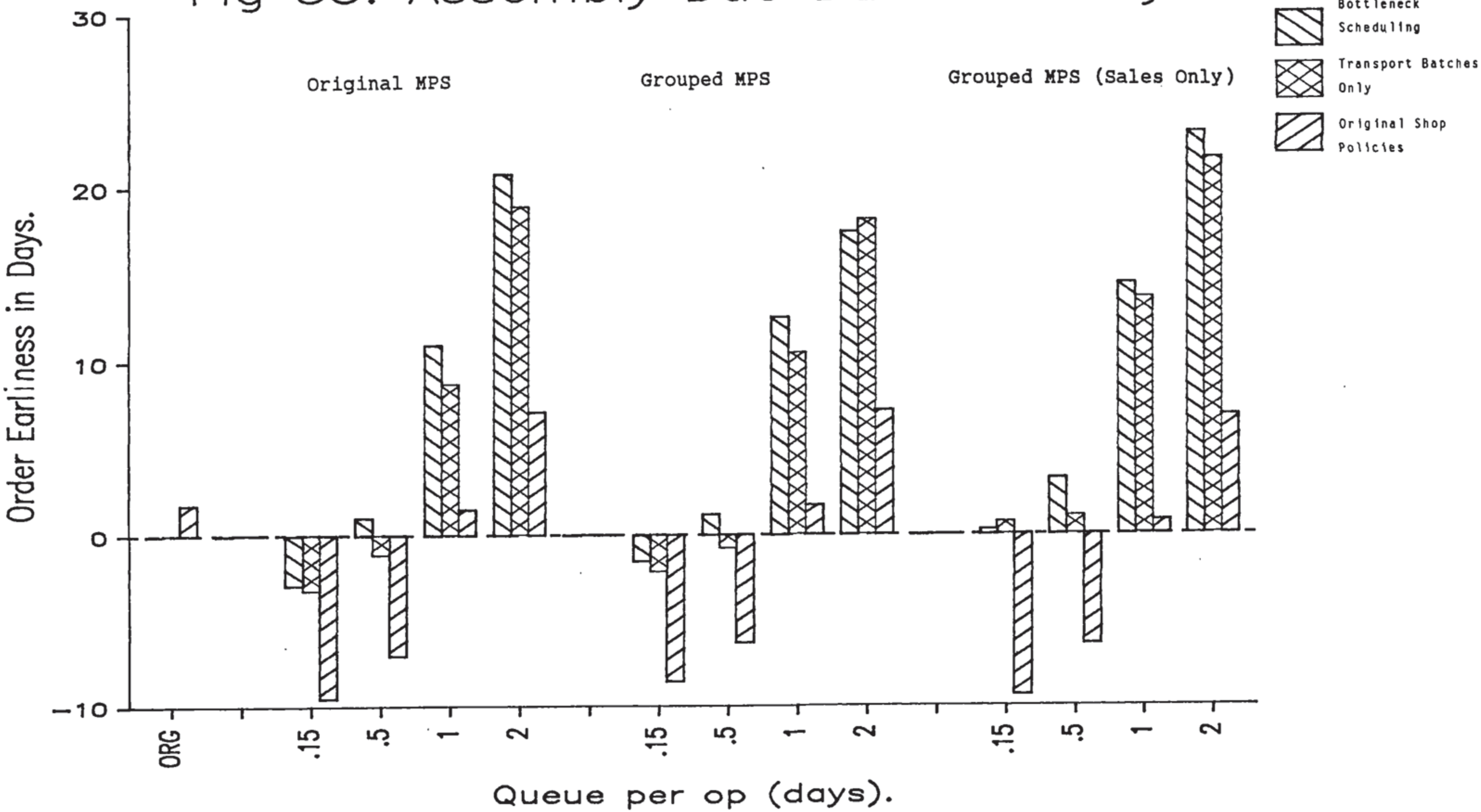
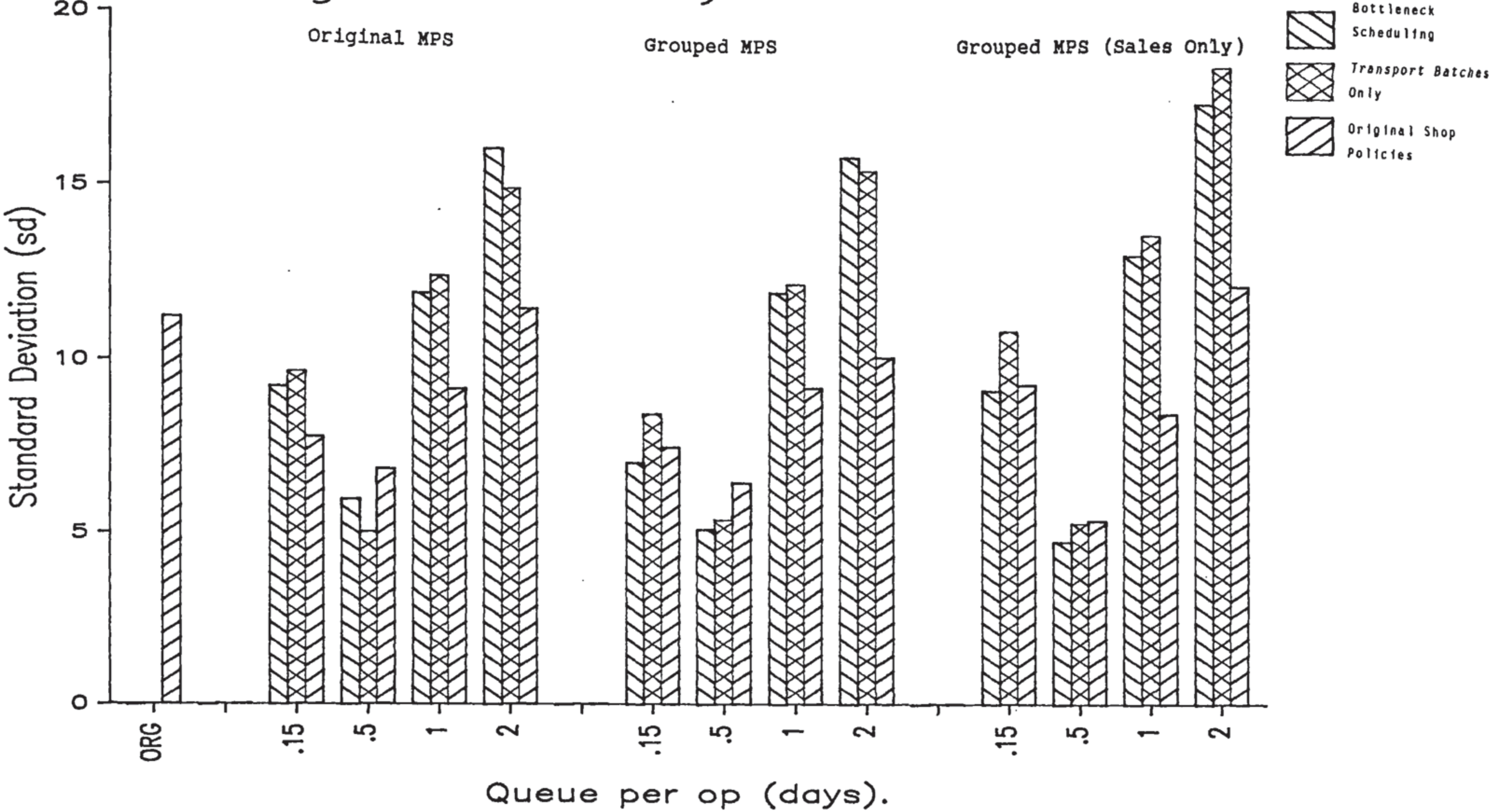


Fig 54. Assembly Due Date s.d.



actual order completion date for each batch. The results are consistent for each group of MPS, MRP and shop policies. It can be seen that average earliness increases with queue element for all combinations of MPS and shop policy. As with all previous results, bottleneck sequencing out-performs transport batching which in turn out-performs the original shop policies. Bottleneck sequencing shows the greatest improvement over transport batching with the "grouped sales only" MPS.

It is interesting to note that at the zero safety level (queue element = .15 days per op) the completion performance is negative indicating that batches are arriving late. This suggests that a safety allowance may be required in the uncertain environment to counter the effects of late occurring orders. From these results, it is evident that an allowance of one day per operation is required, to achieve near zero due date performance with the bottleneck sequencing shop policies. However, this approach must be treated with some caution.

One characteristic of FCL's business environment, is that some MPS demands will always arise within their composite lead time and will inevitably result in lateness at one or more BOM level. Others will reach stability at an earlier time. Therefore it is likely that WIP orders relating to these will have a greater probability of completion on or prior to their due date. The addition of the safety element to lead time, may serve only to increase the earliness of these orders. Whilst this would balance the late orders to give an agreeable mean value, the late orders themselves would be largely unaffected.

If the due date figures are compared to those for the original MPS and MRP policies, it can be seen that with the original shop policies all of the results are worse (later) than original. However, these mean values represent one characteristic of a distribution of due date performance. For a more complete understanding the spread of these distributions must be included in the analysis. Figure 50. shows the standard deviation of due date performance for each of the policy combinations. This exhibits similar characteristics to the mean values in that standard deviation increases with lead time queue element and "bottleneck sequencing", out-performs "transport batch" which in turn out performs the original policies.

The standard distribution of due date performance for the original policy conditions, is higher than that for any of the alternative policy combinations. If six standard deviations are taken to cover the span of each distribution, then the seemingly better mean due date performance of the original policies is seen to be part of a distribution which encompasses those of all of the alternative policies. This is shown in Figure 51. Thus, in terms of overall due date performance, the original MPS and MRP policies must be judged worse than the alternative MPS and MRP policies when used with the original shop policies.

It is possible that the positive shift of the mean due date values exhibited by the original policies is in part related to the higher mean stock levels associated with these policies. It is probable that on occasions MPS demands arising within the composite lead time will result in their associated PCB demands being supplied from stock. This is likely to result in a shift in the distribution of late PCB orders and thus PCB due date performance.

10.4.2 Assemblies and Products

The MRP and Shop policies used to control the manufacture of assemblies and products (with the exception of lead time) remained constant throughout this work. Therefore, variations in the performance of this area are limited to variations induced by; the choice of MPS policies, linear lead time queue element and changes to the availability of sub-components (PCBs and sub assemblies) brought about by alternative PCB shop policies.

Figure 52. shows the total assembly inventory associated with each of

the policy combinations. The relationship between assembly inventory level and policy combination is seen to be similar to that observed for PCB inventory. Average levels are seen to increase with lead time queue element. Of the three MPS policies "grouped sales only" results in consistently lower inventory levels, the "grouped with forecast" are the next highest and the original MPS highest of all.

At the shop policy level, bottleneck sequencing of the PCBs results in consistently higher assembly inventory levels. This is likely to be a consequence of higher levels of component "fluidity" at the assembly WIP order launch date, achieved through better PCB due date performance. The use of transport batches in isolation at the PCB level, results in the next highest assembly inventories followed by the original PCB shop policies.

The original MPS, MRP and shop policies result in a lower assembly inventory level than is found with the original PCB shop policies and a queue element of 2 days. It is probable that this results from fluidity problems associated with the spread of PCB due dates discussed above. It is therefore probable that the extra inventory resulting from the inclusion of batching functions within the original order policy, is of the wrong mix to support the timely launch of assembly WIP orders.

Figure 53. shows average assembly due date performance, whilst Figure 54. shows the standard deviation of assembly due date performance. It is these figures which are of greatest importance to the selection of operating policies, since these determine the level of customer satisfaction and whether any de-coupling is required.

The average assembly due date results follow similar trends to the average PCB due date results. Taking the shop policies first, bottleneck sequencing produces a consistently earlier mean completion date. The results for transport sequencing are consistently less early, whilst the original shop policies are latest. The difference between bottleneck sequencing and the original shop policies is approximately 10 days.

The results for the "grouped sales only" MPS are consistently earlier than for the "grouped original" MPS, which in turn are earlier than for the original MPS. This suggests that the addition of the forecast element in the MPS, does not offer any benefits and may even be detrimental to system performance. This result implies that the disruption caused by forecast revisions and forecast error may negate any positive influence expected to accrue through a forward view of product demand.

Again average earliness increases with lead time. However, unlike the PCB results, a positive due date performance can be achieved with considerably less queue element. This indicates that a small negative mean PCB due date performance can be tolerated at the assembly level.

It is interesting to note that the due date performance produced by the original "datum" policy set, is worse than that produced by each of the alternative policy sets with a lead time queue element of 2 days. Furthermore, mean assembly due date performance equivalent to that with the original policies can be achieved with a queue element of .5 days in conjunction with the bottleneck sequencing shop policies. This strengthens the argument that a mix problem exists at the lower levels of BOM with the original policies. This is probably related to the effects of the generic lead time and the batching contained in the original order policy.

Again it is necessary to include an appraisal of the spread of due date performance in this analysis. From Figure 54. it can be seen that for the three policy sets the spread of assembly due date performance follows a "U" shaped curve, which for each policy combination has a minimum value when the queue element is equal to .5 days per operation. Thus, at the lower and higher values the distribution of due date

Queue per op (days)	Average Weekly Load in Standard Hours. .15	.5	1	2
Original MPS	1479.031	1465.578	1354.355	1280.710
Grouped MPS	1509.323	1497.500	1428.442	1314.622
Sales only MPS	1506.619	1498.872	1422.212	1387.628
Average increase over 2 days per operation.	12.9%	12.14%	6.41%	-

Table 28. Average Weekly Load In Standard Hours

performance increases in span. It is probable that these distributions are not in fact normal and that at the .15 day queue level each distribution is skewed toward lateness, whilst at the higher queue levels the distributions are skewed toward earliness. The assumption of normality by the models statistical algorithm reduces the ability to analyze this issue.

10.4.3 Production Plan Load and Lead Time Allowance

A further important feature of the production plans generated against the above policies, is the consistent increase in average weekly load with decreasing queue element. Figure 55. shows this for the interactive production plans. It was considered that this resulted from a bias induced by variations in lead time interacting with the relatively short length of the MPS. At the longer average lead times resulting from the higher queue elements, the 52 week MPS resulted in low level BOM orders being distributed over a longer time span, whilst the converse would be true of the low queue values. From Table 28. it can be seen that the production plans corresponding to the .15 days per op queue time exhibit an average 12.9% increase in load relative to the 2 days per operation based production plans.

Two methods for overcoming this bias were evaluated. The first was to increase the MPS length and conduct experiments over a longer time period. This was rejected because the paucity of data would require that the additional demand be synthesized. It was considered that this would introduce further potential for bias and would reduce the validity of a comparison between the experimental results and historical performance data.

The approach adopted was to establish (by experimentation) relationships between; WIP, stock, flow time and due date accuracy, against production plan load. These relationships were then used to compensate for load variations such that the analysis could be verified for the load adjusted case.

Fig 55. Production Plan Load v Queue.
Measured in standard hours.

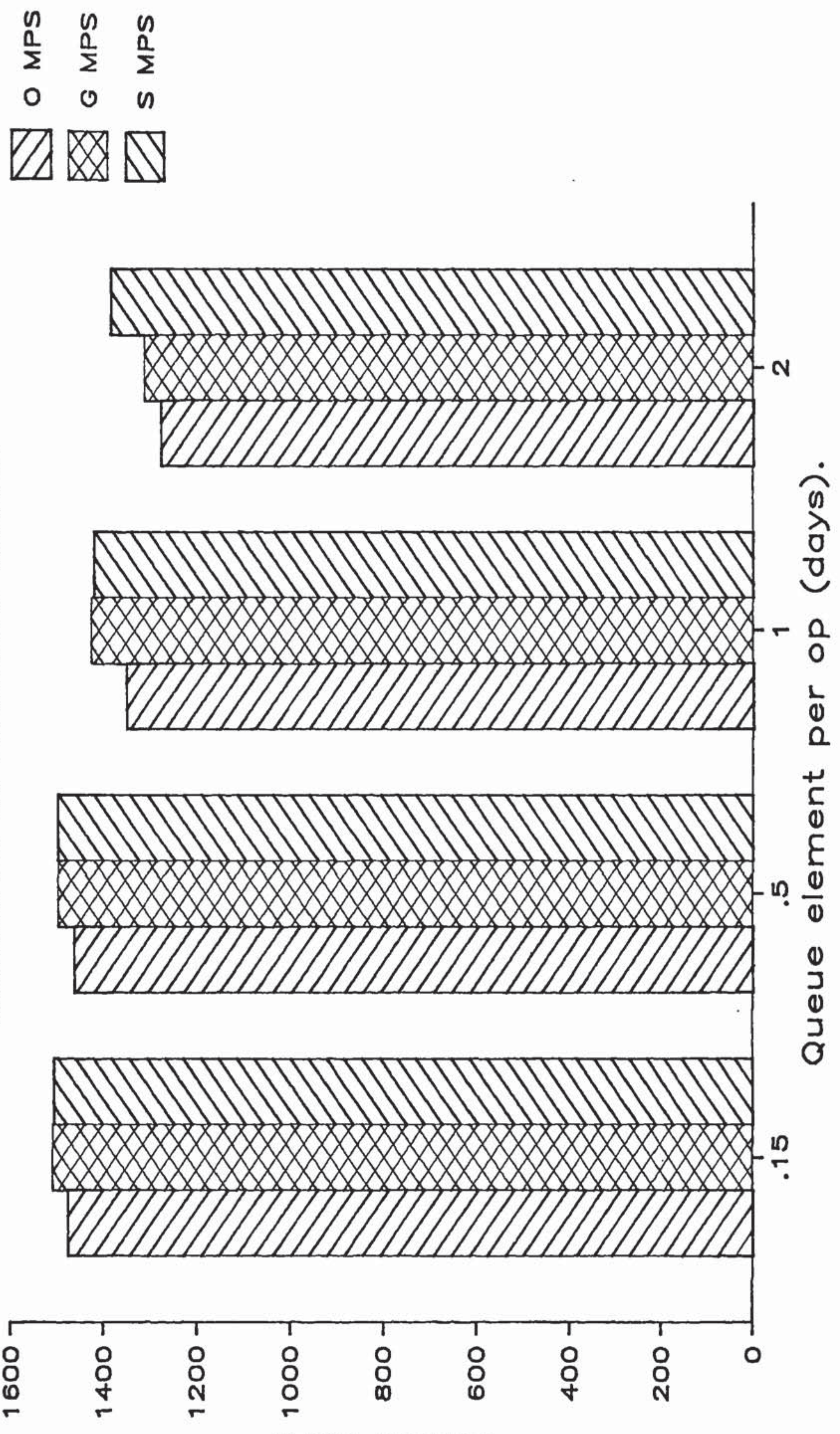
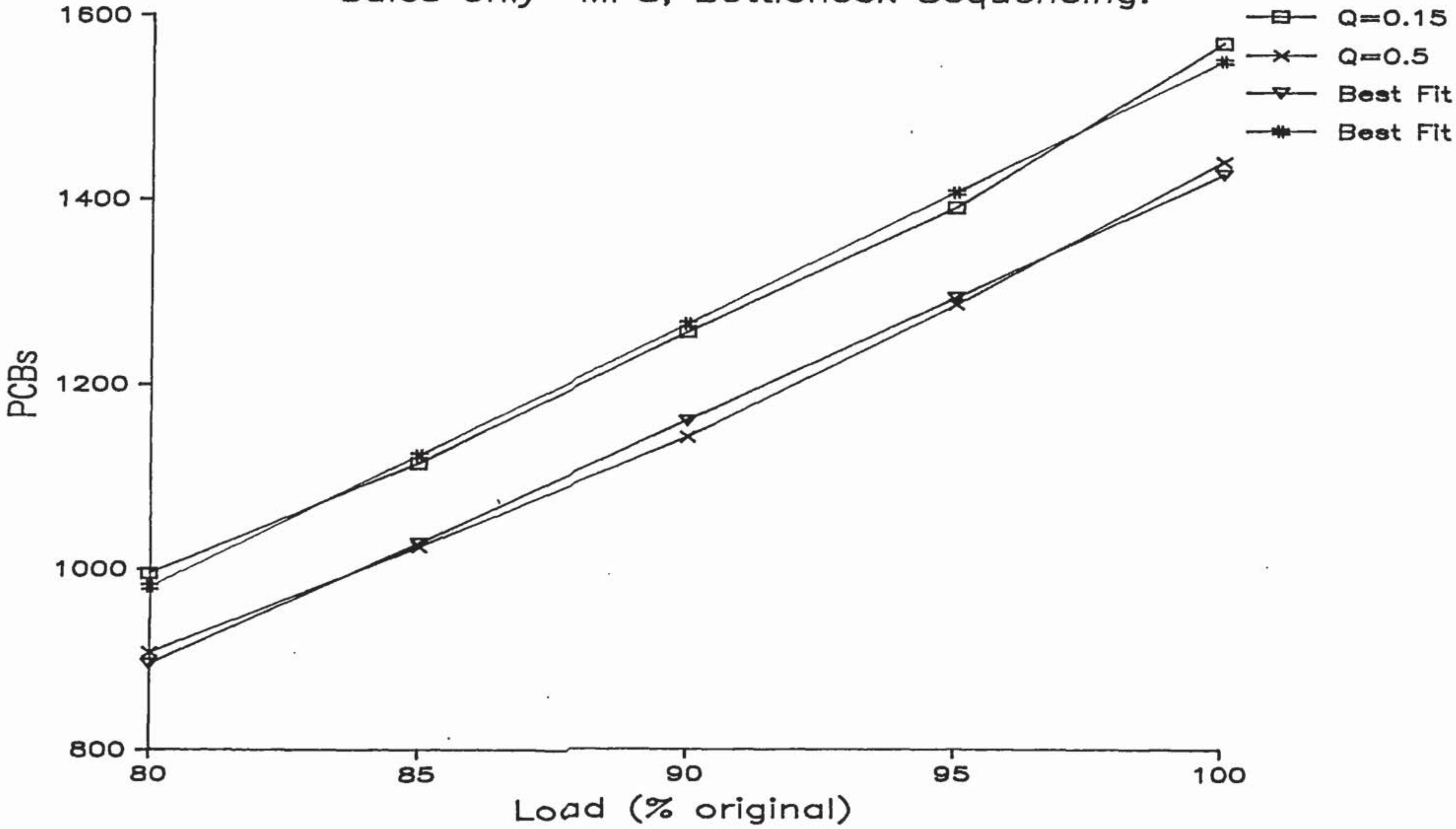


Fig 56. PCB WIP v Input Load.
"Sales only" MPS, Bottleneck Sequencing.



From the previous analysis of the results the; "grouped sales only" MPS, bottleneck sequencing shop policies, and a lead time queue element of 0.15 and 0.5 days per operation offered the best performance. Therefore, the factory model was run against these two policy combinations.

Each of the above production plans were used to drive the supply model with the load adjusting algorithm enabled. This automatically increased the quantity of each WIP order by a pre-set load factor, prior to the action of the batch splitting algorithm. For a description of this algorithm see Gooden (1988). The aim of this work was to evaluate the effect of the 12% increase in load at the queue level of 0.15 and 0.5 days per operation; load factors of 80, 85, 90, 95 & 100% were used to investigate the effects of a reduced load at these lead time queue levels.

10.4.4 Load Compensation

Figure 56. shows the effects of load on average PCB WIP levels. From this, it can be seen that over the 80 - 100% range the effects are consistent and linear. Therefore, the following relationship was used to adjust the PCB WIP levels for the .15, .5, 1 and 2 day per operation lead times.

From equivalent triangles,

$$\frac{WIP100 - WIP80}{L100 - L80} = \frac{WIPo - WIPa}{Lo - La}$$

since,

$$L100 = Lo, \quad A = WIP100 - WIP80,$$

and,

$$L100 - L80 = .2\ L100 = .2\ Lo$$

then,

$$WIPa = WIPo - 5A \times \left(\frac{L2 - Lo}{L2} \right)$$

Where; WIPa = Load adjusted average WIP level.
WIPo = Original average WIP level.
WIP100 = WIP at 100% load
WIP80 = Wip at 80% load.
A = WIP decrease due to 80% load reduction.
L2 = Average input load at queue = 2 days.
Lo = Original average input load.

Figures 57, 58, 59, 60, 61, 62 & 63 show the effects of load on PCB and assembly, WIP, stock, flow time and due date values. From these it can be seen that over the 80 - 100% range the effects are consistent and linear for PCB WIP, stock, flow time and due date. Also the effects for Assembly WIP and stock are seen to be consistent and linear. Therefore the technique outlined above, was used to compensate for load variations. However, assembly lead time and due date was found to be inconsistent and non linear over this range. Therefore, the model was run against an increased range of load factors to investigate this phenomenon.

Figures 64. and 65. show the relationships between assembly lead time and due date accuracy against input load, for loads between 30 to 125% of the original input load. Over this range the load effects were found to be linear, therefore load adjustment values corresponding to 80% were taken from these curves.

Table 29. shows the adjustment values corresponding to a 20% reduction in load used in the calculations.

10.4.5 Factory Performance and Input Load

Figures 66, 67, 68, 69, 70, 71, 72, 73 & 74 show the load adjusted results for each of the policy combinations. From these results, the most notable effects are of a general improvement in all performance measures at the shorter lead times. This is consistent with expectations. The main findings therefore still hold and the performance potential of those policy sets offering short lead time offsets (0.15 and 0.5 days per operation), is strengthened.

Fig 57. PCB Stock v Input Load.
"Sales only" MPS, Bottleneck Sequencing.

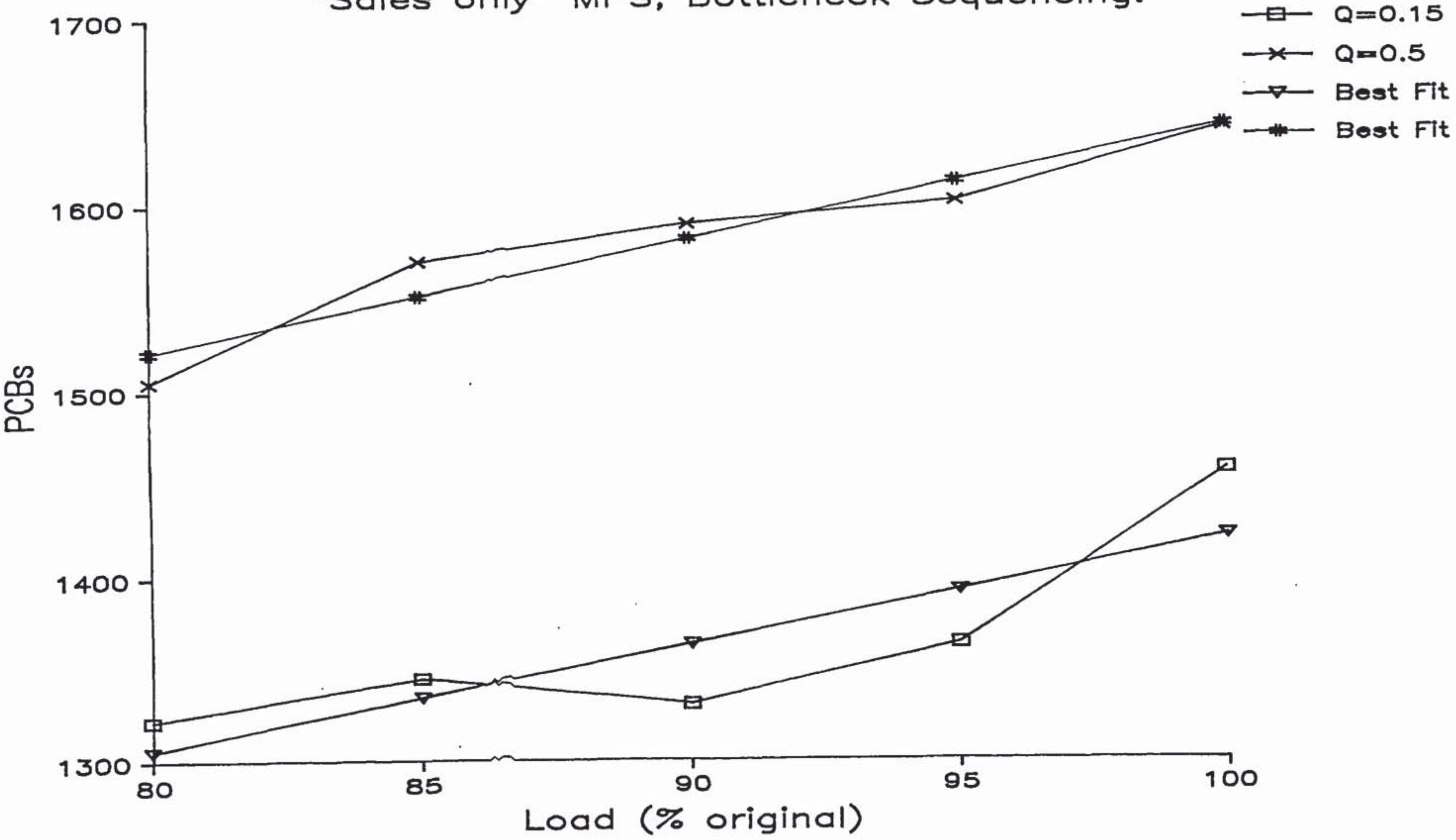


Fig 58. PCB Flow v Input Load.
"Sales only" MPS, Bottleneck Sequencing.

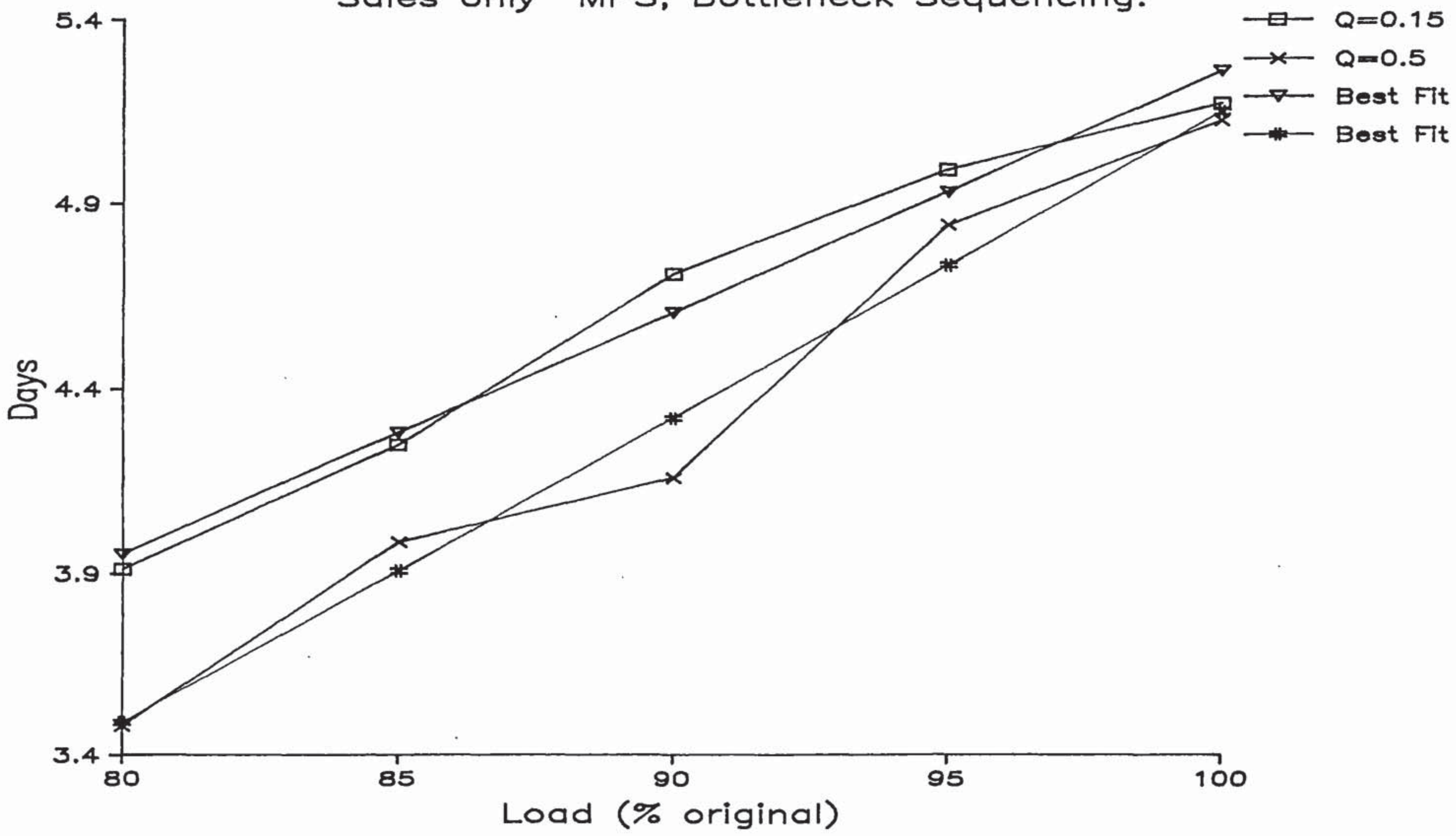


Fig 59. PCB Due Date v Input Load.

"Sales only" MPS, Bottleneck Sequencing.

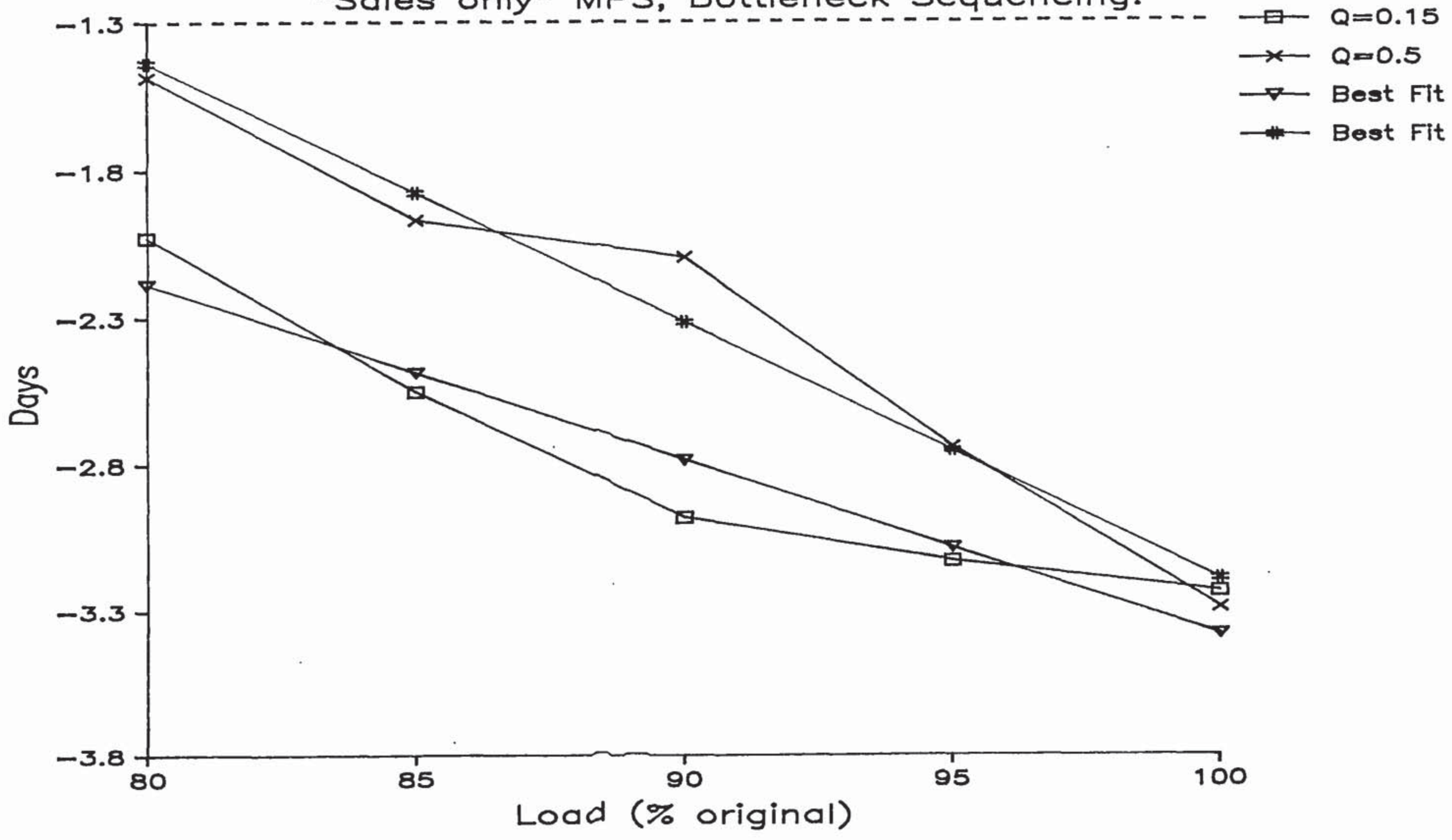


Fig 60. Assembly WIP v Input Load.
"Sales only" MPS, Bottleneck Sequencing.

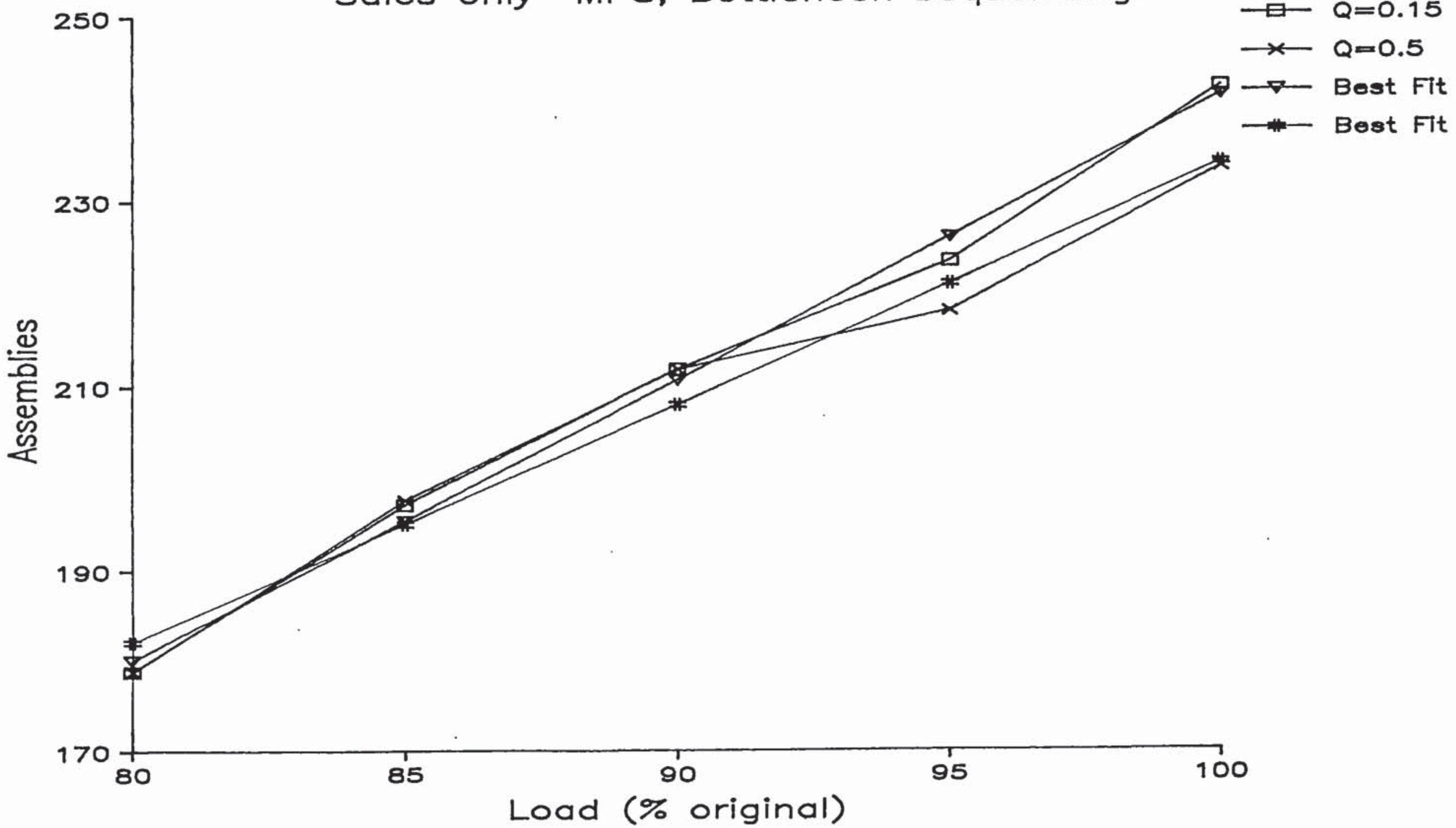


Fig 61. Assembly Stock v Input Load.
"Sales only" MPS, Bottleneck Sequencing.

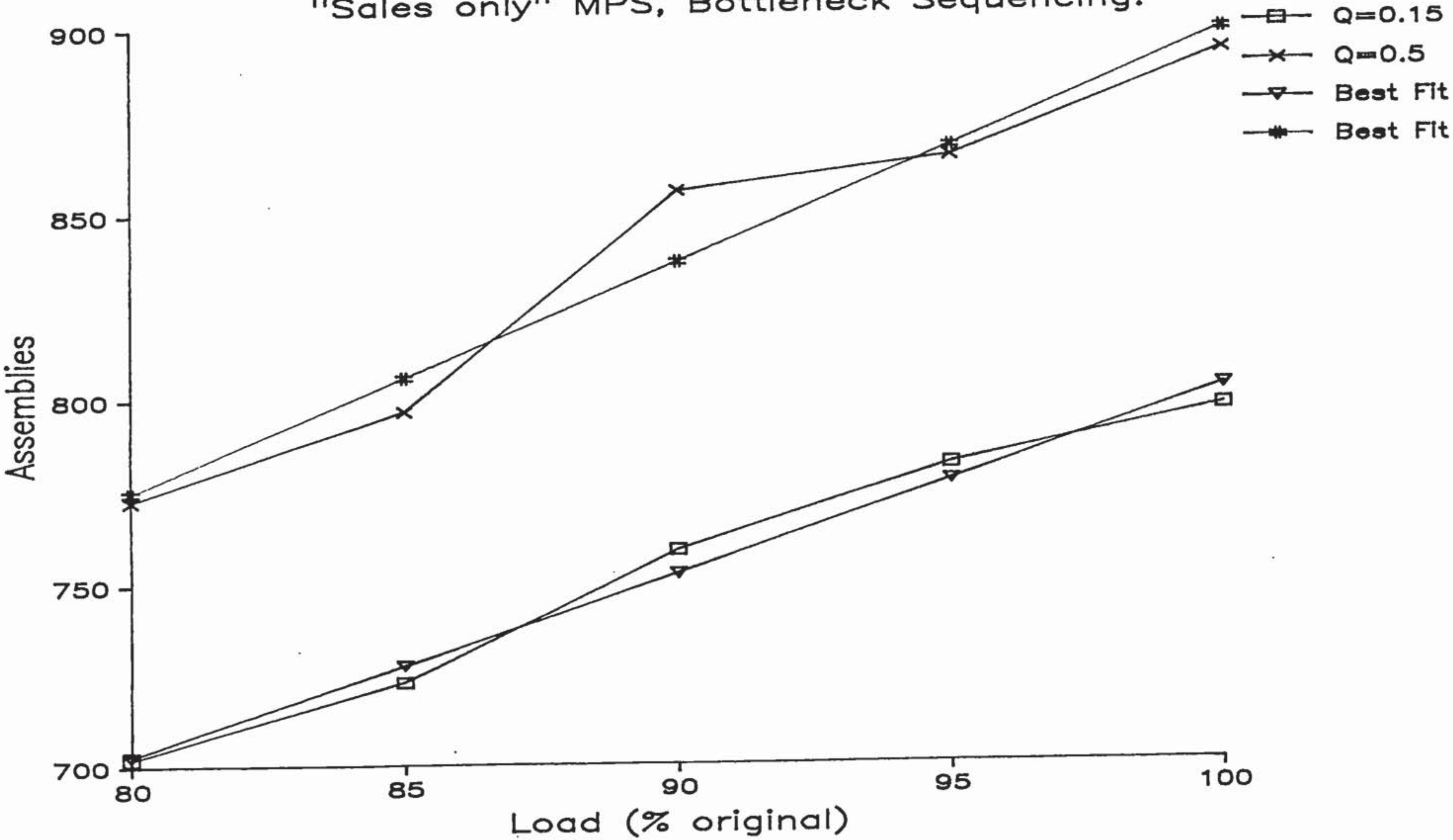


Fig 62. Assembly Flow v Input Load.

"Sales only" MPS, Bottleneck Sequencing.

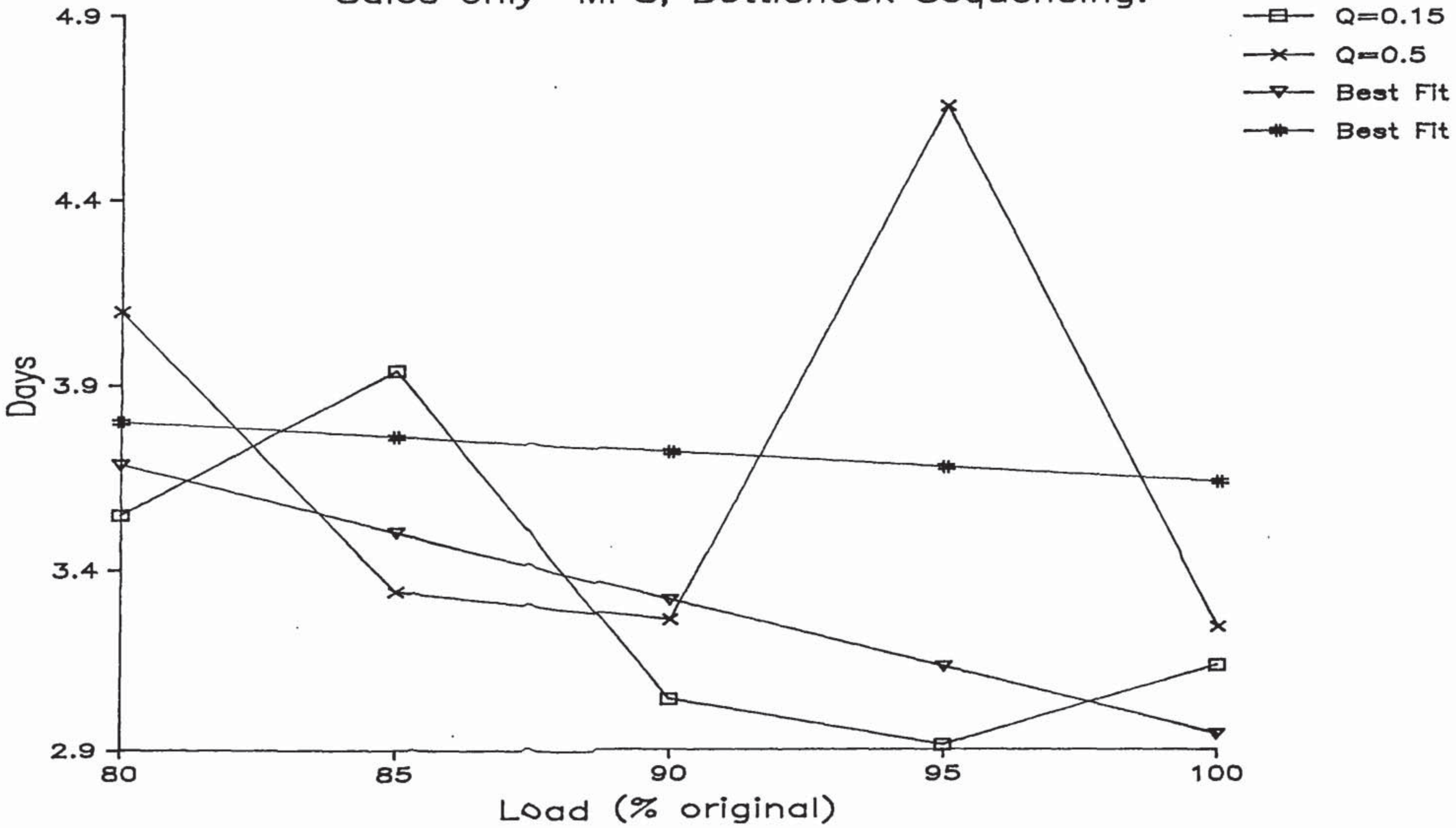


Fig 63. Assembly D/Date v Input Load.
"Sales only" MPS, Bottleneck Sequencing.

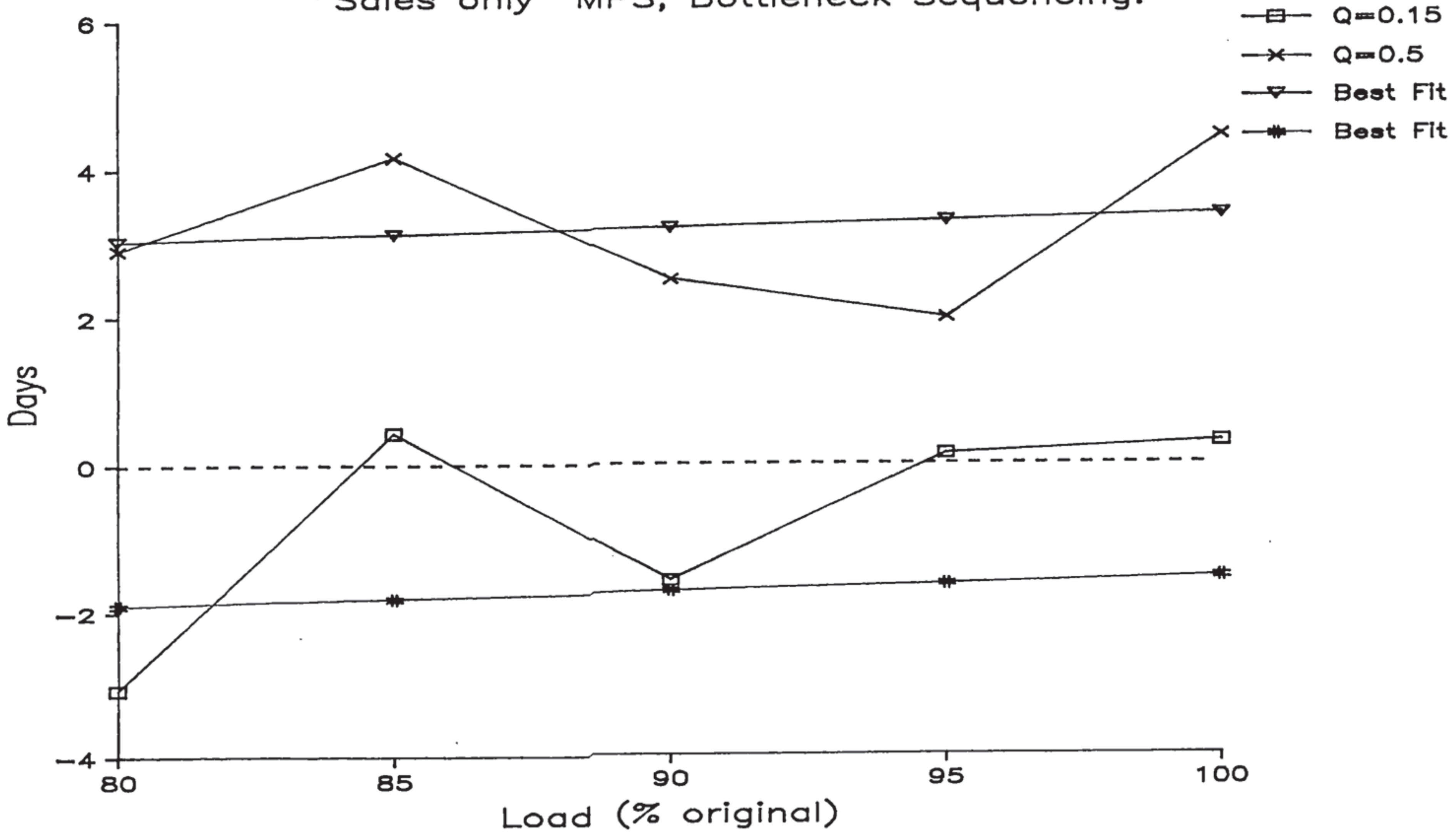


Fig 64 Assembly Flow Time v Load.

"Sales only" MPS, Bottleneck Sequencing.

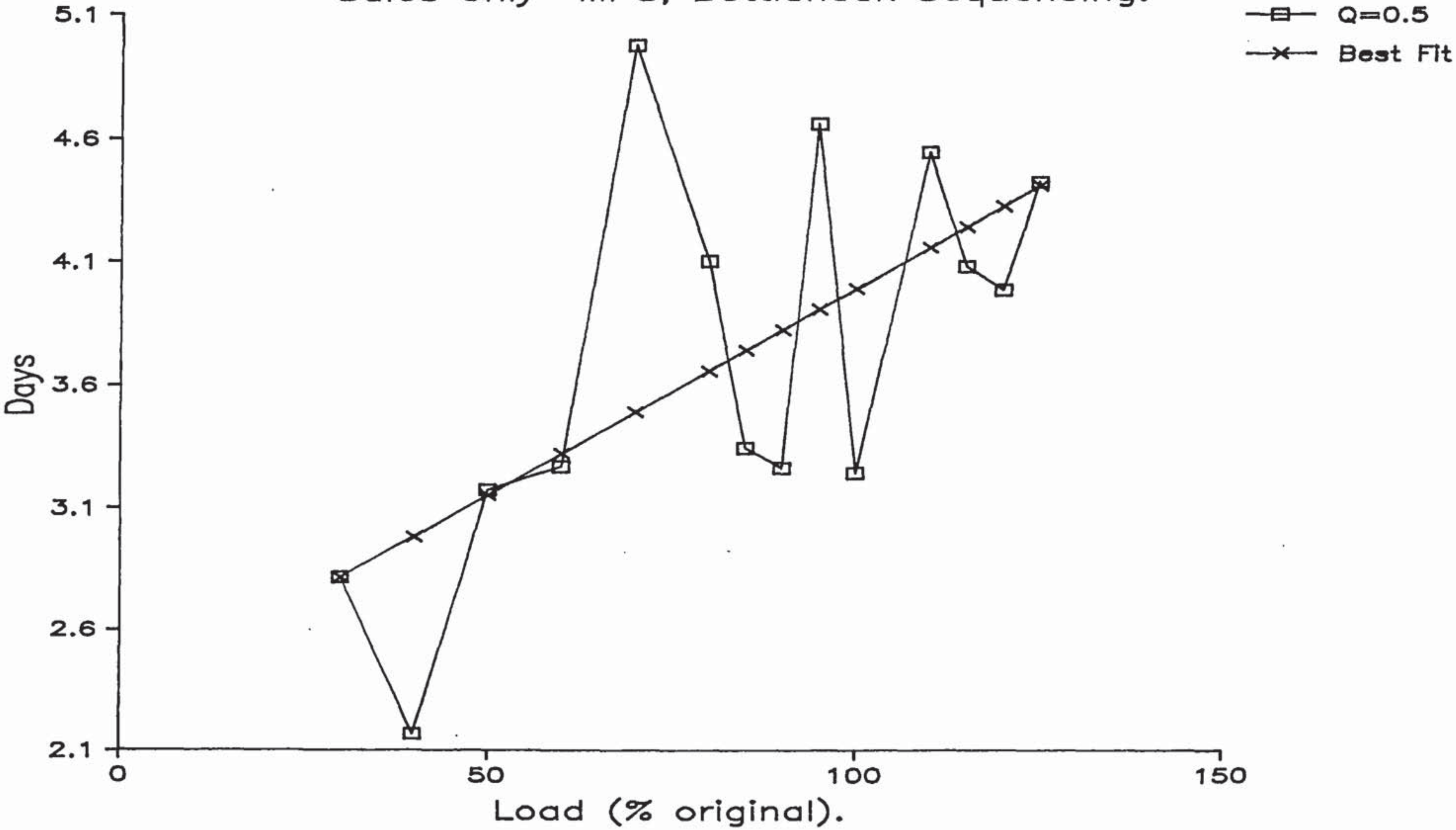
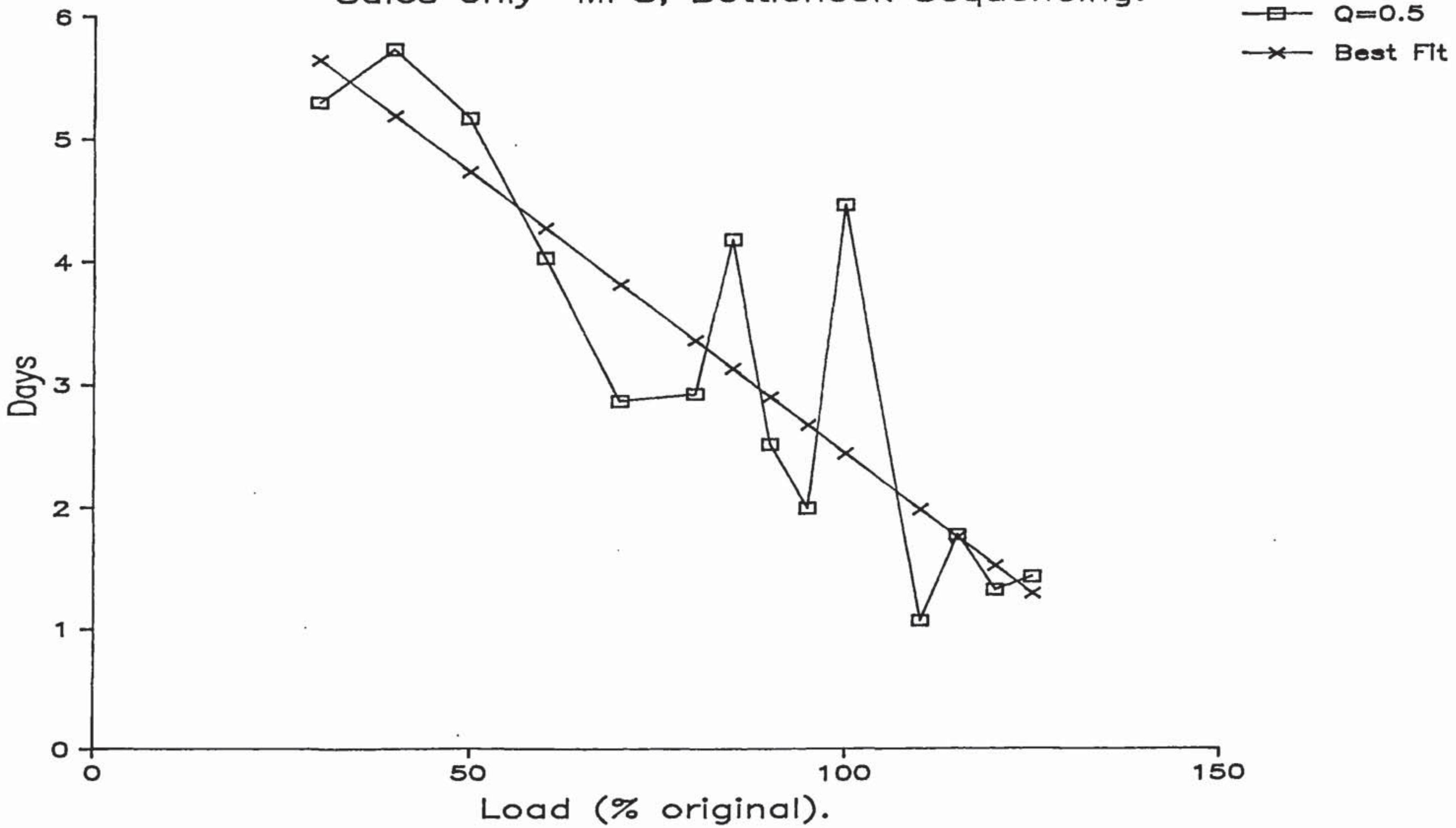


Fig 65. Assembly Due Date v Load.

"Sales only" MPS, Bottleneck Sequencing.



	Lead Time Queue Element (days per op)			
	0.15	0.5	0.15	0.5
	PCBs		Assemblies	
WIP	570.58	532.66	61.23	51.89
Stock	116.4	122.4	99.6	123.2
	Days		Days	
Flow	1.297	1.659	---	0.3347
D/Date	-1.197	-1.75	---	-0.9158

Table 29. Adjustment Factors for 80% load reduction ("sales only" MPS & Bottleneck Sequencing)

Fig 66. PCB WIP v Policy.
Load Adjusted.

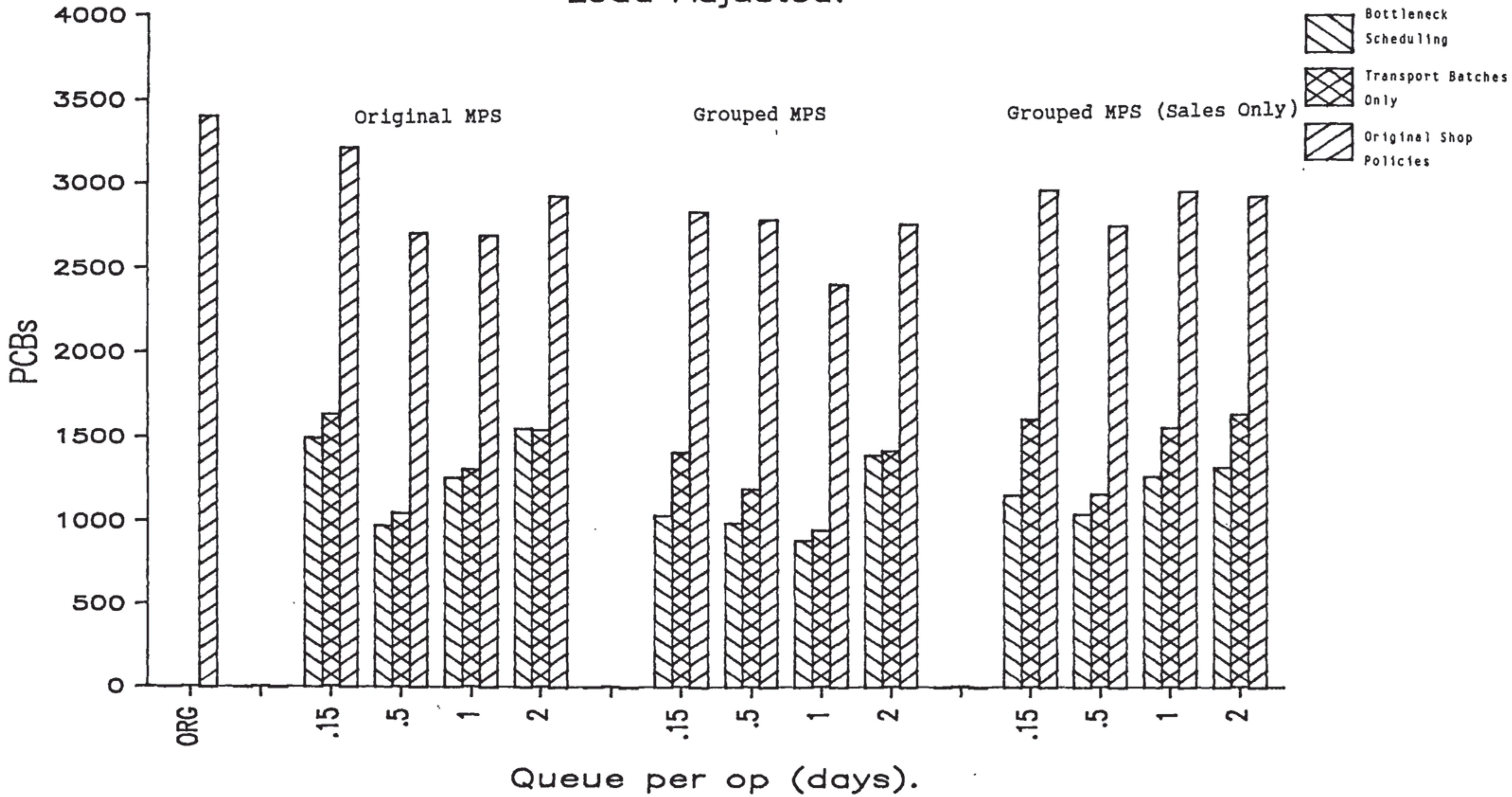


Fig 67. PCB Stock v Policy.
Load Adjusted.

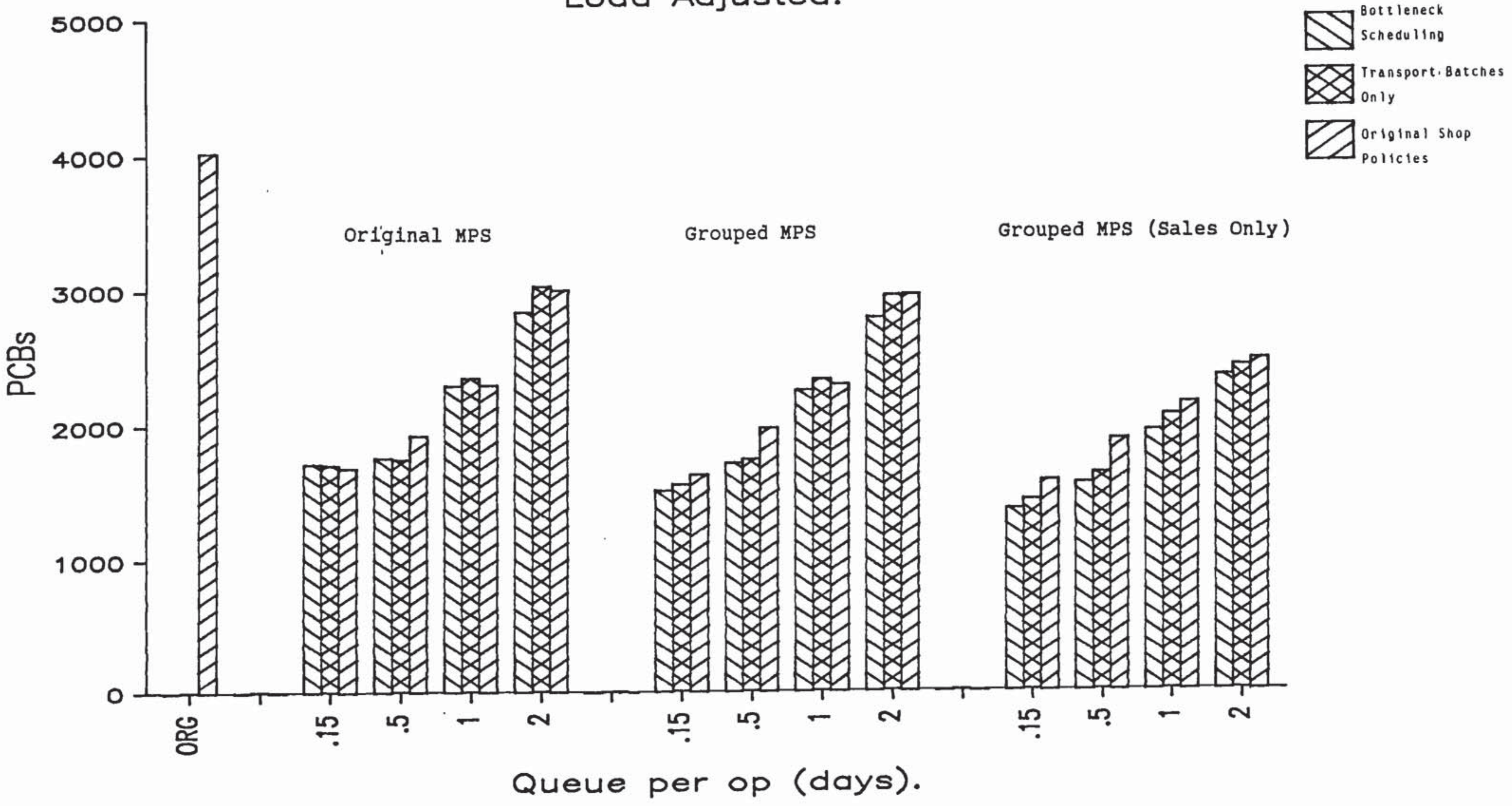


Fig 68. PCB Inventory v Policy.
Load Adjusted.

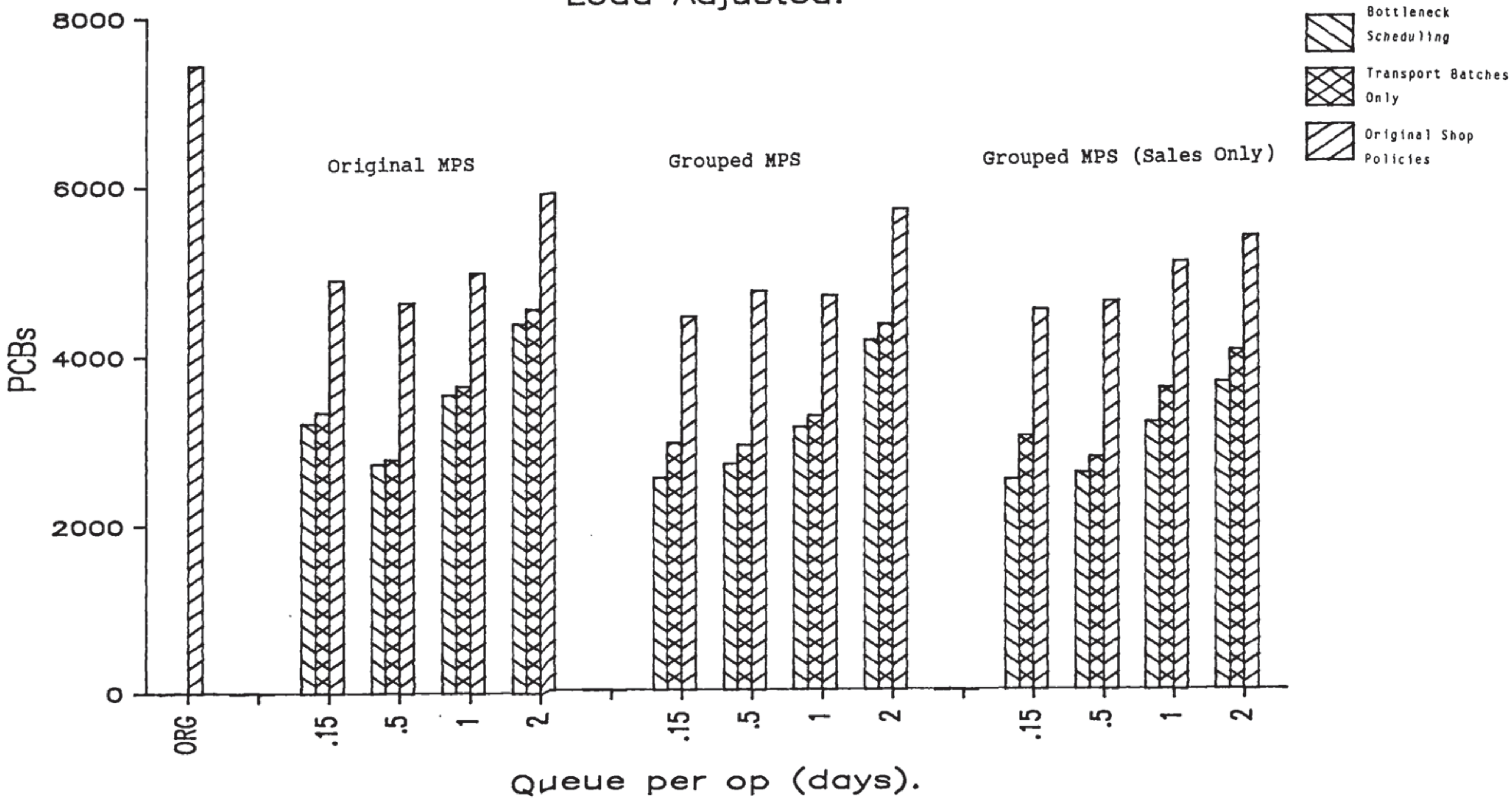


Fig 69. PCB Flow Time v Policy.

Load Adjusted.

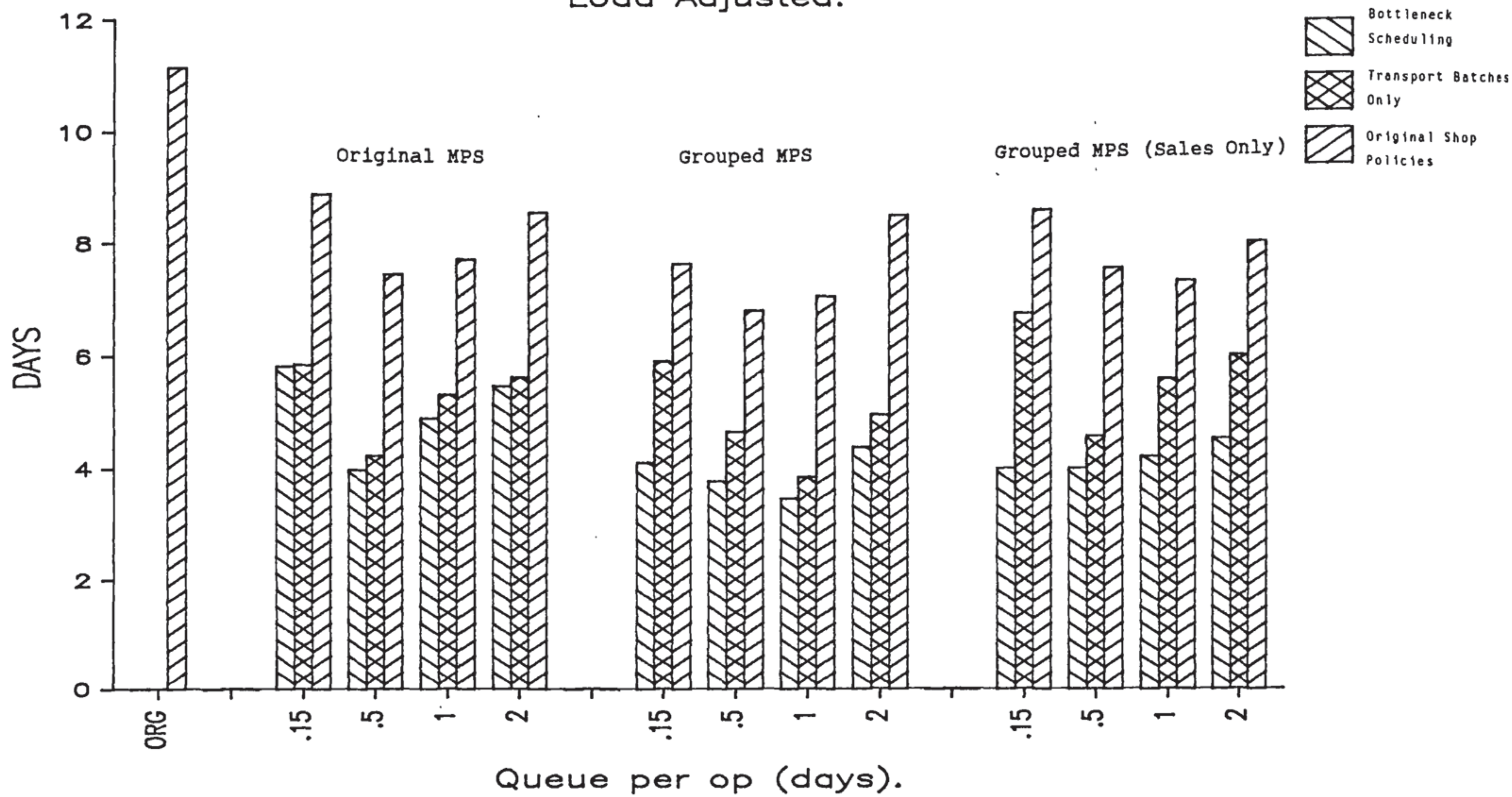


Fig 70. PCB Due Date v Policy.

Load Adjusted.

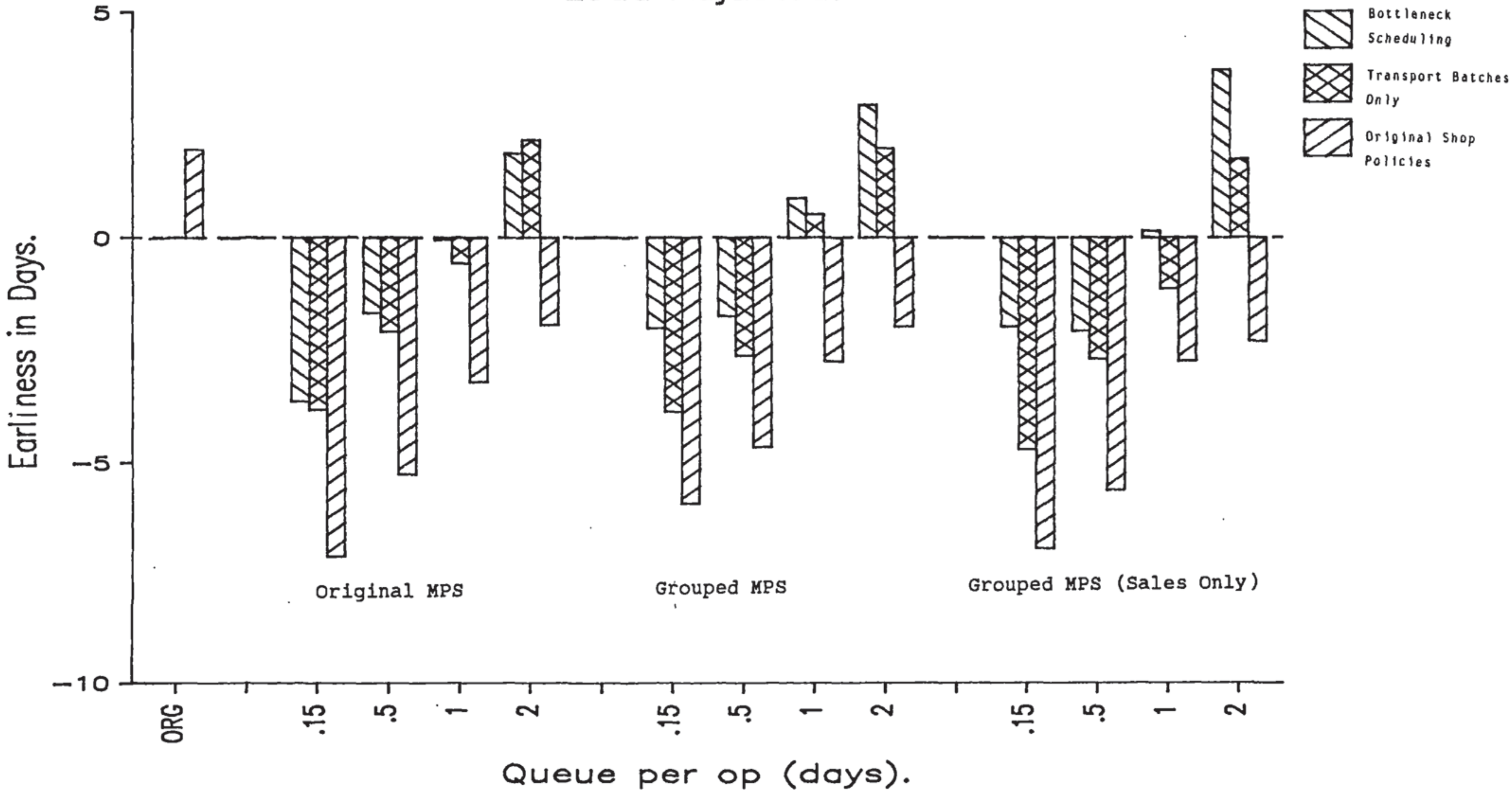


Fig 71. PCB Due Date s.d. v Policy.
Load Adjusted.

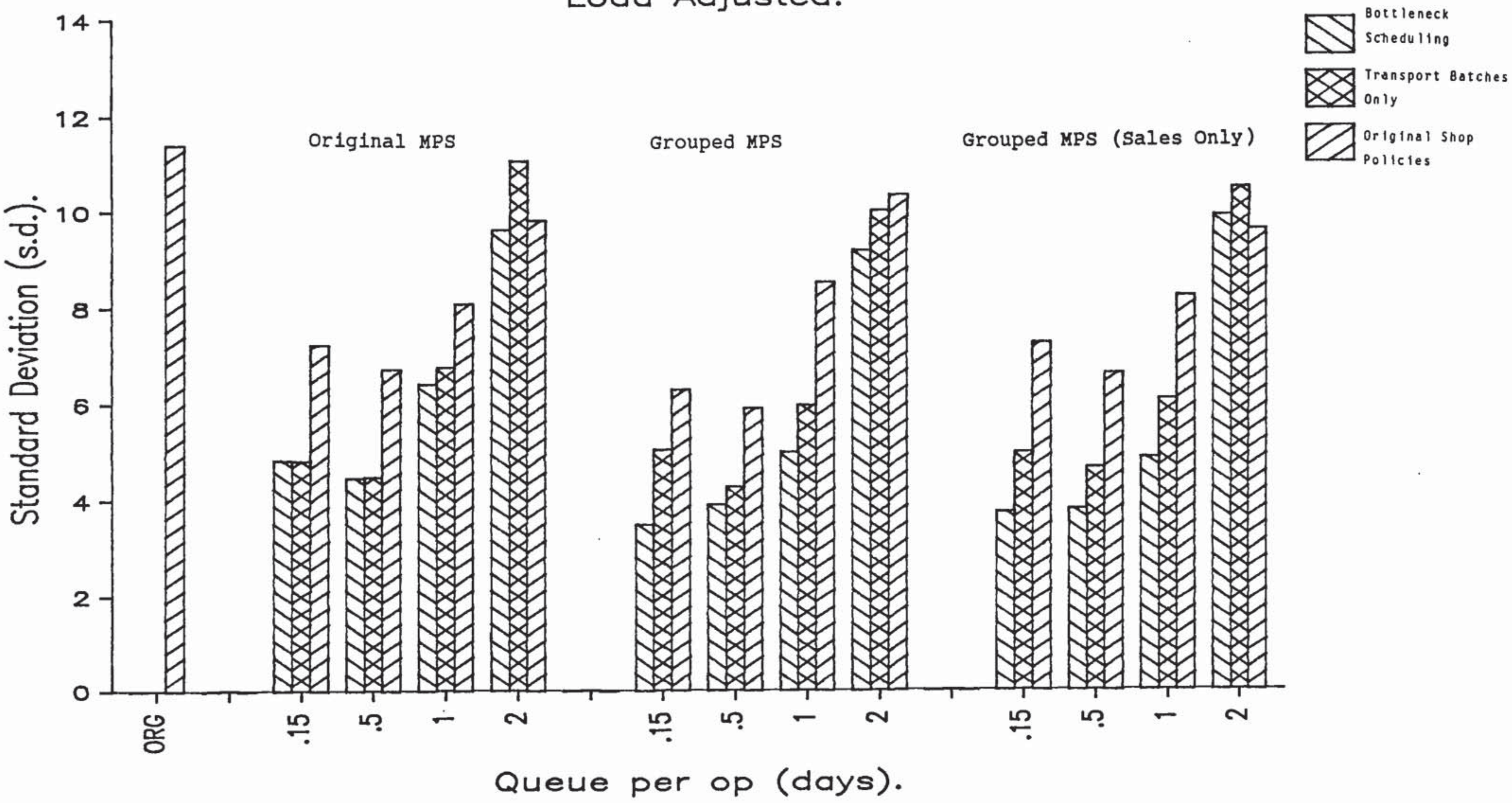


Fig 72. Assembly Inventory v Policy.

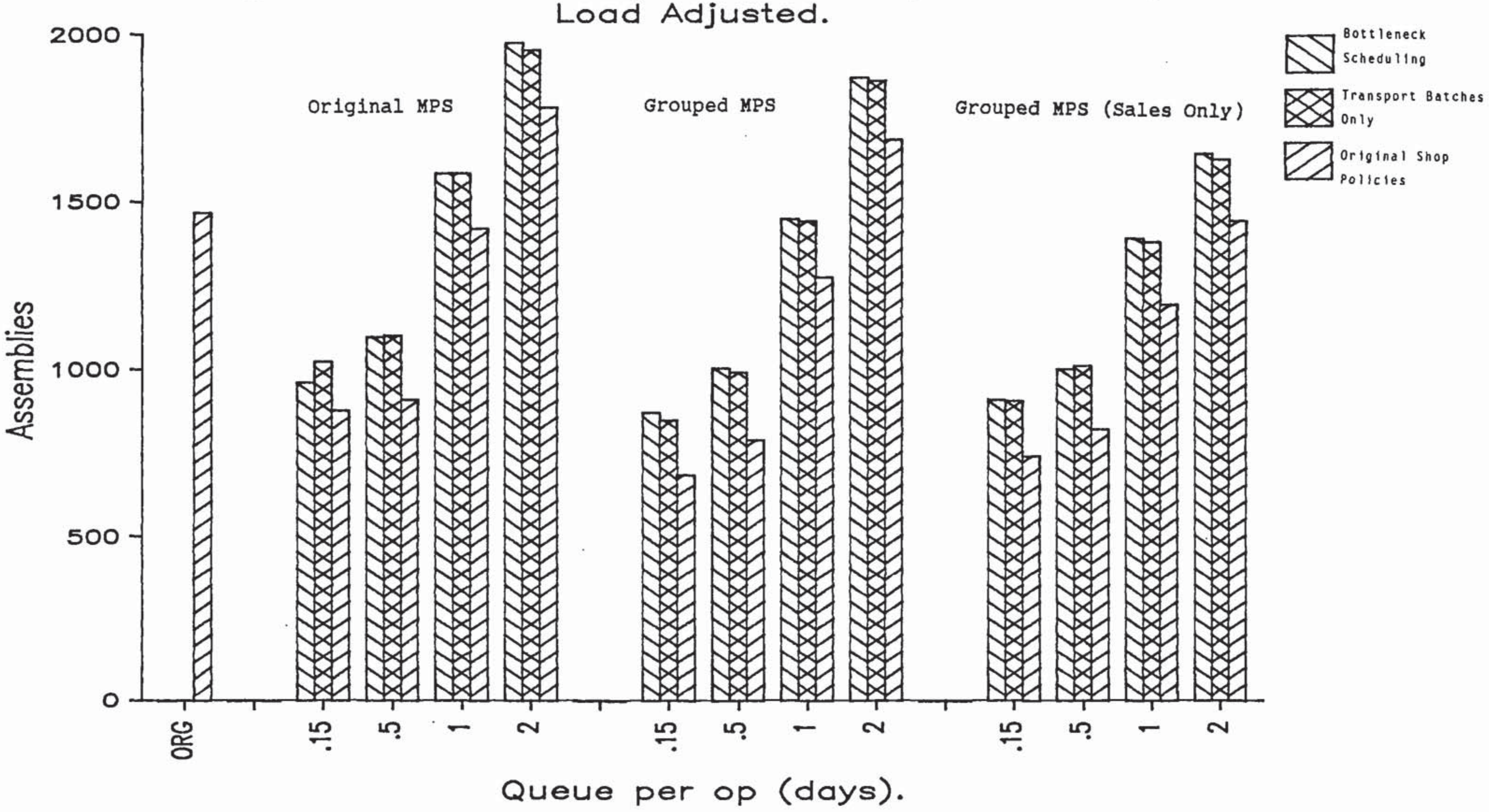


Fig 73. Assembly Due Date v Policy.

Load Adjusted.

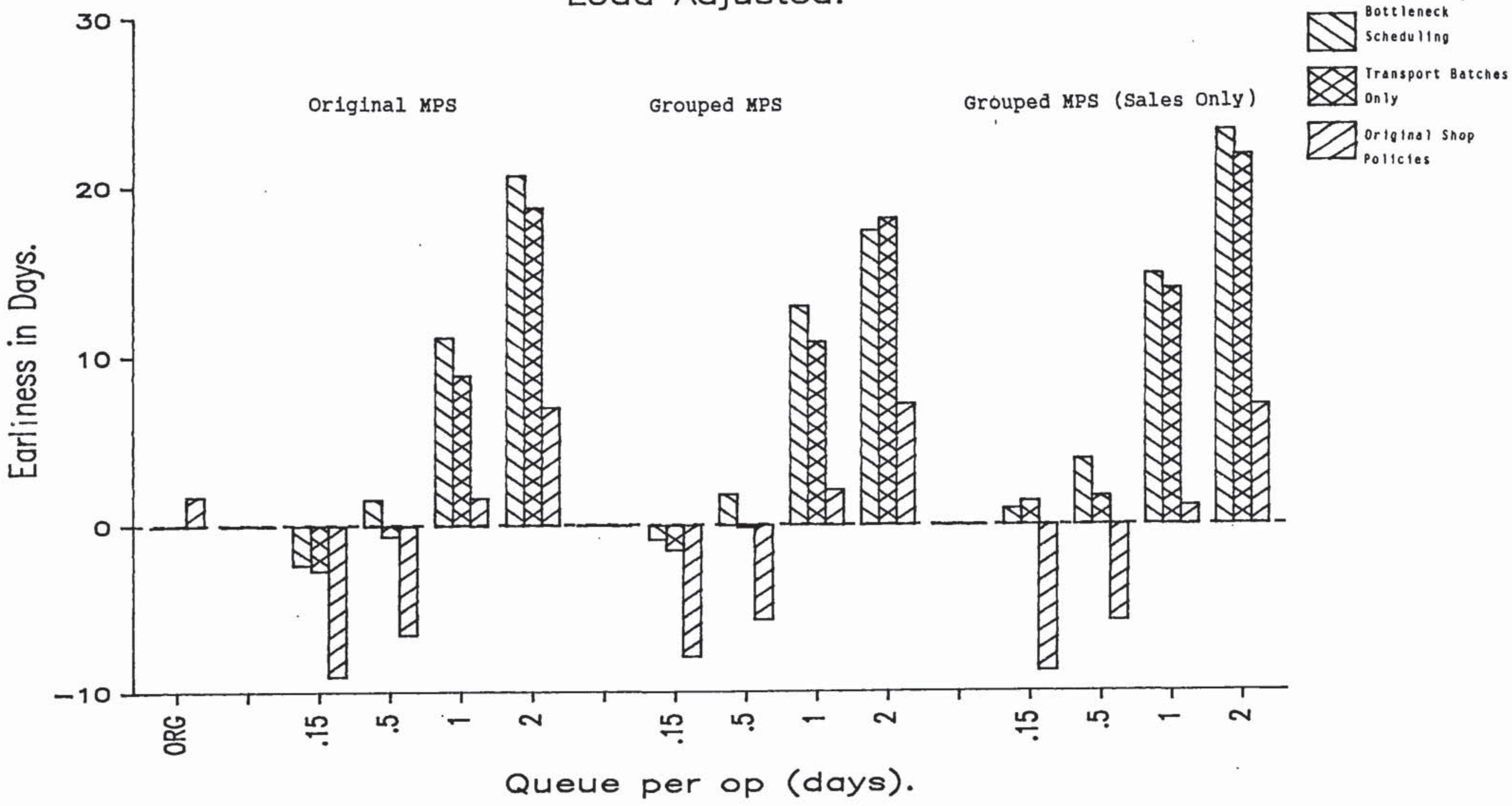
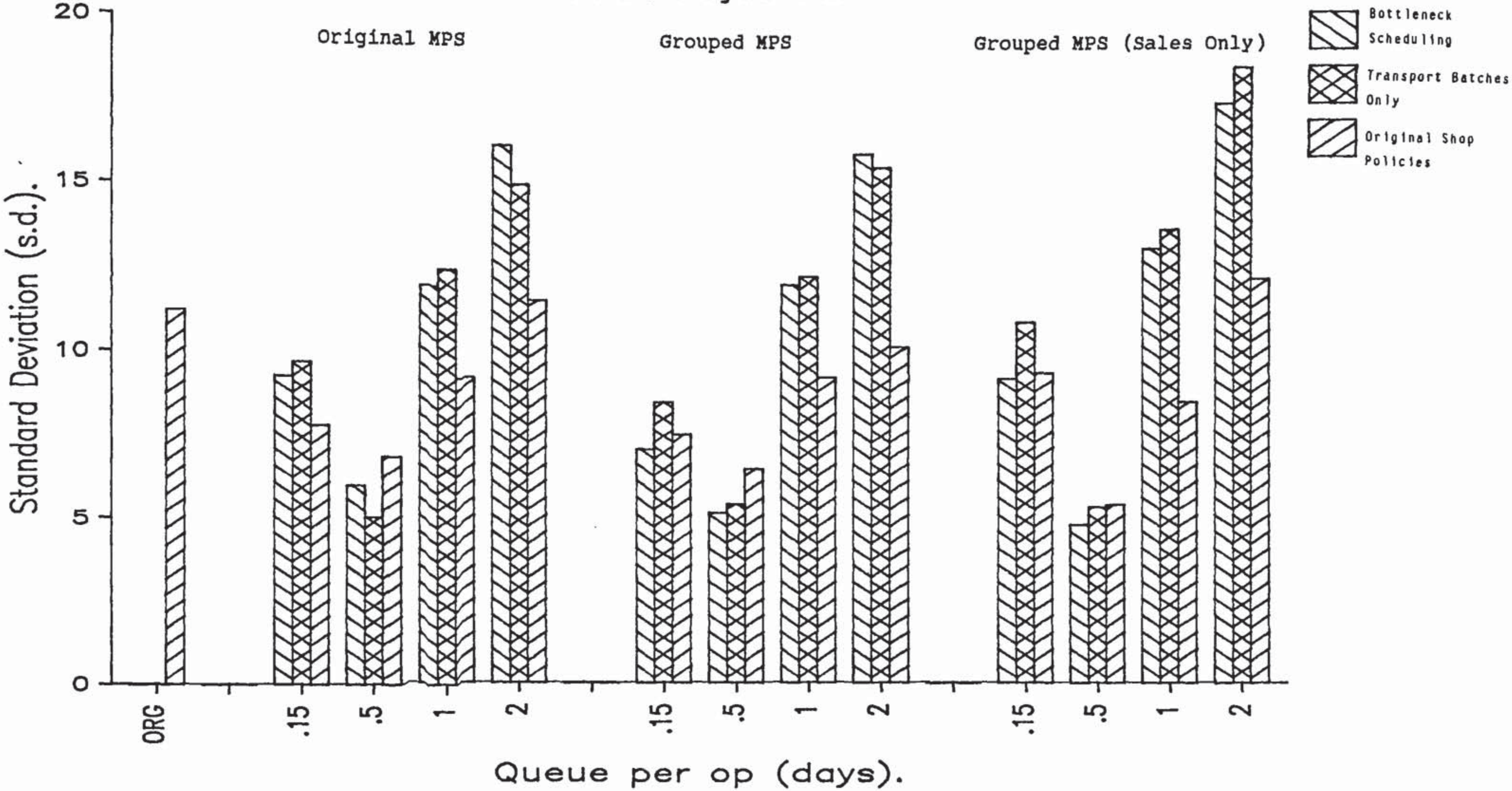


Fig 74. Assembly Due Date s.d. v Policy.
Load Adjusted.



10.5 Discussion of the Results

A central feature of the methodology is a move toward the re-coupling of the production system to the needs of the market place. The intention was to exploit the low inertia characteristics of AMT, and to combine this with a JIT configuration of MRP. The experimental results will now be discussed in this context.

At the shop floor level the use of transport batches to break down order quantities was found to be a powerful technique for the reduction of WIP and lead time at the BOM level at which it is applied. This was true whether this technique was used in conjunction with bottleneck sequencing rules or applied in isolation. This technique was seen to be a powerful method for unlocking the low inertia potential of FCL's AMT facility.

Within MRP, extension of lead time by the inclusion of safety elements resulted in additional stock costs. This may lead to an improvement in launch accuracy for the parent item, however a prerequisite for this to occur is an appropriate component mix.

Reductions in flow time (at the shop floor level) resulting from the use of smaller batches only resulted in savings in inventory costs when linked to reductions in lead time allowance.

Bottleneck sequencing produced a limited further reduction in WIP over that produced by smaller transport batches. However it did produce substantial improvements in due date performance at the level at which it was applied. This in turn produced a further WIP reduction through the ability to support shorter average lead times within MRP. In addition this reduction in lead time produced a reduction in average stock levels. At the next higher level of BOM a further increase in performance was made possible by a potential improvement in component availability. Thus whilst bottleneck sequencing appears to offer little benefit in WIP over small batches for a given lead time offset, it can in fact produce substantial indirect inventory savings.

An explanation for the enhanced due date performance of the bottleneck sequencing shop policies can be found in the relationship between the bottleneck and non-bottleneck work centres. Under all policies, the work profile and the fact that work centre 1 (and to a lesser extent work centre 2) are predominantly at the beginning of PCB production routes, results in these performing an "input gate" function for the rest of the shop. Consequently they smooth the flow of work through the remainder of the shop and perform in (real time) one of the functions traditionally assigned to the production control area.

Under the bottleneck sequencing policy, these two work centres are allowed to maximize their utilization and thus maximize their output. In addition the non bottlenecks are then set the task of maximizing throughput (ie work movement) and achieving due date performance by the use of the earliest due date first rule. The superior performance of this policy could therefore be expected. However the due date performance of the transport batches in isolation is somewhat surprising in that this policy out-performs the original shop policies, whilst accepting the overhead of some additional set ups. It is evident that the increased work flow achieved with transport batches, outweighs any potential losses due to additional settings.

At the lower BOM levels the achievement of acceptable inventory volumes and due date performance was shown to be insufficient to support any given policy set. In addition the mix of parts produced must support the requirements at the higher levels.

The mix is a fundamental characteristic of the production plan and is a central feature of MRP. Mix was controlled by the BOM explosion and netting process and as such was influenced by the stock, order and lead time policies. Thus the use of batching functions (pan size, minimum order quantity, optimised order quantities, etc.) and generic lead times are likely to mask the true requirements and priorities. This in turn will have a deleterious effect on component mix at the next higher level in the BOM. This is evidenced by the results:

- The original policies gave mean a PCB due date performance which was better than that with the shorter linear lead times and bottleneck sequencing. However poor component availability at the next higher level in the BOM was evidenced by the worsening assembly due date accuracy.

- With a number of alternative policy sets the mean PCB due date accuracy was negative (-3.235 days with the non-adjusted results and -1.957 days with the load adjusted adjusted results). In addition the PCB inventory level was lower (58.46% non-adjusted and 59.23% adjusted) which indicates the potential for component shortages. However the mean due date performance of the parts at the higher levels of BOM was improved (1.484 days non-adjusted and 2.125 days adjusted).

- This indicates that the component mix (PCBs) was also improved by the example policies and that the extra inventory associated with the original policies was not used to support accurate order launching.

The experimental results were found to support complete coupling between the marketplace and the production system. At the most rigorous level the complete removal of all demand forecasting was found to offer the best performance. The inclusion of the forecast element of MPS demand offered comparable but slightly worse performance. Both of these scenarios can be considered to represent re-coupling in that safety stocks are not used and the MPS is not artificially smoothed or fixed.

10.6 A Summary of Stage II

The objectives of Stage II of the policy design methodology are twofold. The first is to design and select MPS, MRP and Shop policies which support the "low inertia" characteristics of the AMT based PCB facility, and a JIT configuration of MRP. The second objective is to evaluate the performance of these in the re-coupled environment (ie the complete removal of all "safety" elements between market demand and the manufacturing system). Chapter 9. discussed policy design and selection in which a "first principles" approach was combined with appropriate "first cut" experimentation techniques. Chapter 10. has addressed the exposure of the policies selected in Chapter 9. to the re-coupled uncertain MPS environment. This included the use of a myopic "known sales only" based MPS, which offered a particularly rigorous test of re-coupling.

The general behaviour of these policies was evaluated and it has been shown that a number of substantial performance increases are possible. In particular, the removal of "optimising" and safety parameters within MRP and the realization of the PCB shop's potential through the breaking down of large order quantities, have demonstrated particular potential. Chapter 11. will address the selection of a particular set of policies for use at FCL.

This concludes Stage II of the policy design methodology. The following chapter will evaluate the implications of these results in total performance terms (Stage III).

11. THE SELECTION OF A PREFERRED POLICY SET (STAGE III)

11.1 Introduction

This chapter will discuss the final stage of the policy design methodology outlined in Chapter 5. The goals of Stage III are twofold. The first is to select one policy set (from those suggested in Chapters 9. and 10.) for use at FCL. This selection was based on the holistic approach to system performance and included an analysis of the performance advantages resulting from the adoption of these policies, over the original (traditionally specified) policies. This provided a measure of the utility of the policy design methodology.

The second goal of Stage III was to assess the need for any additional de-coupling or safety policies in the light of total system performance.

In addition, the selected policy set was subject to evaluation under varying levels of input load. This formed a test of the robustness of the policies and a general "load mapping" of the total system.

11.2 The Selection of a Preferred Policy Set for use by FCL

This work was targeted at the design of operating policies for the PCB manufacturing areas at FCL. However, the potential for interactions within and beyond the BOM levels associated with PCBs has been examined fundamentally (Chapters 2., 3., 4. and 5.) and demonstrated by experiment (Chapters 8., 9. and 10.). Therefore, the criteria for policy selection was based on an assessment of total system behaviour. An acceptable level of customer order satisfaction and an assessment of the associated total inventory levels were considered to form the primary selection measures.

Customer satisfaction was assessed by comparing the distribution of product completion accuracy resulting from the various policy combinations. At the upper BOM levels this study was based on 17 products and 80 sub-assemblies. Many of the sub-assemblies had multiple parents and some were products in their own right. Within the FCL model, products and assemblies were treated as equivalent for data recording purposes as they used identical resources. Therefore, the assembly due date accuracy distribution had the product due date accuracy distribution embedded within it.

It was recognized that some bias would result if assembly data was taken to represent product data. The primary source of this bias was the positioning of a part within the BOM. Exposure to MPS uncertainty increased with BOM level, as a result of cumulative lead time offsets. In addition, average lateness increased with exposure to uncertainty. Therefore top level parts (level 0) would be expected to be less late than lower level parts in the uncertain MPS environment. On this basis, any bias resulting from the use of the assembly distribution to represent the embedded product distribution, would be expected to result in reduced average product earliness. It was therefore considered that the use of assembly due date results to represent product due dates, would provide a stringent test of an acceptable mean and spread. That is, if the assembly due date accuracy was found to be acceptable, then the product due date accuracy must also be acceptable (because it was an embedded distribution). The known bias would result in a slight increase in earliness when taken into consideration. Thus the error would be on the side of caution. It was therefore considered appropriate to use the assembly due date distributions to represent products.

The objective of policy selection was to achieve a narrow spread of assembly due date error, with a near zero mean. It was recognized that any excessive mean earliness would result in an inventory cost penalty. From the results discussed in Chapter 10., the performance of the

Fig 75. Assembly Due Date Spread
Without Load Adjustment.

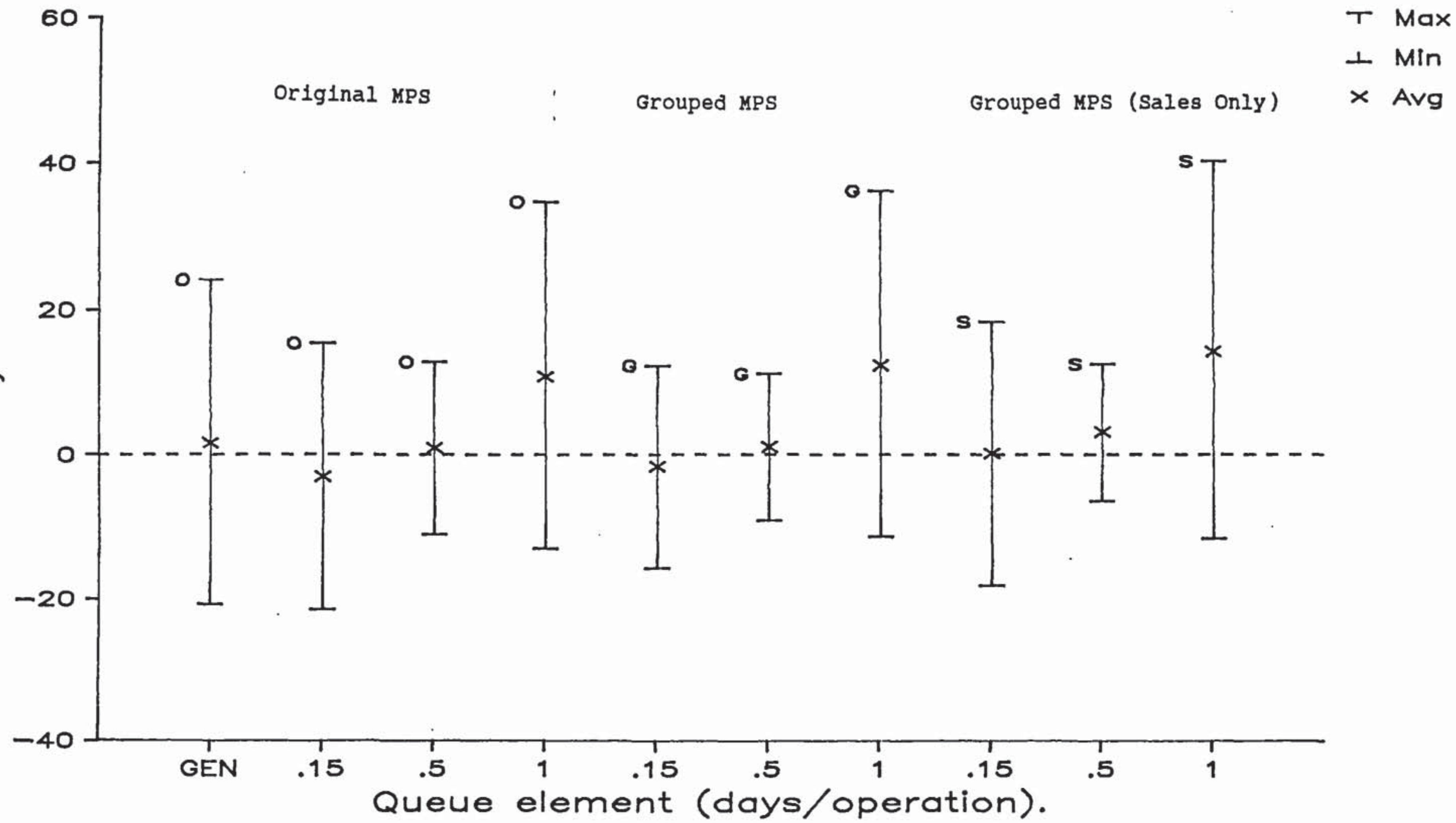
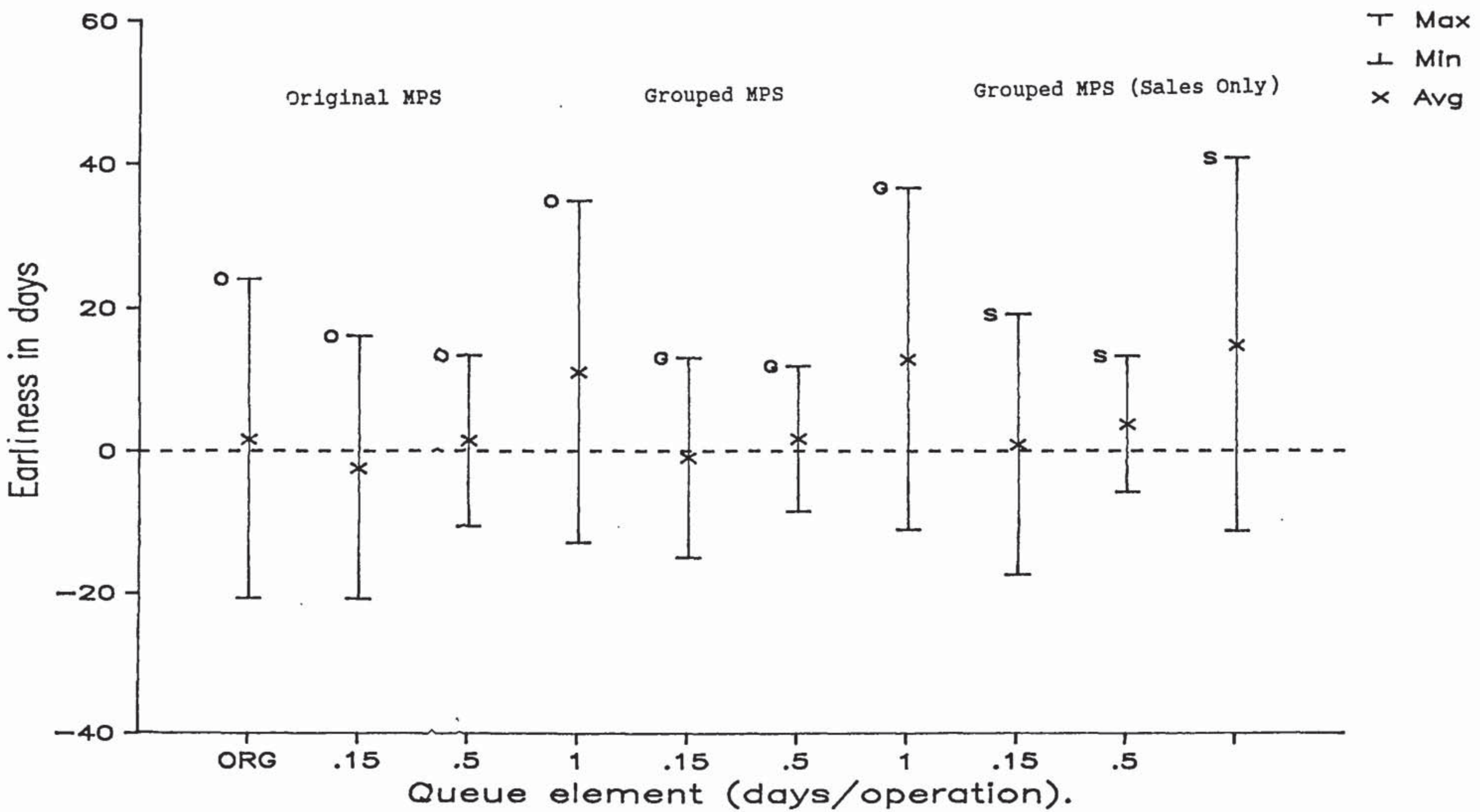


Fig 76. Assembly Due Date Spread
With Load Adjustment.



bottleneck sequencing shop policies were seen to offer the best assembly due date performance for each MPS and queue element combination.

From Figures 53. and 74. the bottleneck sequencing policies at queue elements of .15 and .5 days per operation are seen to offer near zero due date error for each of the MPS combinations. Assuming normality, the spread was calculated for each distribution from 4 x the standard deviation to give 95% coverage.

Figures 75. and 76. show these distributions in the form of a high - low chart for the original and load adjusted results respectively. For each of these charts, at the furthest left is the distribution of assembly due dates for the original "datum" policies. Moving from left to right the next three are for the new MRP policies (with queue elements of 0.15, 0.5 and 1 day per operation) with the original MPS (O). The next three are for the "grouped with forecast" MPS (G), and the final three are for the "grouped sales only" MPS (S). From this chart it was considered that a lead time queue element of 0.5 days per operation, offered acceptable assembly due date performance with all three MPSs. The portion of these distributions corresponding to late orders was found to be within acceptable limits for both the original and load adjusted cases. It follows therefore, that the results for lead time queue elements in excess of 0.5 days would also be acceptable.

Further selection of policies were based on an analysis of total inventory costs. For this a common unit of inventory was required. An analysis of assembly composition determined that assemblies contained an arithmetic mean of 3.6 PCBs. In addition to this, assemblies included racks, cases and wiring harnesses. Study showed this equipment to be equivalent to a further 2 PCBs per assembly. Therefore, an average assembly was considered equal to 5.6 PCBs in value. This

	Inventory Reduction %.		
	Q=0.15	Q=0.5	Q=1
Original Results			
Original MPS	37.026	35.637	16.986
Grouped MPS	43.436	37.940	21.621
Sales Only MPS	42.187	38.615	23.551
Load Adjusted Results			
Original MPS	44.633	42.726	19.825
Grouped MPS	52.188	46.292	27.407
Sales Only MPS	50.847	47.013	29.011

Table 30. Inventory Saving Over Original Policy Set

Fig 77. Total Inventory.
Without Load Adjustment.

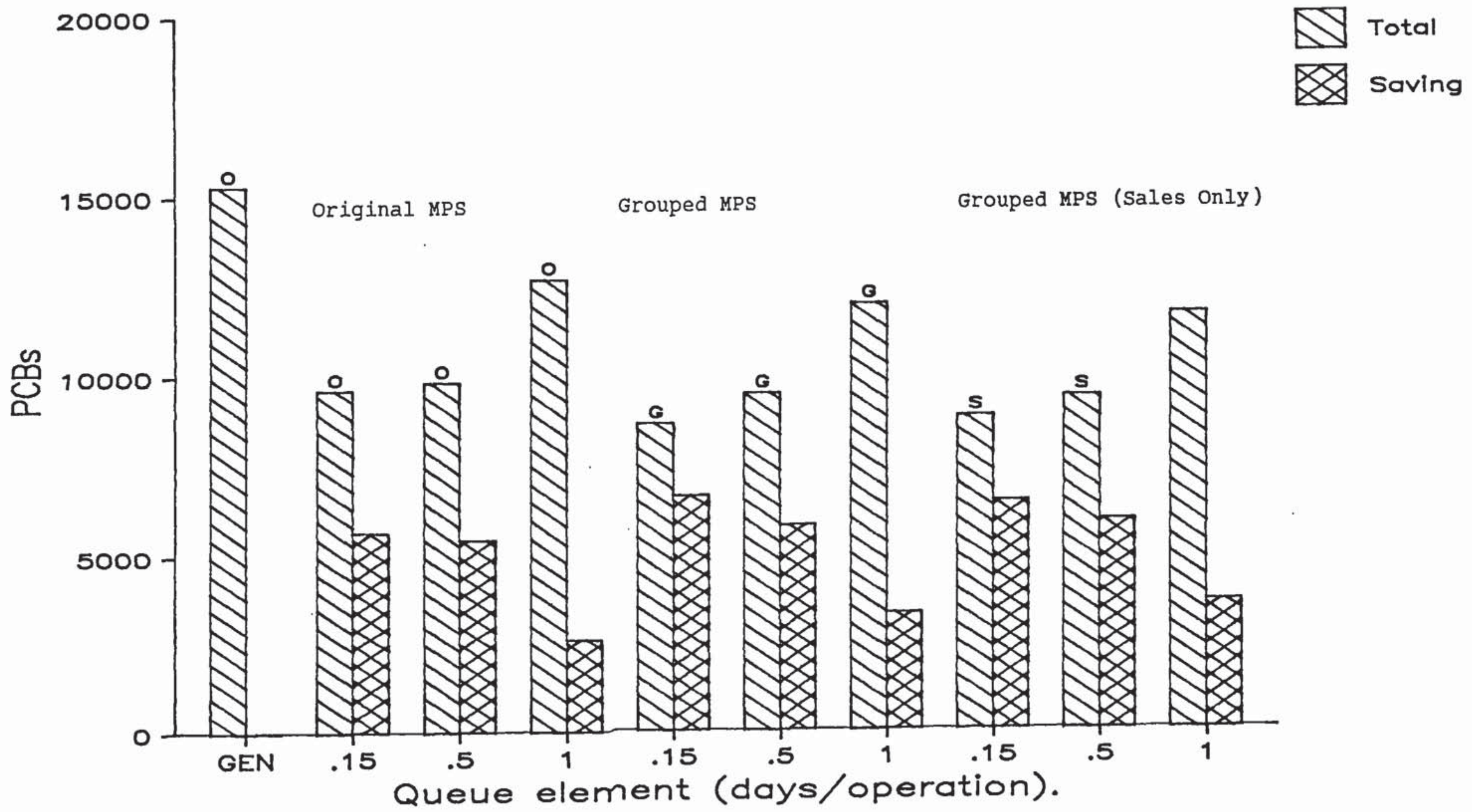


Fig 78. Percentage Inventory Savings.
Without Load Adjustment.

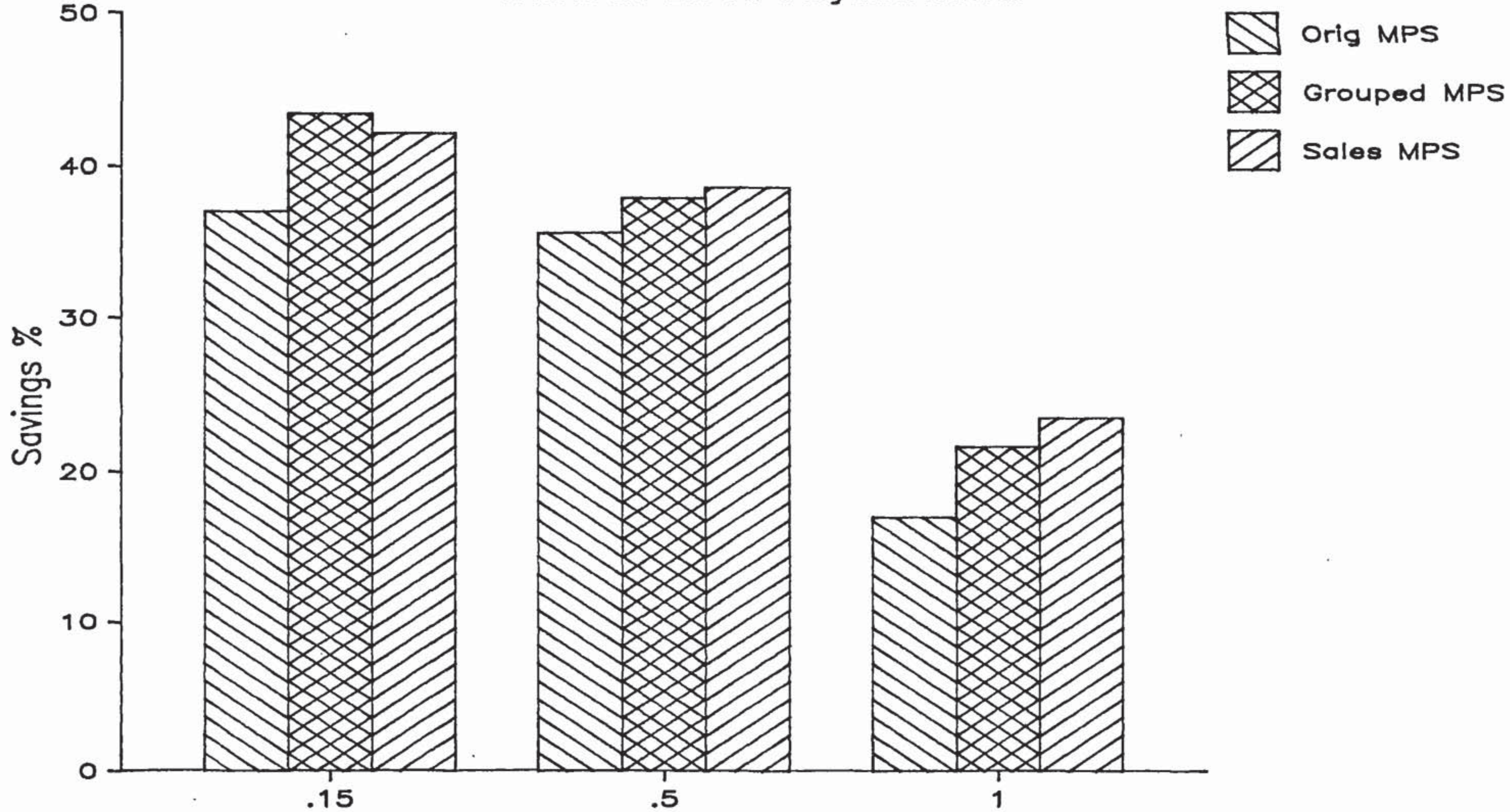


Fig 79. Total Inventory.
With Load Adjustment.

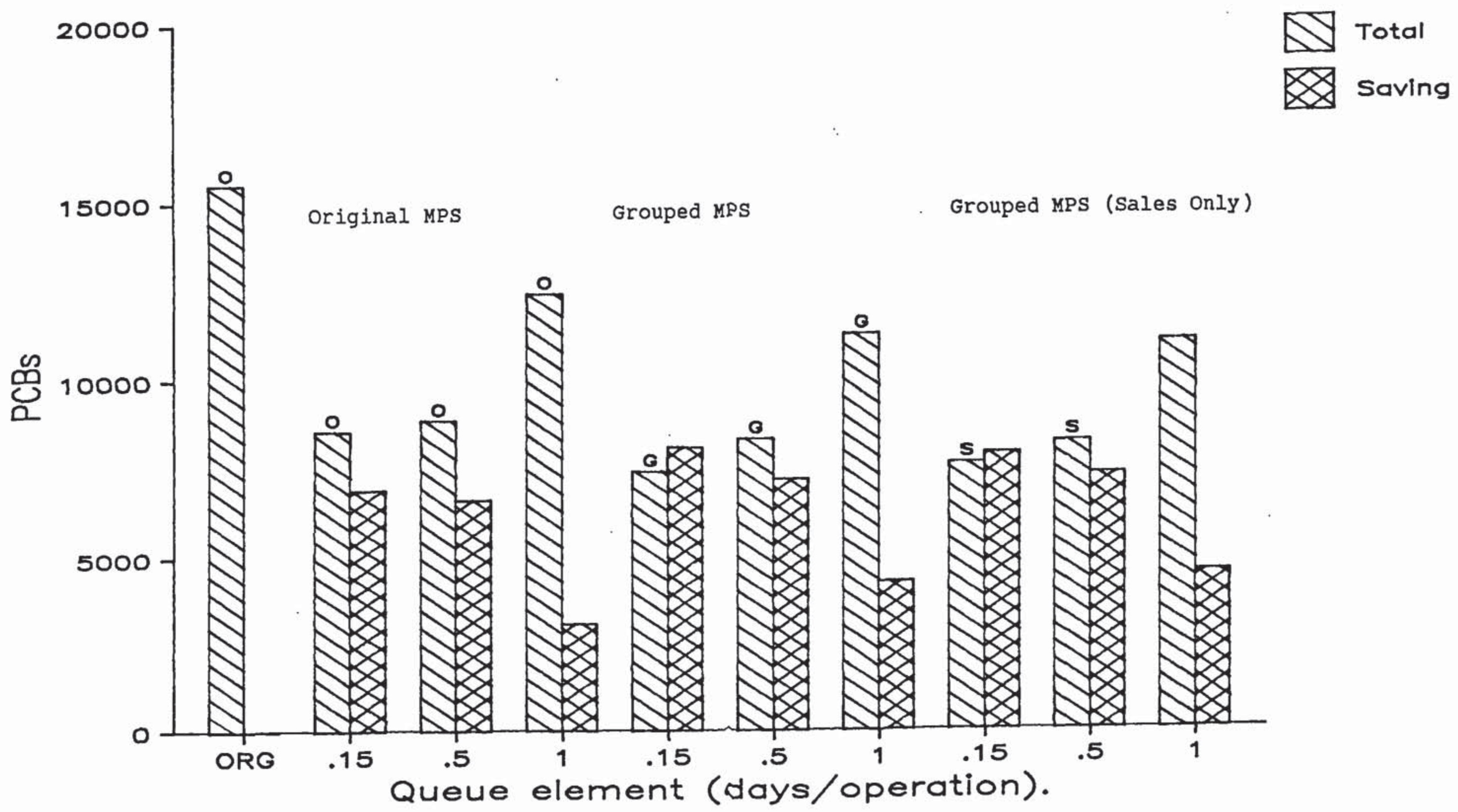
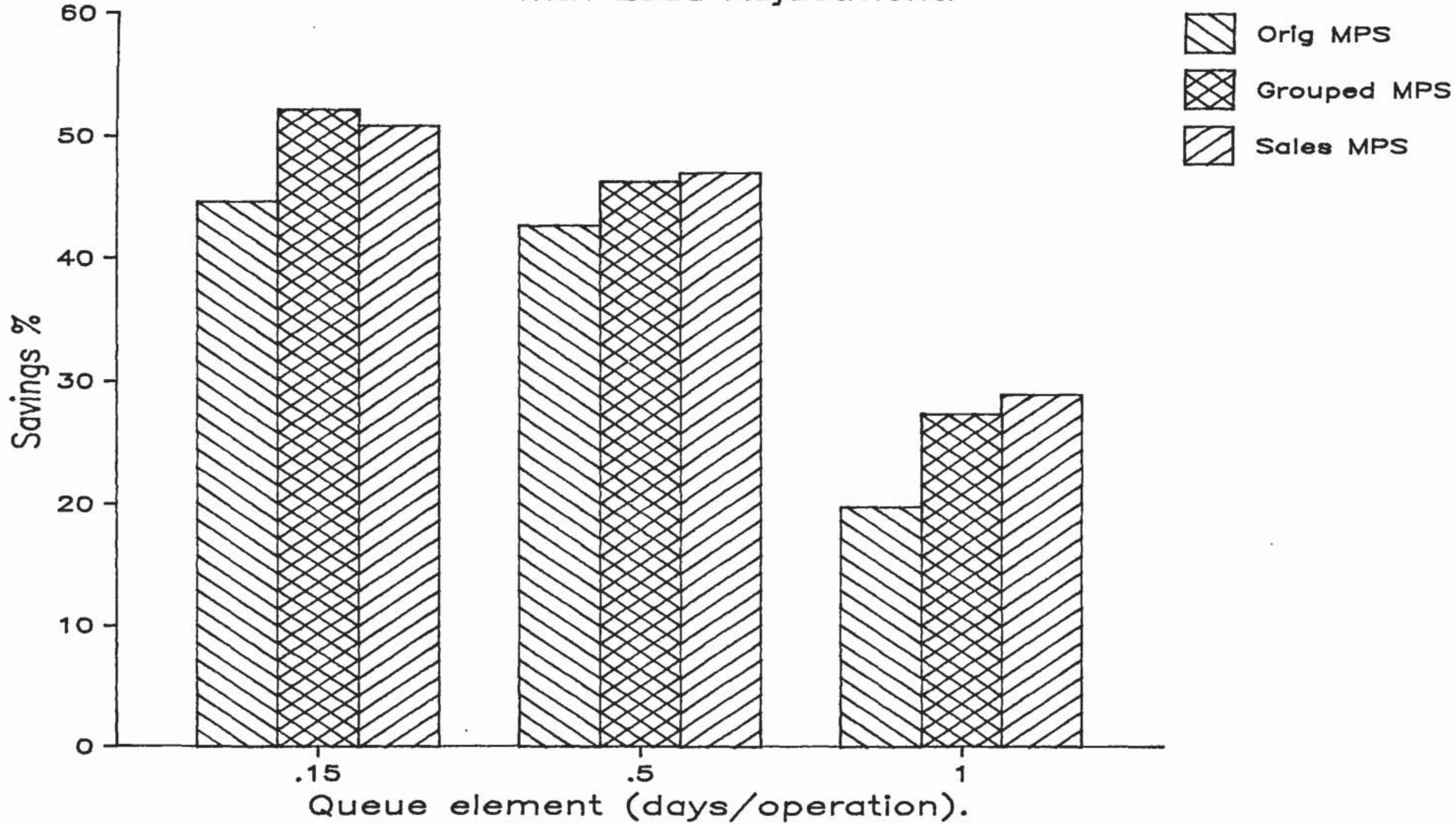


Fig 80. Percentage Inventory Savings.
With Load Adjustment.



relationship was used to convert the separate inventory measures into "PCB equivalents".

Figures 77, 78, 79 & 80 show the total inventory costs and percentage reduction for these policies against the original set. From these, it was found that the lowest inventory costs and best due date performance was obtained with the "grouped sales only" MPS, bottleneck sequencing shop policies and a lead time queue element of 0.5 days per operation. With the original results an inventory reduction of 38.615% was obtained whilst allowing for the load induced bias raised this to 47.013%. These results are summarized in Table 30.

The inventory reduction between the original, "grouped original" and "grouped sales only" MPSs were found to be consistent at each lead time level, with "grouped sales only" resulting in the lowest inventory and the original MPS resulting in the highest. The only exception was that "grouped original" marginally out-performed "grouped sales only" at the 0.15 days per operation level.

From this work it was proposed that the following policy set be adopted by FCL:

MPS: Product Groups assigned to time buckets.
weekly review with sales only demands.

MRP: Order policy = POQ, minimum batch & pan size = 0
minimum stock = 0 for all manufactured parts.
Linear Lead time offset calculated against
the transport quantity.

Shop: Launch all WIP to suggested start date.
Do not attempt to smooth production plans by
releasing WIP early.
Use bottleneck sequencing rules and transport
batches to manage shop-floor WIP movements.

11.3 Evaluation of the Need for De-coupling

One important feature of this finding, was that the best performance was achieved with the greatest exposure to the raw market demand (ie. the myopic sales based MPS) and that the product due date accuracy was acceptable. This indicated that de-coupling, in the form of product stocks or MPS fixing, was not required.

The above indicated that the assumptions made during the formulation of the original policy set were invalid. For example, the AMT based product shop was found to be capable of producing a variety of products in small batches simultaneously. Furthermore, the large elements of safety built into the original generic lead times were found to be both unnecessary and detrimental to system performance.

The performance of the manufacturing facilities was validated against an MPS containing customer orders only (subject to re-schedule) and no forecast demand. However it was recognised that a forecast element of total MPS demand may have a role to play in deriving purchase demands. This would be dependent on the relationship between composite manufacturing lead times, purchase lead times and the timing of sales orders. As such, the issue would need to be addressed during the formulation of purchase policies. This will be discussed in Chapter 12. In the interim the "grouped original" MPS specification would provide an acceptable alternative if doubts over purchase part supply were significant.

11.4 Performance of The Preferred Policies with Variations in Input Load

One outcome of the load bias investigation, was a re-affirmation of the effects of changes in input load on system performance, indicated by the Stage I static MPS experiments. It was therefore decided to perform a more complete analysis of these effects. The preferred policy group was run with the linear lead time queue element set at 0.5 and 1 days per operation, against a range of input loads ranging from 30 to 140% of the original.

Figure 81. shows the results of these experiments for PCB WIP. It was found that WIP follows an approximately exponential relationship with input load, and passes through the origin. This relationship conformed to expectations in that it is closely related to the theoretical relationship between WIP and utilization discussed in Chapter 3.

This was explored further by plotting work centre utilization against the bottleneck work centre input queue length for each of these loads. Figure 82. shows individual work centre utilization for the above policy set with a queue element of 0.5 days and the three alternative shop policies. From this, it was determined that work centre 1 (the dual in-line insertion machine) was the capacity-limiting bottleneck. Following this analysis, the utilization of this work centre and that of work centre 5 (taken to represent a non bottleneck work centre) was plotted against average work centre input queue for the preferred MPS and MRP policies (Figure 83.). It was noted that the shape of this curve closely conforms to that of Kanet's theoretical relationship (Chapter 3.).

It is important to note that a finite limit to PCB shop capacity occurred at 135% of the original load. This was indicated by the PCB WIP and lead time measures becoming transient (ie. the average value increased throughout the experiment) at this load, indicating an accumulation of WIP. This was accompanied by the input queue for work centre 1 also becoming transient, which confirmed it as the capacity-limiting work centre. It is of further interest to note that the bottleneck sequencing rules provided performance benefits throughout the load range and before the capacity bottleneck occurred. This indicates that transient bottlenecks must occur at load levels below that of the capacity limit.

Figure 84. shows the relationship between stock level and input load. This was found to be linear over the measured range, and tended toward the origin. The curve representing the 1 day queue element, exhibited a

higher gradient than that of the .5 day queue element and gave a consistently higher stock level. Both curves showed consistent deviations from linearity over the 80 to 110% load range. This is indicative of a systematic influence.

Figure 85. shows the relationship between PCB flow time and load. Neither of these curves tended toward the origin at the 0% load level. This resulted from the fact that a hypothetical batch of zero PCBs would have a finite lead time (resulting from the set, queue and transport times associated with a hypothetical batch of zero PCBs) at the zero load level. Both curves were similar to those of PCB WIP and the gradient increased at loads above 100%.

Figure 86. shows the relationship between PCB due date accuracy and load. Both curves tended toward maximum earliness values at 0% load, corresponding to the lead time of a hypothetical zero quantity batch. The values for the 1 day queue element were consistently higher than those of the 0.5 day queue element. Again the gradient of the curves approached the vertical at loads beyond 120% indicating the onset of shop overload.

Figure 87. shows the assembly WIP against load. Both curves were found to be linear and to tend toward the origin. The curve representing the 1 day queue element exhibited a slightly higher gradient. The linearity of these curves indicated that the assembly facility was well below its maximum capacity and would not therefore constrain the performance of the total system.

Figure 88. shows the assembly stock against load. Both curves were linear and tended toward the origin. Again the curve representing the 1 day queue element exhibited a higher gradient in a similar manner to that found with PCB stock. However, the local departures from linearity found with the PCB stock levels were not present.

Figure 89. shows the average assembly flow time values against load.

Both curves were found to exhibit large departures from the norm. These departures were considered to be a consequence of the lot splitting algorithm. In Chapter 7. it was noted that in the assembly areas, batches were broken down into smaller units to which labour would then be applied. Therefore a batch splitting algorithm was incorporated into the assembly model. However, the mean order quantity for assemblies was found to be close to the split batch size. This resulted in cyclical changes to the distribution of assembly batch sizes as the load (and thus order quantity) was adjusted. This in turn, resulted in systematic changes to assembly flow time and PCB stock.

Support for the above can be found in Table 31. which summarizes the inconsistencies in flow time and average batch size between loads of 85% & 95%. Further support can be found in the link between batch size and PCB flow time demonstrated in Chapters 8. and 9. The relationship for assemblies would be more extreme in the absence of significant levels of work centre queuing (resulting from the excess capacity).

Figure 90. shows average assembly due date against load. Again departures from the norm were observed and were considered to be due to cyclical changes in batch size. Regression indicated linearity, which further supported the view that the assembly area was well below its capacity limit. As expected the curve representing the 1 day queue element was consistently and significantly earlier than that of the 0.5 day queue element.

The above results demonstrated the effects of increasing work load on system performance. The non linearity of the WIP lead time and due date measures at the PCB level demonstrate a need for an overview of shop load within the planning function. The relevance of this point to

Load %	80	85	90	95
Queue = 0.15				
Mean Batch	5.41	6.376	5.852	5.403
Mean Flow	3.55	3.94	3.04	2.91
Queue = 0.5				
Mean Batch	6.2	6.336	5.906	6.436
Mean Flow	4.101	3.342	3.262	4.6

Table 31. Variations In Assembly Batch Size With Load

Fig 81. PCB WIP v Input Load.
Sales MPS, Bottleneck + Linear L.T.

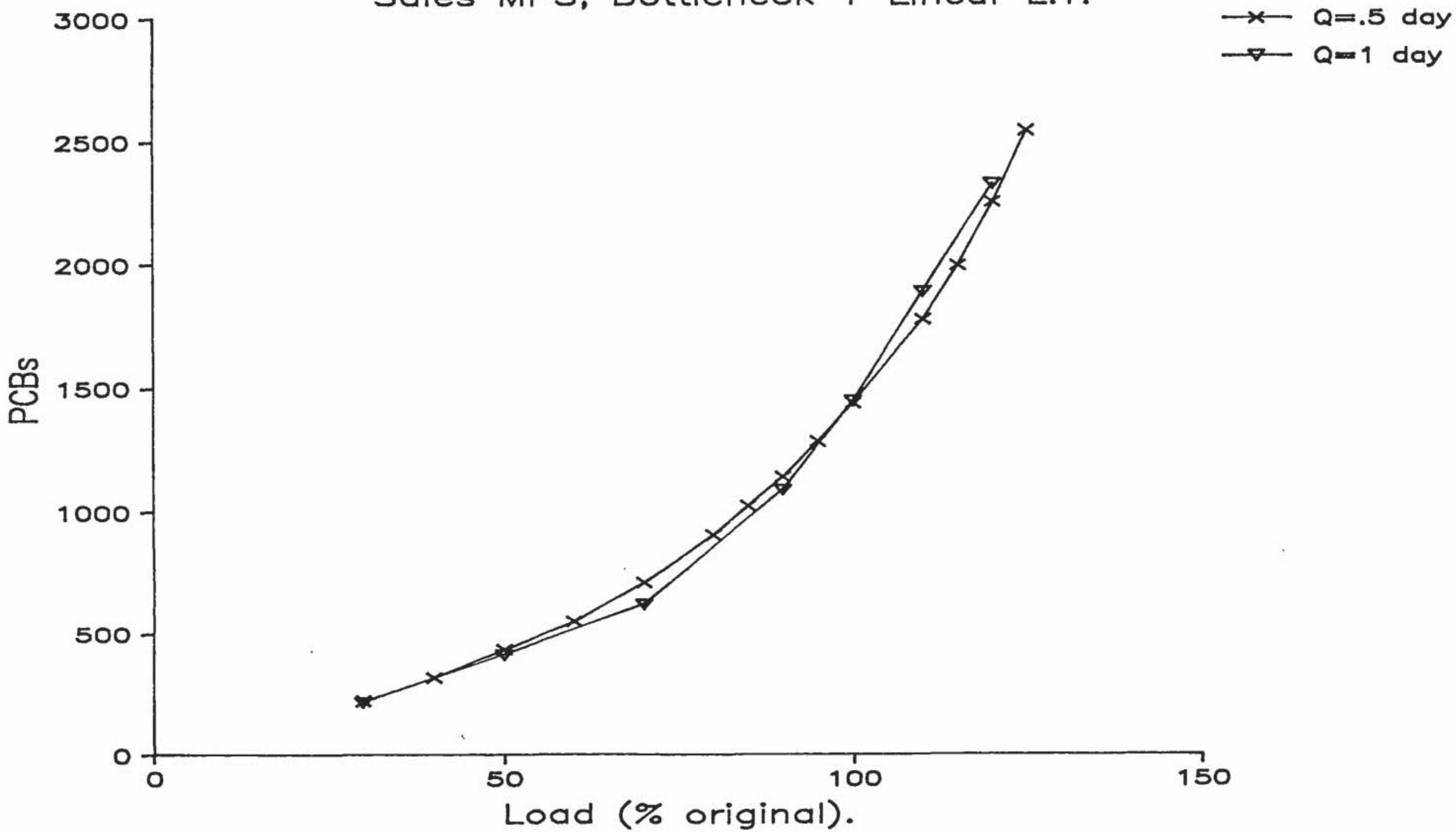


Fig 82. Average WC Input Queue.

Shop policies: Bottleneck, Transport & Original.

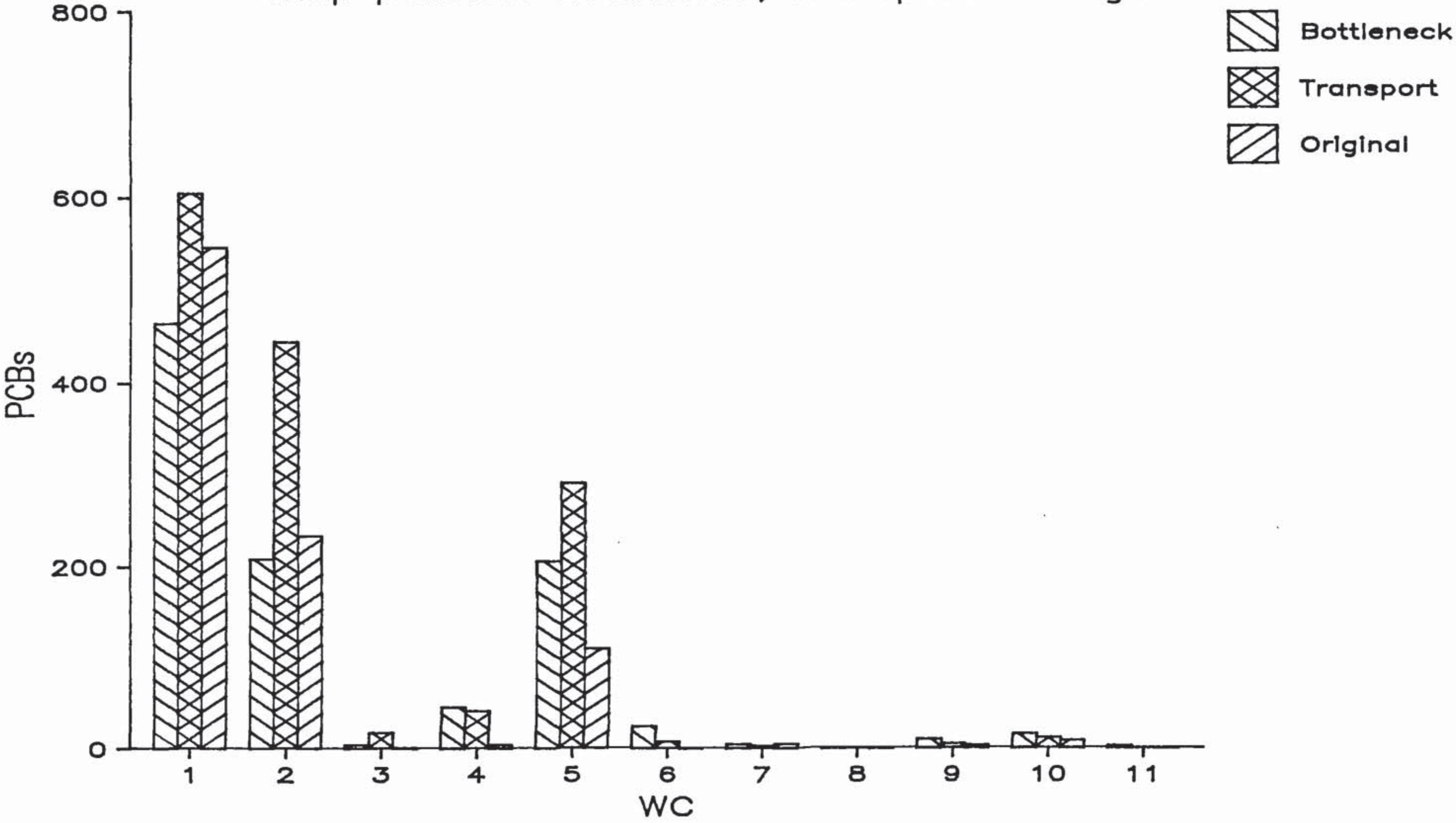


Fig 83. Input Queue v Utilisation.

Shop policies = original & bottleneck

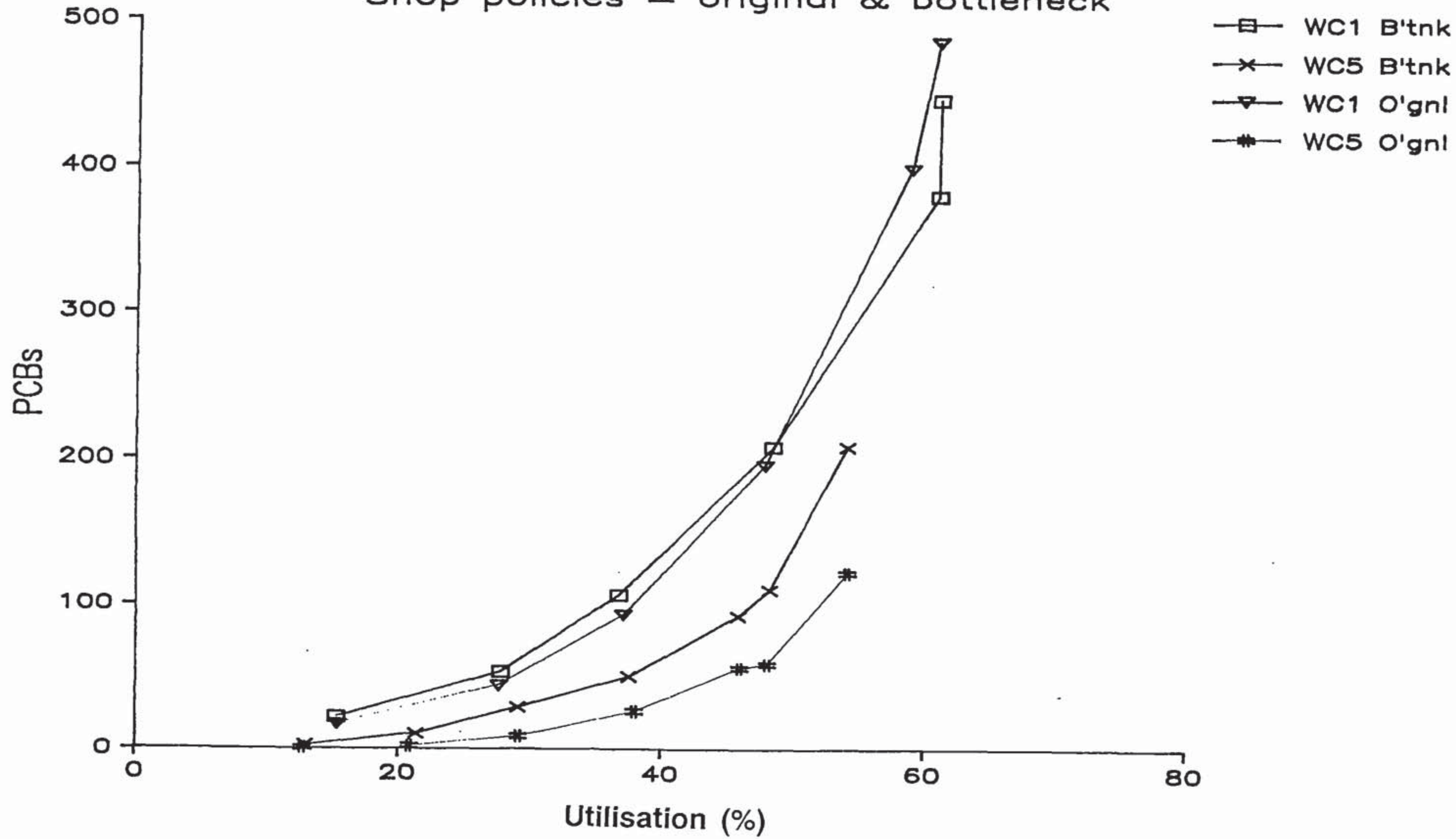


Fig 84. PCB Stock v Input Load.

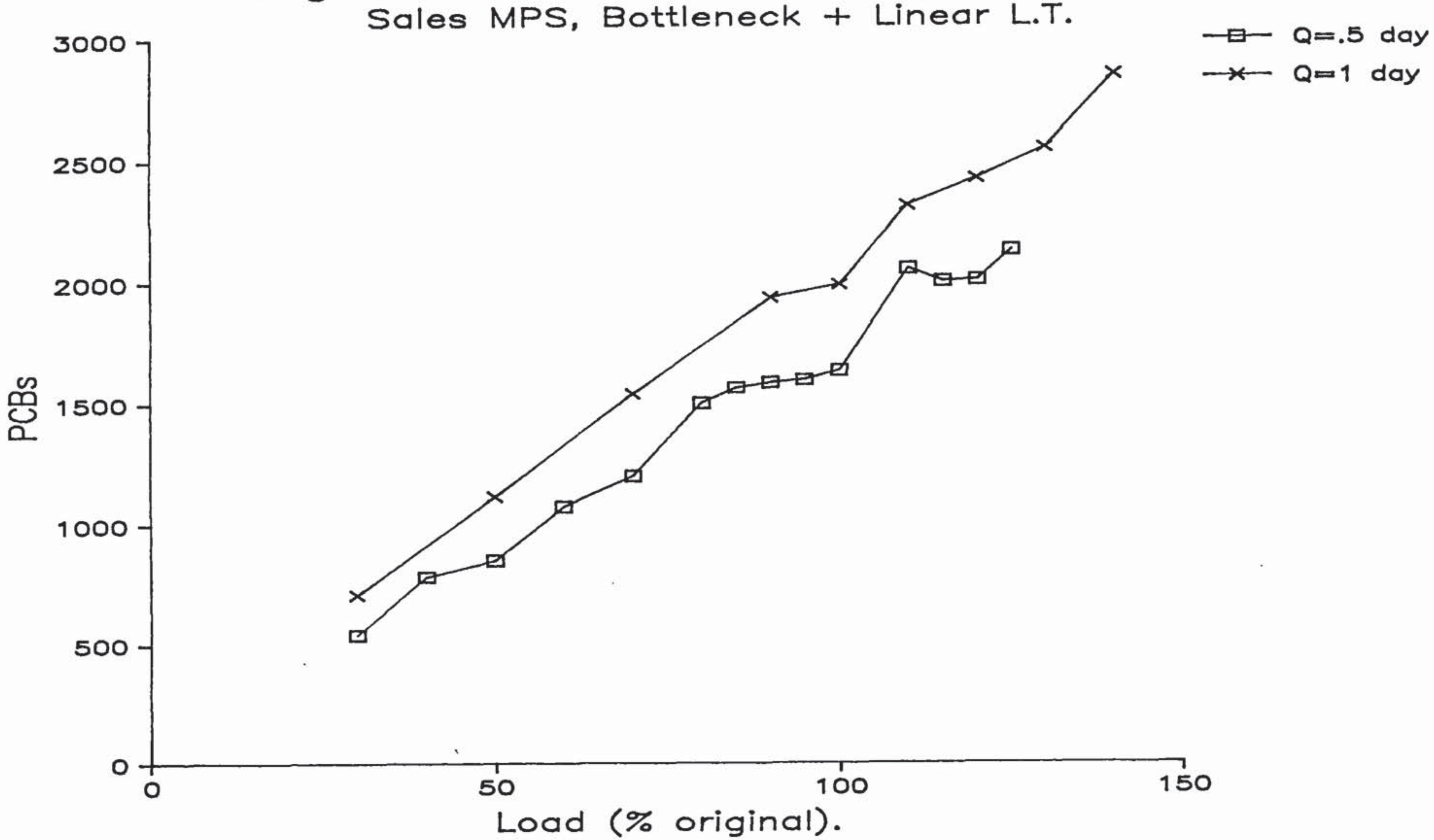


Fig 85. PCB Flow Time v Input Load.
Sales MPS, Bottleneck + Linear L.T.

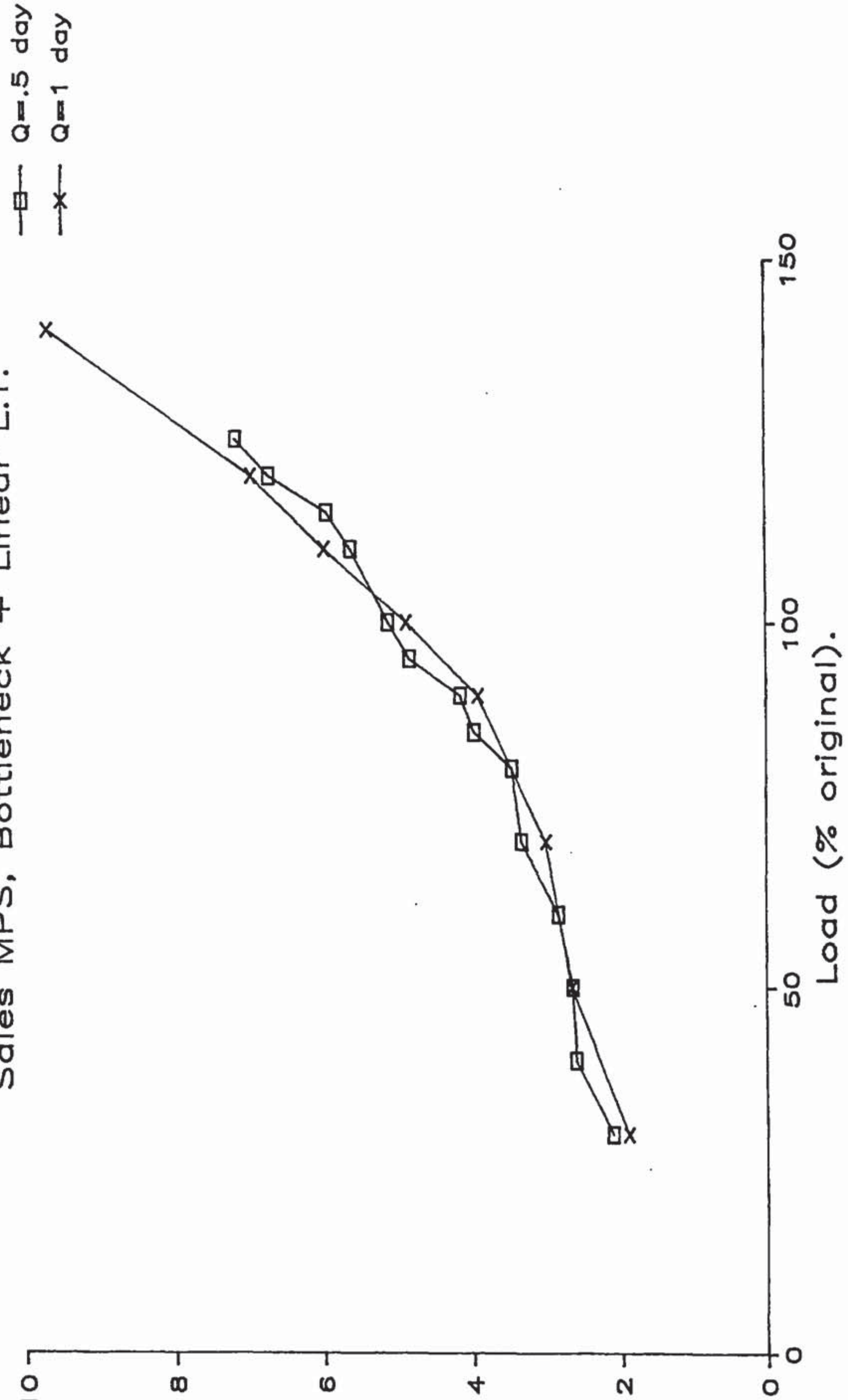


Fig 86. PCB Due Date v Input Load.

Sales MPS, Bottleneck + Linear L.T.

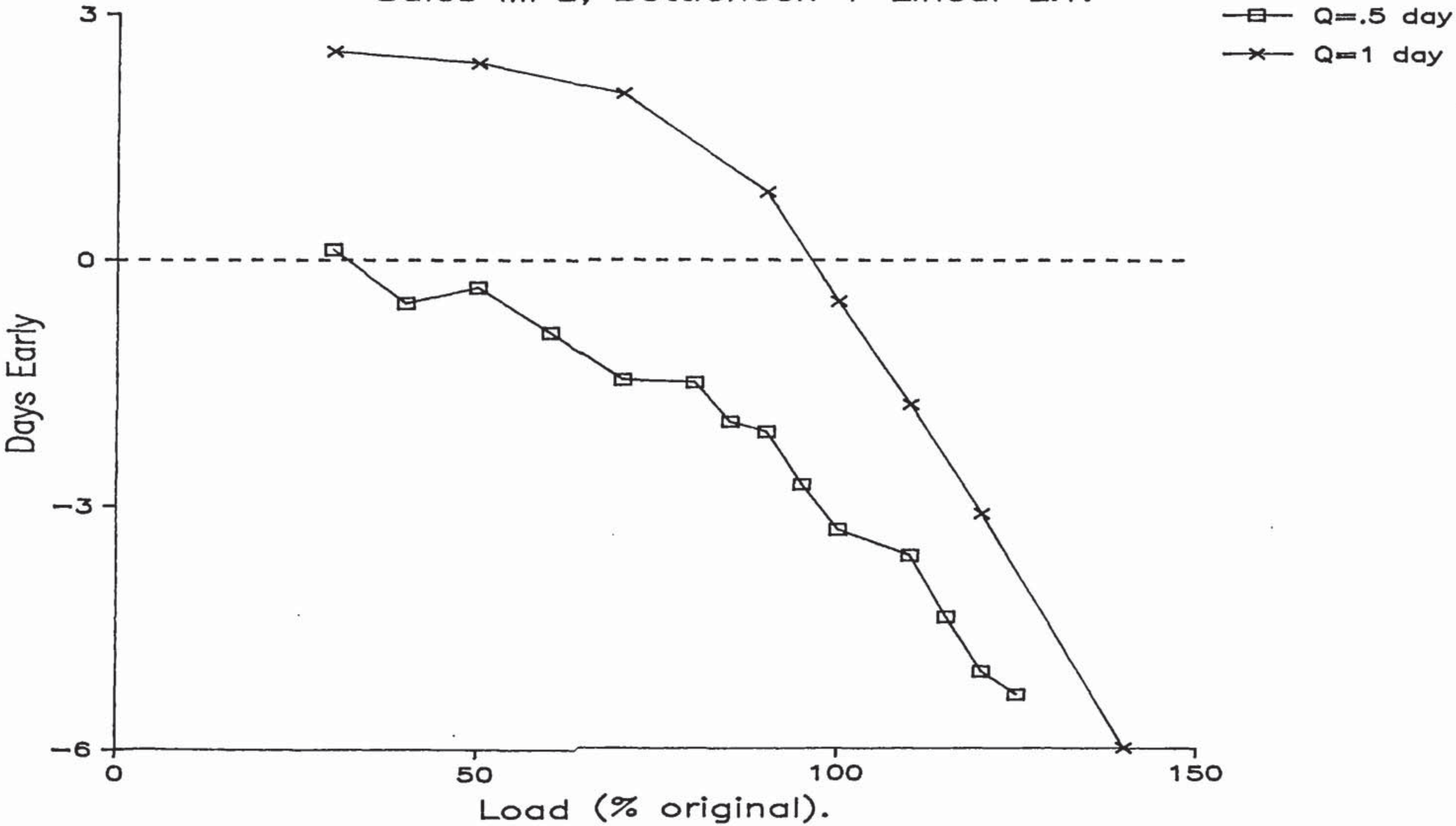


Fig 87. Assembly WIP v Input Load.
Sales MPS, Bottleneck + Linear L.T.

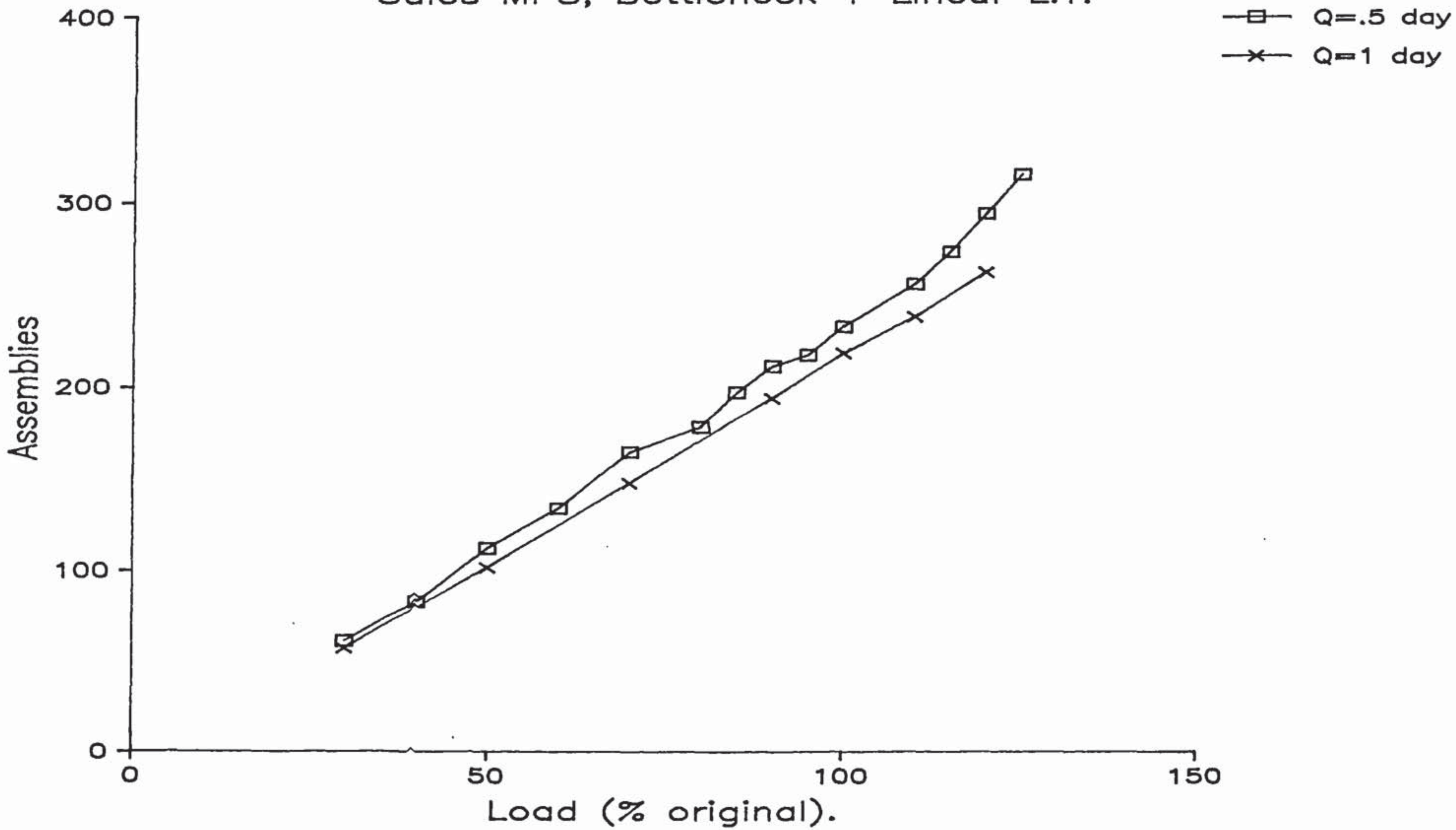


Fig 88. Assembly Stock v Input Load.
Sales MPS, Bottleneck + Linear L.T.

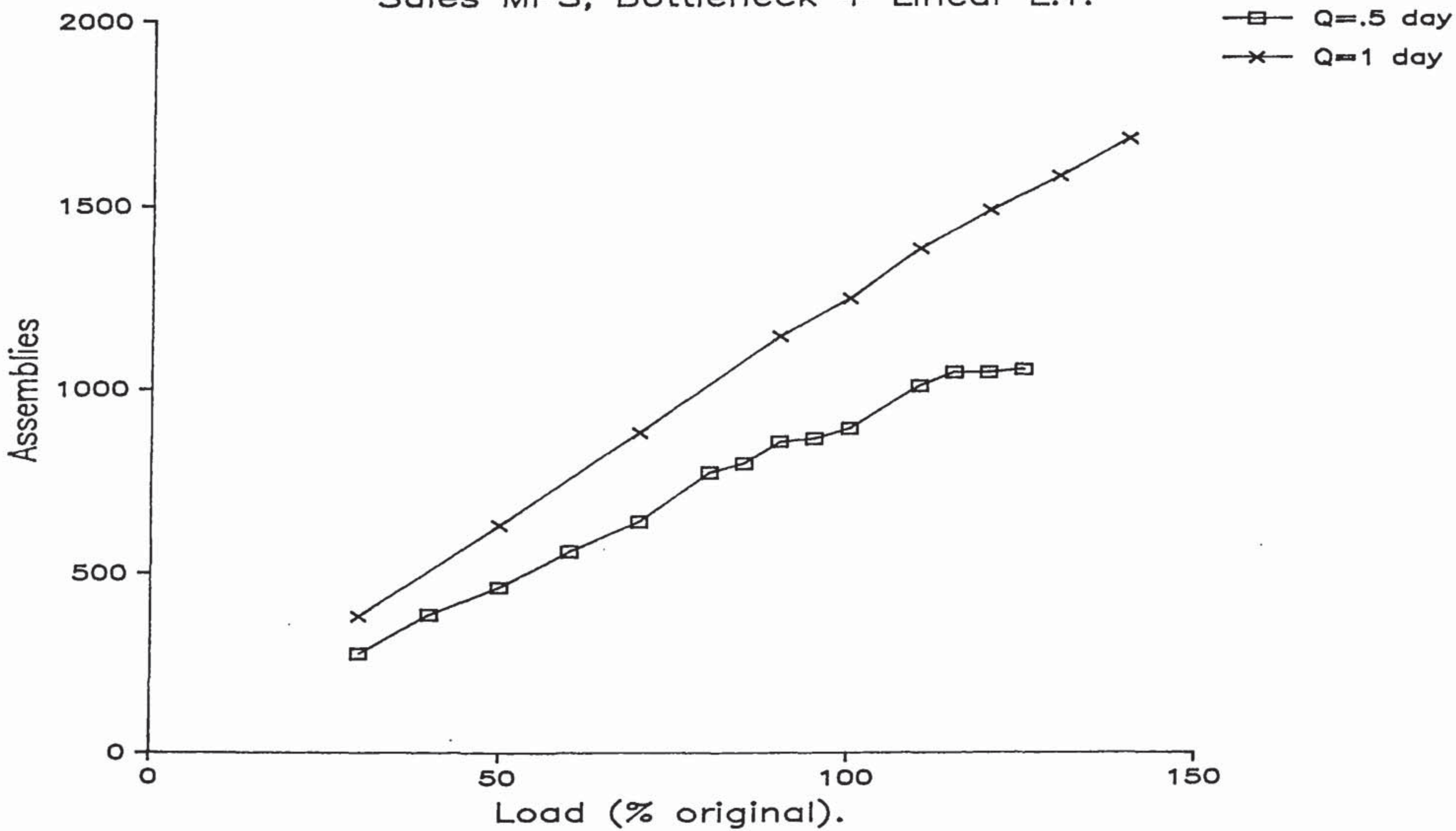
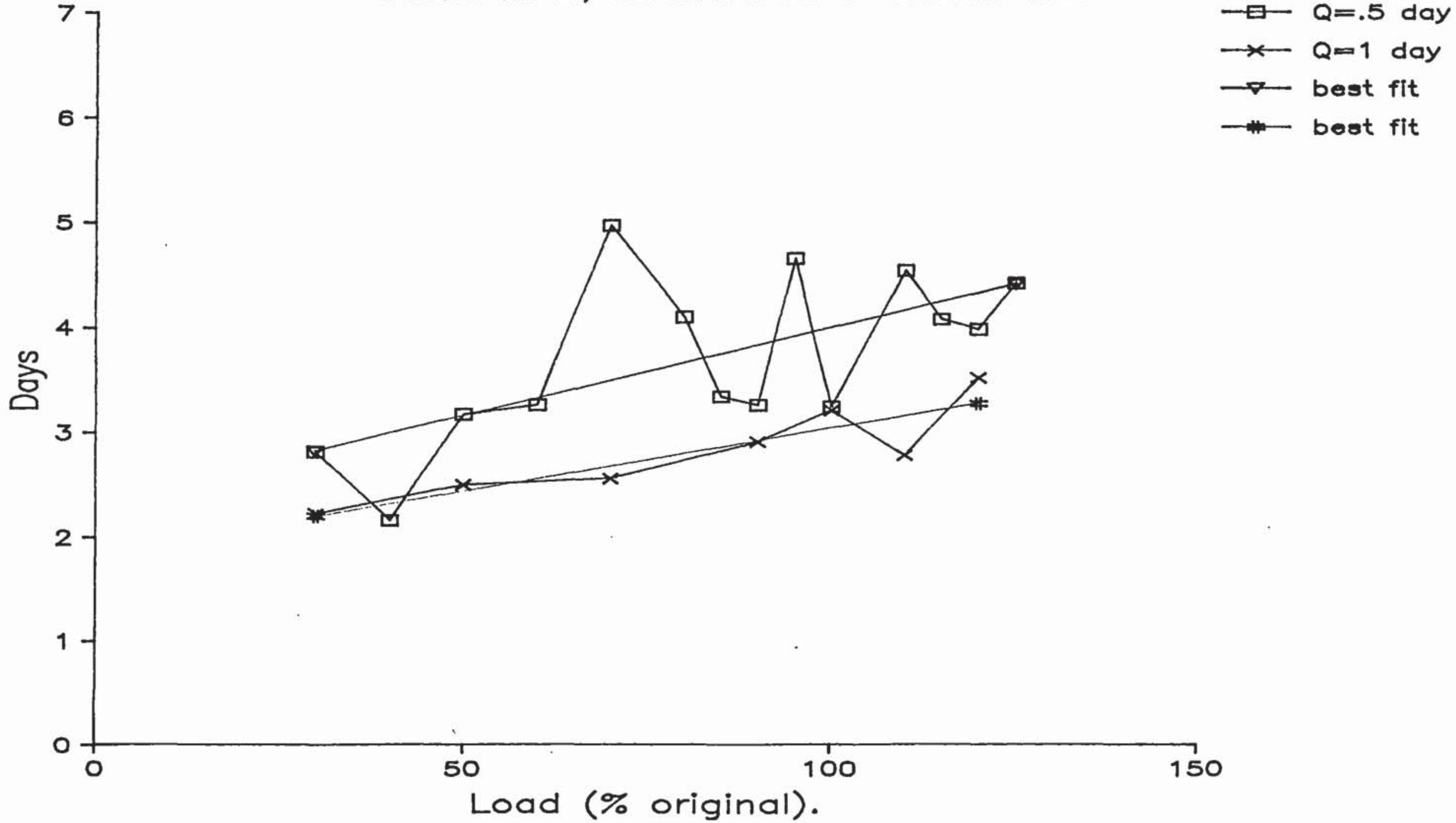


Fig 89. Assembly Flow Time v Load.

Sales MPS, Bottleneck + Linear L.T.



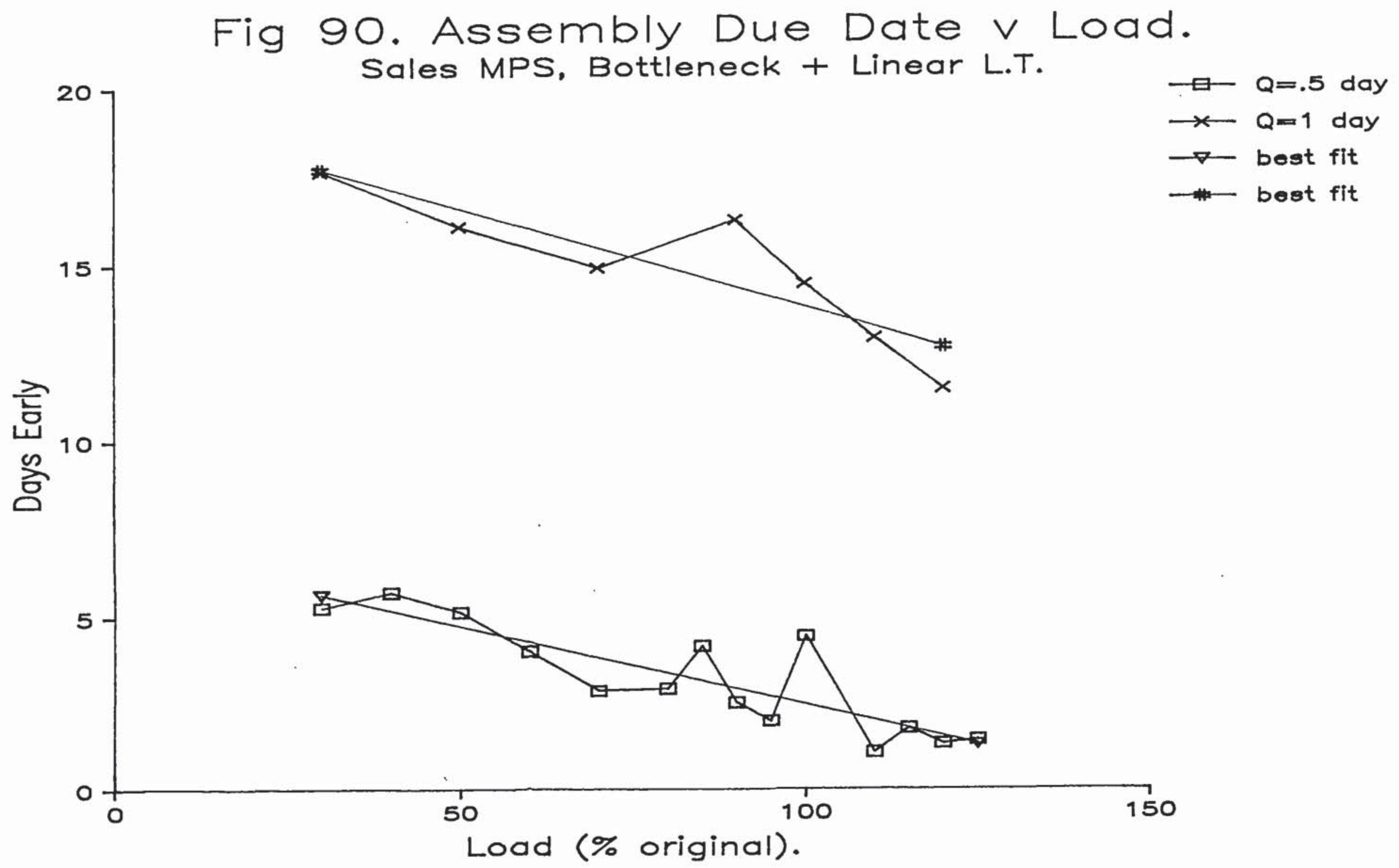


Fig 90. Assembly Due Date v Load.
Sales MPS, Bottleneck + Linear L.T.
Q=.5 day
Q=1 day
best fit
best fit
Days Early
20
15
10
5
0
0
50
100
150
Load (% original).

FCL is increased by the fact that the current load levels are within 35% of the maximum indicated capacity. This issue will be discussed further in Chapter 12.

The linearity of the assembly performance measures in the face of increasing work load is a little surprising. This would indicate that performance is not impaired by the late delivery of PCBs. However, the variability in the due date and lead time results preclude a more detailed analysis of this point. It is probable that a departure from linearity at the higher loads is masked by the variability. The need for further work in this area will be discussed in Chapter 12.

This analysis concludes the final part of the policy design methodology (Stage III). The adoption of a holistic approach to policy design and the implementation of such through the proposed methodology has been demonstrated to yield important benefits to manufacturing performance. Chapter 12. will summarize this work and will discuss a number of areas of potential for future work.

12. A DISCUSSION OF THE RESEARCH AND SUGGESTIONS FOR FURTHER WORK

12.1 A Discussion of the Research

This work has addressed the integration of two elements of CIM, namely MRP and an AMT based manufacturing facility. It has been argued that successful integration of sub-elements of the total system will only be achieved if the performance characteristics of each are matched at their boundary interfaces.

It has been shown that both MRP and AMT have suffered disappointing returns on expectations. In addition, a number of fundamental potential incompatibilities between these two systems have been presented. These are associated with the "low inertia" potential of AMT (often the sole reason for use) and the traditional "optimised", "high inertia" approach to MRP. *These factors have combined to increase the probability of failure* when attempting to integrate the two systems. This has increased the requirements for performance matching at the system boundaries.

The role of operational policies as performance determinators was presented. Chapters 2., 3. and 4. discussed policy design in a context of system performance and a number of failures in the accepted views on policy design were presented. Significant in these was the inappropriate selection of underpinning assumptions, deficiencies in the performance measures used and the omission of market uncertainty from design studies. In Chapter 5. it was demonstrated that a holistic approach to policy design is a prerequisite to success, both in the general area of policy design and in system integration. It was argued that the complexity of issues resulting from a holistic approach required the formulation of a structured design methodology.

Such a methodology, for policy design in the MRP/AMT environment, was subsequently developed and discussed. This combined a first principles approach to the behaviour of system elements with an experimental approach. The objective was to increase the efficiency of policy developments and the applicability of the methodology to the industrial environment.

This methodology was underpinned by a recognition of the need to match the performance of the total system to that of its environment (the marketplace) in addition to the harmonization of sub-element performance. Consequently, the methodology aimed to make full use of the "low inertia" characteristics of AMT, whilst adopting a JIT configuration of MRP and re-coupling the total system to the market demands.

The methodology was designed around three stages:

Stage I addressed the size and nature of the policy design problem for a particular case. A sensitivity analysis of the performance of system elements (market, production control and supply) formed the first part of this stage. The second part of Stage I concerned the determination of "core" policies. These were defined as those policies which would directly influence sub-element performance.

Stage II concerned the development of policy sets supporting the concepts of "low inertia" and "de-coupling". A first principles approach was combined with appropriate experimentation at this stage.

Stage III evaluated the performance of a preferred policy set and determined the need for any additional de-coupling or safety policies resulting from mismatches between the manufacturing system performance and the requirements of the marketplace.

A further important aspect of the methodology was the use of a manufacturing system model as a vehicle for policy design experiments. The historical use of modelling techniques was reviewed and a number of failings were discussed. Significant in these, was the use of inappropriate assumptions, boundaries and measures, by successive model builders. These issues were closely related to the failures in policy design discussed earlier. The holistic approach to the specification of a general research model was adopted. This resulted in the specification of a complex three element hybrid model for use with the policy methodology. The key points of this specification were that the model must accurately represent the market, production control and supply elements of the total system. In addition, an operational mode which supported MPS demand uncertainty and interactive rolling schedules was deemed to be mandatory.

Chapter 6. introduced a case study, based on Fulcrum Communications Ltd (FCL) which offered the opportunity to apply this methodology to a live industrial problem. In addition, this provided the opportunity to compare the performance of policies designed using this methodology, with historical data relating to the performance of the factory using traditionally designed policies. A description of the experimental facility used in this research was included in Chapter 7.

Chapter 8. discussed the application of Stage I of the methodology to the FCL case study, whilst Chapters 9. and 10. covered the application of Stage II and Chapter 11. addressed Stage III.

The case study was primarily concerned with the design of a policy set for use in controlling PCB manufacture. However, in keeping with the holistic approach, performance was assessed in total system terms and included an analysis of assemblies and products.

As discussed earlier, a central feature of the methodology is a move toward the re-coupling of the production system to the needs of the marketplace. The intention was to exploit the low inertia characteristics of AMT, and to combine this with a JIT configuration of MRP. Consequently, a novel approach to production control resulted from the application of the design methodology to the FCL case study.

This approach restricted manual intervention in the MRP processing and scheduling logic (all suggested orders were automatically actioned), but increased human involvement in the management of work flow on the shopfloor.

At the MPS level, the timing of customer demands was managed to produce a realistic and smooth demand. In addition, the destructive effects of market uncertainty at this level were reduced by increasing the frequency of review but applying it to a proportionately smaller volume of MPS demands. This was accomplished by developing four product groups of equal standard hour content. The demands for each were then assigned to a particular week in each month (ie group a. to week 1, group b. to week 2).

Within MRP, policy choices were restricted to those which would accurately reproduce the requirements of MPS demands in the production plan. The use of "optimising" policies were avoided, such that the true (demand driven) priorities would not be masked and policy induced lumpiness would be removed from the production plan. The recommended MRP policies were a one week POQ order policy and linear lead time policy calculated against the average transport batch size. All decoupling parameters (minimum stock level, minimum order quantity, pan size etc.) were set to zero. However, a small element of safety was recommended for the lead time queue element. This was primarily to cover the variance in flow times due to fluctuations in work load at the shopfloor level.

At the production planning and shopfloor levels, the "top down" approach usually associated with MRP was replaced. The application of production plan load smoothing and finite scheduling of shop operations was avoided. Under the proposed system, raw MRP output (in the form of suggested orders) was applied directly to the AMT facility. The task of the production control department altered from that of load balancing, rescheduling shop operations and the preparation of "work to lists", to preparing for the timely launch of all suggested orders.

At the shopfloor level, "work to lists" were replaced by a novel form of distributed control. Under this system, all order quantities greater than 40 were broken down into transport batches of mean size 20. At each work centre an input area was defined and all work was transported to the next operation immediately on completion of each transport batch. Work was then allowed to accumulate in the input queue area of each work centre. Individual work centre supervisors were then set the task of managing their throughput by sequencing their input queues according to a set of rules.

The existence and size of the input queue was used to determine the operation status of a particular work centre. The existence of a queue greater than 5 transport batches determined that such a work centre was operating as a capacity bottleneck. Under these circumstances, the input queue was sequenced to minimize set-up times. The absence of an input queue greater than 5 transport batches in length denoted that such a work centre had some spare capacity with relation to average current load. This capacity was then utilized to achieve flow time and due date accuracy targets.

Under the proposed policies, the shop management adopted a "hands off" role in work centre loading and would therefore be able to address higher issues, such as the size and nature of shop bottlenecks. In addition, it was considered that the direct involvement of work centre operators and supervisors in the management of work flow and the achievement of work movement objectives would provide additional benefits.

Following completion of this work, the experimental results and the recommended policy sets were presented to FCL management. The recommendations were accepted in total and the research team were contracted to lead their implementation. A detailed implementation strategy was formulated and the policies (with the exception of the removal of MPS forecast element) were implemented by stages. FCL's commitment to the proposed operational policies will be discussed in relation to the suggestions for further work.

12.2 Suggestions for Further Work

This research has identified a number of areas of potential for future work, much of which would continue the holistic approach in general and the use of a holistic model in particular. This resulted from the demonstrated utility of such a model in the area of operational policy design. These suggestions will now be discussed in the context of the FCL case study.

12.2.1 MPS Load

The experiments detailed in the preceding chapters, have demonstrated the effects of variations in MPS load and lumpiness, on the performance of the manufacturing system. The capability of the recommended policy set was tested over input loads varying from 30% to 135% of the original load. It was found that all performance measures reacted unfavorably to increases in average input load. In particular, it was found that at loads greater than 115% of the original, product due date performance began to suffer.

It is accepted that MPS load and to a lesser extent MPS lumpiness is a consequence of external market conditions. Throughout the policy design work it was assumed that FCL would not alter the areas in which it trades. However, it is unlikely that FCL's future MPSs will continue to replicate that of the previous 12 months in terms of load, product mix and lumpiness. It follows therefore, that if the consequences of excessive production load and inappropriate order timing are to be avoided, then a tool capable of analyzing MPS, product plan and performance characteristics would be required.

Traditionally, MRP offers capacity requirement planning (CRP) as the tool for this purpose. Typically CRP packages offer the following solution. Following changes to the MPS, MRP is run in a "non-planning" mode and the output is analyzed to produce reports of the total load against each work centre within individual time buckets. Following this, demands are adjusted in time, either at MPS level or at production plan level.

The assumption of infinite capacity is implicit in the above technique. Planned operation start dates are used to derive work centre load profiles. However, the planned operation start dates are generally calculated against the assumption of infinite capacity. Each planned start date assumes that the part will have cleared the preceding work centre in time to start the current operation.

This research has demonstrated the presence of bottlenecks in manufacturing systems. It is argued that the bottleneck queue (which has been found to be transient in nature) will invalidate the planned start dates for each of the downstream work centres. This in turn will invalidate the profiles of all of these work centres.

It can be argued that the validity of the planned due dates and load profiles for non-bottlenecks, is of limited importance. This argument is implicit in the recommended shop policies, in that work is allowed to flow according to "real time" constraints. It follows that the real issue is the size and nature of the input queue at the bottleneck. If the bottleneck were to remain static and finite (ie the same work centre is always the bottleneck) then the problem would reduce to one of scheduling the bottleneck operations. This was the approach adopted by OPT. However, this work has identified the presence of a number of secondary transient bottlenecks in the example facility. Figure 82. illustrated input queue length for each of the PCB work centres. From this, a number of work centres were found to exhibit bottleneck characteristics of a transient nature. Under increasing load conditions the potential for these transient bottlenecks to develop would seriously undermine planned performance.

From the above, it would appear that an alternative to the CRP based tool would be of significant benefit. Such a tool must be capable of assessing the effects of MPS changes at the shop level and must be underpinned by realistic assumptions.

It is suggested that a holistic model of the type used for this policy research, could be used as a basis for such a tool. Taking the FCL example, a copy of the live manufactured parts database could be placed on the B5900 development machine. The effects of MPS changes could be evaluated by running this test database against those changes and then using the output to drive an enhanced version of the factory simulator. This would then facilitate an analysis of work centre queues, flow times, etc and would provide an accurate measure of effective capacity.

One of the general problems associated with "what if? MRP" is that of MPS processing time. In the case of the FCL model, it was found that the removal of the purchase parts from the database yielded MRP processing times which were short enough for this mode of operation to be practicable. In addition, the processing speed of the factory simulator was found to be well within requirements. For a more general application, a modification to the MRP algorithm which locked out purchased parts would be likely to achieve processing times short enough for this technique to be practicable.

At a higher level, such a facility would offer the opportunity to develop comprehensive cost/benefit breakpoints against MPS load. This could form the basis of a powerful strategic tool.

12.2.2 Assembly Policies

This work has been primarily concerned with the formulation of control policies for PCB manufacture. The decision to investigate the PCB facility resulted from a traditional desire to maximize a return on fixed assets and the capital intensive nature of the AMT based facility. However, one outcome of this research has been a move away from the traditional views on asset utilization and the recognition of the importance of work flow. Indeed, one of the major benefits of this work has been a substantial potential reduction in total inventory, primarily by addressing work flow.

It would now be appropriate to rank policy design in terms of inventory reduction potential. In the case of FCL, the assembly area was found to be highly inventory intensive, with average total values approximately twice that of the PCB area. This suggests that there would be significant potential in applying these policy design techniques to this area. Reduction in average assembly flow time would accompany any reductions in inventory. This would have a positive secondary effect on the PCB area, in that exposure to uncertainty would be reduced at each of the BOM levels below the assemblies. It is probable that this would facilitate the use of a reduced queue element in the PCB lead time calculation and thus generate further total inventory reductions.

12.2.3 Purchase Policies

It has been argued that the design of purchase policies will be influenced by the relationship between the timing of MPS demands, composite manufacturing lead time and supply lead time. This study has resulted in a much greater understanding of these factors within FCL's current environment. Furthermore, it has been accepted that some aspects of MPS policy (eg. the inclusion of a forecast element in total product demand) cannot be fully defined until the issues surrounding purchase parts have been addressed. It follows therefore, that detailed appraisal of the policies controlling the supply of purchased parts would now be appropriate. It is expected that the policy design model would have a significant role to play in this exercise. This results from the fact that the utility of purchase policy sets must be measured in total system terms.

12.2.4 The Application of the Holistic Approach to the Strategic Level

It must be noted that policy design is an ongoing process. The relevance of any given policy set will be influenced by changes at the strategic level. There are two potential applications of the holistic approach to this issue. At one level, a study of the effects of a company repositioning against external influences through changes in product range or markets entered would determine the effects on manufacturing performance in terms of delivery and cost. Concurrent to this, policy design could be used to adjust company performance to gain a competitive advantage. This would expand on the policy design study undertaken by this work. It would be necessary to include the effects of product mix and volume changes with varying levels of demand uncertainty, which would result from changes in market sector and competitive forces.

The model requirements would be based on an enhanced version of the type used for operational policy design at FCL. A more sophisticated market model would be required for this work, which would be able to synthesize uncertain MPS data representative of various scenarios. It is probable that the inclusion of a system dynamics element, capable of modifying demand against company performance, would yield additional benefits. In addition, it is considered that a financial element would significantly enhance the scope and credibility of such a model and would result in a comprehensive and sophisticated strategic tool.

At a separate level, policy design would need to be considered in relation to changes in the internal influences and pressures within the company. This would include a study of the effects of changes to the manufacturing strategy.

This work has produced a number of insights into the strengths and weaknesses of manufacturing facilities, in particular the AMT based PCB facility. At this level, it is considered that a number of potential benefits would accrue from a study into the organization of shop facilities. A comparison of the performance of the shop organized along group technology lines (maintaining multiple part and small batch flow) against product flow lines (with dedicated machines supporting unit transport batches) would be of particular interest. In addition, concepts such as "total quality" and "manufacturing by-off" (in which sealed product specifications are "bought" from the design department) would further support the low inertia concepts, and be worthy of further investigation.

Again a holistic model would contribute significantly to such studies allowing alternative strategies to be evaluated in total system terms. This should avoid the potential for failure discussed in Chapter 4.

Appendix 1. Sample PCB and Assembly Data.

PCB Process Data:

Work Centre	Process Time (min)	Set Time (min)	Work Centre	Process Time (min)	Set Time (min)
Type 100			Type 101		
2.0000	.7860	35.0000	2.0000	1.3020	35.0000
4.0000	1.7700	10.0000	4.0000	1.7700	10.0000
4.0000	.7860	5.0000	4.0000	.8640	5.0000
8.0000	.2160	15.0000	7.0000	1.3200	.0000
9.0000	6.0240	7.0000	8.0000	.2640	15.0000
10.0000	1.0200	.0000	9.0000	2.0760	7.0000
9.0000	2.0700	3.0000	10.0000	1.2300	.0000
10.0000	1.0200	.0000	9.0000	15.6900	3.0000
11.0000	1.3560	10.0000	10.0000	1.2300	.0000
			11.0000	2.4660	10.0000
Type 103					
			Type 104		
9.0000	2.8140	7.0000			
10.0000	.4800	.0000	9.0000	7.2480	7.0000
11.0000	.3180	10.0000	10.0000	.7500	.0000
99.0000	.0000	.0000	11.0000	1.0000	10.0000
			9.0000	1.8420	3.0000
Type 105			10.0000	.7500	.0000
9.0000	17.5680	7.0000	Type 107		
10.0000	2.6880	.0000			
			9.0000	7.1640	7.0000
Type 108			10.0000	1.2350	.0000
4.0000	2.4900	10.0000	Type 109		
1.0000	2.1000	50.0000			
7.0000	1.1220	.0000	1.0000	1.1520	40.0000
2.0000	.8520	45.0000	7.0000	.6960	.0000
3.0000	.4380	50.0000	2.0000	.6960	35.0000
5.0000	3.4260	72.0000	5.0000	3.1020	57.0000
7.0000	1.1220	.0000	7.0000	.6960	.0000
8.0000	.3120	15.0000	8.0000	.2160	15.0000
9.0000	9.9120	14.1000	10.0000	.6960	.0000
10.0000	1.1220	.0000	11.0000	1.3980	10.0000
11.0000	2.2500	10.0000			

Sample Assembly and Sub-Assembly Data.

Type	Work Centre	Process Time	Type	Work Centre	Process Time
3	18	240.0000	4	18	50.0000
	21	60.0000			
5	18	12.0000	6	15	7.8900
	19	60.0000		15	12.6780
7	15	1.6300		16	1.1840
	15	3.0000		15	13.0100
	16	.6100		16	1.9650
	15	5.0900		15	9.5500
	16	.6100	8	15	4.2780
	15	12.6600		15	8.7300
				16	1.3100
				16	1.9000
				17	2.1390

Sample Assembly Pick List Data:

Component Type	Quantity Used
Type 3	
100.0000	1.0000
101.0000	1.0000
102.0000	1.0000
103.0000	1.0000
Type 4	
5.0000	1.0000
Type 5	
6.0000	1.0000
116.0000	1.0000
117.0000	1.0000
122.0000	1.0000
123.0000	1.0000
124.0000	1.0000
125.0000	1.0000
126.0000	1.0000
127.0000	1.0000
128.0000	1.0000
131.0000	1.0000
230.0000	1.0000
231.0000	1.0000
Type 6	
50.0000	.1000
7.0000	1.0000

Appendix 2. Factory Simulator Source Code.

```
C Primary Subroutine.

          SUBROUTINE OPTIK

     $INCLUDE COM.ICL

          CALL VSPACE (1,30,150)
          CALL FMSPIC
          CALL ASYPIC
          CALL OTHERS
          CALL UPDATE(-1.0,10.0)
          CALL ESPACE(900)
          CALL ALCLFB(20000,20)
          CALL FMSINT
          CALL ASYINT
          CALL MISINT
          CALL STOINT
          CALL FMSDAT
          CALL ASYDAT
          CALL PRTNUM
          CALL EXPARM
          IFLAG = 2
          IBABEL = 1
          CALL SETMOD('V')
          CALL REDRAW
          CALL PCBLST
          CALL SYSLST
          CALL CALDAT
          CALL SFNAME('F:SAVER.DAT')
          IDAY =0
          IPER =0
          IYEAR=87
          CALL COMS
          CALL STPER
          CALL EXEC

          RETURN
          END

C Picture, PCB work center & ASSY work center initialization
C is held in the following include files.

     $INCLUDE PINIT.ICL
     $INCLUDE FMSINT.ICL
     $INCLUDE ASYINT.ICL

C Stores initialisation.

          SUBROUTINE STOINT
     $INCLUDE COM.ICL

          REAL LEVEL
          BSTK = 0.0

          DO 10 J = 1,255
              CALL MAKEPT(IBUFST(J),CFI(J,3),'R',1)
              CALL SRPV(IBUFST(J),1,BSTK)
              CALL ABSROB(SLEV(J),BSTK)
   10     CONTINUE

          DO 20 JJ = 1,2
```

```
      CALL MAKEPT(ISTK(JJ),'SK'//CFI(JJ,1),'R',1)
20    CONTINUE

      CALL SRPV(ISTK(1),1,BSTK*156.0)
      CALL SRPV(ISTK(2),1,BSTK*99.0)
      CALL MAKEPT(ISTOCK,'STK','R',1)
      CALL SRPV(ISTOCK,1,BSTK*255.0)

      RETURN
      END

C Miscellaneous initialisation, including statistics
C and event processors.

      SUBROUTINE MISINT

$INCLUDE COM.ICL

      CALL MAKEPT(NAME,'EXNA','I',1)
      CALL MAKEPT(ITRANS,'TRAN','R',2)
      CALL MAKEPT(ITRBAT,'TRB','R',2)
      CALL MAKEPT(ISAMPL,'SAMP','R',2)
      CALL MAKEPT(ASYLAB,'LABR','I',2)
      CALL SIPV(ASYLAB,1,30)
      CALL SIPV(ASYLAB,2,30)
      CALL MAKEPT(IWIP(1),'BWP','R',1)
      CALL MAKEPT(IWIP(2),'SWP','R',1)
      CALL MAKEPT(NMAC(1),'NMB','I',11)
      CALL SIPV(NMAC(1),1,1)
      CALL SIPV(NMAC(1),2,1)
      CALL SIPV(NMAC(1),3,1)
      CALL SIPV(NMAC(1),4,9)
      CALL SIPV(NMAC(1),5,3)
      CALL SIPV(NMAC(1),6,6)
      CALL SIPV(NMAC(1),7,2)
      CALL SIPV(NMAC(1),8,2)
      CALL SIPV(NMAC(1),9,20)
      CALL SIPV(NMAC(1),10,3)
      CALL SIPV(NMAC(1),11,8)
      CALL MAKEPT(NMAC(2),'NMS','I',2)
      CALL SIPV(NMAC(2),1,8)
      CALL SIPV(NMAC(2),2,2)
      CALL MAKEPT(IPLAN,'PLAN','R',10)
      CALL SRPV(IPLAN,5,1.0)
      CALL MAKEET (ITOPS,'TOPS',0,255)
      CALL MAKEET(IMACH(20,1),'M20H',0,5)
      CALL SETIAT(IMACH(20,1),1,20)
      CALL SETIAT(IMACH(20,1),2,1)
      CALL MAKEPT(ICAL87,'C87','I',365)
      CALL MAKEPT(ICAL88,'C88','I',366)
      CALL MAKEPT(ICAL89,'C89','I',365)
      CALL MAKEPT(IPER87,'P87','I',52)

      DO 100 II =1,52
              IF(II.EQ.16.OR.II.EQ.17.OR.II.EQ.19
     &        .OR.II.EQ.36)THEN
                      ILL=4
              ELSEIF(II.EQ.22)THEN
                      ILL=3
              ELSEIF(II.EQ.52)THEN
                      ILL=2
              ELSEIF(II.EQ.1)THEN
                      ILL=1
              ELSE
```

```
                        ILL=5
                ENDIF

                CALL SIPV(IPER87,II,ILL)

  100   CONTINUE

        CALL MAKEPT(IPER88,'P88','I',51)

        DO 200 II =1,51
        IF(II.EQ.13.OR.II.EQ.14.OR.II.EQ.35)THEN
                        ILL=4
                ELSEIF(II.EQ.22)THEN
                        ILL=3
                ELSE
                        ILL=5
                ENDIF

                CALL SIPV(IPER88,II,ILL)

  200   CONTINUE

        CALL MAKEPT(IPER89,'P89','I',51)

        DO 300 II =1,51
        IF(II.EQ.1.OR.II.EQ.14.OR.II.EQ.15
     &   .OR.II.EQ.18.OR.II.EQ.35)THEN
              ILL=4
        ELSEIF(II.EQ.22)THEN
              ILL=3
        ELSE
              ILL=5
        ENDIF

        CALL SIPV(IPER89,II,ILL)

  300   CONTINUE

C Statistics held in the following include file.

    $INCLUDE STATS.ICL

        CALL MAKEBE('TRNSPT','ENDPRO','BEGPRO'
     &  ,'ENDED','RECORD','ASTRAN','ENASSY'
     &  ,'ENDDAY',8)

        CALL MAKECE('BEGSET','BEGASY',2)

        RETURN
        END

C EVENT PROCESSOR ROUTINES.

C Next day, end of experement and record events are held
C in thefollowing include file.

    $INCLUDE NEWDAY.ICL
    $INCLUDE ENDED.ICL
    $INCLUDE RECORD.ICL

C PCB - Transpotr event.

        SUBROUTINE TRNSPT
```

```
$INCLUDE COM.ICL
        WORK = RAT(IPCURE(),7)
        IWORK = INT(WORK)
        CALL ADDRAT(IPCURE(),6,1.0)
        TYPE=RAT(IPCURE(),1)
        OPER=RAT(IPCURE(),6)
        WRKSTN=RPV(IPBDAT(INT(TYPE),INT(OPER)),1)
        CALL SETRAT(IPCURE(),7,WRKSTN)

        IF(OPER.EQ.1.0)THEN
                CALL SRPV(IWIP(1),1,(RPV(IWIP(1),1)
     &                          + RAT(IPCURE(),4)))

                RELE=TIME()
      IPOS = LOCAT(IPCURE(),IBAOUT(IWORK))
      CALL SETRAT(MEMBER(IBAOUT(IWORK),IPOS),5,RELE)

        ENDIF

        II=INT(WRKSTN)
        IF(II.EQ.99)THEN
        IPOS = LOCAT(IPCURE(),IBAOUT(IWORK))
        CALL ADD(IPCURE(),IOUT(1),0)
        CALL REMOVE(IBAOUT(IWORK),IPOS)
        INSTOR = ISIZOF(IOUT(1))
        CALL DISIV (112,1,1,INSTOR,3)

        ELSE

        IPOS = LOCAT(IPCURE(),IBAOUT(IWORK))
        CALL ADD(IPCURE(),IBATIN(II),0)
        CALL REMOVE(IBAOUT(IWORK),IPOS)

        ENDIF

        RETURN
        END

C PCB - Begin setting operation.

        SUBROUTINE BEGSET

$INCLUDE COM.ICL

        DO 10 II=1,11

            IWORK = IAT(MEMBER(IORDER,II),1)
            CALL SETWLD
            CALL OPTWLD
            IF(ISIZOF(IBATIN(IWORK)).GT.0.AND.
     &         ISIZOF(IWLDMQ(IWORK)).GT.0.AND.
     &                IAT(IWDSET(JSET),1).GT.
     &               IAT(IWDSET(JSET),2).AND.
     &               IAT(IWDOPT(JOPT),1).GT.
     &               IAT(IWDOPT(JOPT),2))THEN

         CALL SUCCES
         IMASH=IAT(MEMBER(IWLDMQ(IWORK),1),2)

        CALL ADD(MEMBER(IWLDMQ(IWORK),1),
     &           IMCSET(IWORK,IMASH),0)
        CALL REMOVE(IWLDMQ(IWORK),1)
        CALL ADDIAT(IWDSET(JSET),2,1)
        CALL ADDIAT(IWDOPT(JOPT),2,1)
```

```
        IAB=ISIZOF(IBATIN(IWORK))

        IF(IAB.GE.5)THEN

        RTYPE=RAT(MEMBER(IMCSET(IWORK,IMASH),0),3)
        ROPER=RAT(MEMBER(IMCSET(IWORK,IMASH),0),4)

        DO 15 ILK=1,IAB

             INM=MEMBER(IBATIN( IWORK),ILK)
        IF(RAT(INM,1).EQ.RTYPE.AND.RAT(INM,6).EQ.
&       ROPER.AND.ILK.EQ.1)THEN
                   GO TO 16
        ELSEIF(RAT(INM,1).EQ.RTYPE.AND.RAT(INM,6)
&               .EQ.ROPER.AND.ILK.GT.1)THEN
        CALL SWAP(MEMBER(IBATIN(IWORK),ILK),
&                IBATIN(IWORK),1,ILK)

                   GO TO 16
        ENDIF
15      CONTINUE
        ENDIF

16      CALL ADD(MEMBER(IBATIN(IWORK),1),
&       IBASET(IWORK,IMASH),0)
        CALL REMOVE(IBATIN(IWORK),1)

        IF(RAT(MEMBER(IMCSET(IWORK,MASH),1),3).EQ.
&          RAT(MEMBER(IBASET(IWORK,IMASH),1),1)
&          .AND.RAT(MEMBER(IMCSET(IWORK,IMASH)
&          ,1),4).EQ.RAT(MEMBER(IBASET
&             (IWORK,IMASH),1),6))THEN

        SETIME=0.0

        IDIS=IAT(MEMBER(IMCSET(IWORK,IMASH),0),5)
        CALL SETCOL(IDIS,'GG')
        CALL RESET

        ELSE

        TYPE=RAT(MEMBER(IBASET(IWORK,IMASH),1),1)
        OPER=RAT(MEMBER(IBASET(IWORK,IMASH),1),6)
        SETIME=RPV(IPBDAT(INT(TYPE),INT(OPER)),3)
        IDIS=IAT(MEMBER(IMCSET(IWORK,IMASH),0),5)
        CALL SETCOL(IDIS,'YY')
        CALL RESET

        ENDIF

      CALL SETRAT(MEMBER(IMCSET(IWORK,IMASH),1),3,
 &     RAT(MEMBER(IBASET(IWORK,IMASH),1),1))
      CALL SETRAT(MEMBER(IMCSET(IWORK,IMASH),1),4,
 &     RAT(MEMBER(IBASET(IWORK,IMASH),1),6))
      CALL SCHEDL('BEGPRO',SETIME,IMACH(IWORK,IMASH))

      ENDIF

   10   CONTINUE

        DO 20 KK =1,3

        IRNI = INT(SUFM(1.0,11.0,16))
        IRNO = INT(SUFM(1.0,11.0,26))
```

```
          CALL SWAP(MEMBER(IORDER,IRNO),IORDER,IRNI,IRNO)

    20    CONTINUE

          RETURN
          END

C PCB - Begin process operation.

          SUBROUTINE BEGPRO

$INCLUDE COM.ICL

          ID = IPCURE()
          IWORK = IAT(ID,1)
          IMASH = IAT(ID,2)

          IF(IWORK.EQ.7)THEN
                SAMPLE = RPV(ISAMPL,1)
          ELSEIF(IWORK.EQ.10)THEN
                SAMPLE = RPV(ISAMPL,2)
          ELSE
                SAMPLE = 1.0
          ENDIF
          CALL ADD(MEMBER(IMCSET(IWORK,IMASH
     &                 ),1),IMCPRO(IWORK,IMASH),0)
          CALL REMOVE(IMCSET(IWORK,IMASH),1)
          CALL ADD(MEMBER(IBASET(IWORK,IMASH
     &                 ),1),IBAPRO(IWORK,IMASH),0)
          CALL REMOVE(IBASET(IWORK,IMASH),1)
          CALL SETWLD
          CALL ADDIAT(IWDSET(JSET),2,-1)
          TYPE=RAT(MEMBER(IBAPRO(IWORK,IMASH),1),1)
          OPER=RAT(MEMBER(IBAPRO(IWORK,IMASH),1),6)
          EACH=RPV(IPBDAT(INT(TYPE),INT(OPER)),2)
          BSIZE=RAT(MEMBER(IBAPRO(IWORK,IMASH),1),4)
          PROTIM=EACH*BSIZE*SAMPLE
          CALLADDRAT(MEMBER(IBAPRO(IWORK,IMASH)
     &                               ,1),9,PROTIM)
          CALLSCHEDL('ENDPRO',PROTIM,IMACH
     &                  (IWORK,IMASH))
          IDIS=IAT(MEMBER(IMCPRO(IWORK,IMASH),0),5)
          CALL SETCOL(IDIS,'GG')
          CALL RESET

          DO 5 KK =1,5

             IRNI = INT(SUFM(1.0,11.0,16))
             IRNO = INT(SUFM(1.0,11.0,26))

       CALL SWAP(MEMBER(IORDER,IRNO),IORDER,IRNI,IRNO)
    5              CONTINUE
    15           CONTINUE
    20    CONTINUE

          RETURN
          END

C PCB - End process operation.

          SUBROUTINE ENDPRO

$INCLUDE COM.ICL
```

```
          ID = IPCURE ()
          IWORK=IAT(ID,1)
          IMASH=IAT(ID,2)

          CALL ADD(MEMBER(IMCPRO(IWORK,IMASH)
     &          ,1),IWLDMQ(IWORK),0)
          CALL REMOVE(IMCPRO(IWORK,IMASH),1)
          CALLADD(MEMBER(IBAPRO(IWORK,IMASH)
     &            ,1),IBAO UT(IWORK),0)
          CALL REMOVE(IBAPRO(IWORK,IMASH),1)

          IF(IPRIOR.EQ.1)THEN
          ITYPE = INT(RAT(MEMBER(IBAOUT(IWORK),0),1))
          LEAD  =  RAT(MEMBER(IBAOUT(IWORK),0),8)
          ICOPS = INT(RAT(MEMBER(IBAOUT(IWORK),0),6))
          FLOWT =  RAT(MEMBER(IBAOUT(IWORK),0),9)
          IROPS = IAT(ITOPS,ITYPE) - ICOPS
          PRNUM = (LEAD - FLOWT)/REAL(IROPS)
          CALL SETRAT(MEMBER(IBAOUT(IWORK),0),10,PRNUM)
          ENDIF

          CALL OPTWLD

          CALL ADDIAT(IWDOPT(JOPT),2,-1)

          CALL SCHEDL('TRNSPT',RPV(ITRANS,1),
     &              (MEMBER(IBAOUT(IWORK),0)))

          IDIS=IAT(MEMBER(IWLDMQ(IWORK),0),5)
          CALL SETCOL(IDIS,'RR')
          CALL RESET

          RETURN
          END

C ASSY - Begin assembly.

          SUBROUTINE BEGASY

     $INCLUDE COM.ICL
          DO 10 II=1,8

          IWORK = IAT(MEMBER(IASORD,II),1)
          IF(IWORK.GE.18)THEN
          JKL = 2
          ELSE
          JKL = 1
          ENDIF
          ILABOR = IPV(ASYLAB,JKL)

          IF(ISIZOF(IASYIN(IWORK)).GT.0.AND.ILABOR.GT.0)THEN

          DO 8 KJ = 1,20

          IDENT =MEMBER(IWC(IWORK,1),KJ)

          IF(DSCOF(IDENT).EQ.'     ')GOTO 3
     8    CONTINUE
          GOTO 10
     3    CALL SUCCES

          CALL AIPV(ASYLAB,JKL,-1)
          IMASH=1
```

```
          CALL ADD(MEMBER(IWC(IWORK,
     &           IMASH),KJ),OCUPYD,1)
          CALL REMOVE(IWC(IWORK,IMASH),KJ)
          CALL ADD(MEMBER(IASYIN(IWORK),1)
     &          ,IWC(IWORK,IMASH),KJ)
          CALL REMOVE(IASYIN(IWORK),1)
          TYPE=RAT(MEMBER(IWC(IWORK,IMASH),KJ),1)
          OPER=RAT(MEMBER(IWC(IWORK,IMASH),KJ),6)
          OPTIME=RPV(ISYSOP(INT(TYPE),INT(OPER)),2)
          BSIZE=RAT(MEMBER(IWC(IWORK,IMASH),KJ),4)
          PROTIM = OPTIME*BSIZE

          CALL SCHEDL('ENASSY',PROTIM,
     &                  MEMBER(IWC(IWORK,IMASH),KJ))

          ENDIF

   10     CONTINUE

          DO 20 KK =1,3

          IRNI = INT(SUFM(1.0,8.0,16))
          IRNO = INT(SUFM(1.0,8.0,26))

          CALL SWAP(MEMBER(IASORD,IRNO),IASORD,IRNI,IRNO)

   20     CONTINUE

          RETURN
          END

C ASSY - End assembly operation.

          SUBROUTINE ENASSY

     $INCLUDE COM.ICL

          ID = IPCURE ()
          IWORK=INT(RAT(ID,7))

          IF(IWORK.GE.18)THEN
                  JKL = 2
          ELSE
                  JKL = 1
          ENDIF

          CALL AIPV(ASYLAB,JKL,1)
          IPOS = LOCAT(ID,IWC(IWORK,1))
          CALL ADD(ID,IASYOT(IWORK),1)
          CALL REMOVE(IWC(IWORK,1),IPOS)
          CALL ADD(MEMBER(OCUPYD,1),
     &           IWC(IWORK,1),IPOS)
          CALL REMOVE(OCUPYD,1)

          CALL SCHEDL('ASTRAN',RPV(ITRANS,2),
     &                  MEMBER(IASYOT(IWORK),1))

          RETURN
          END

C ASSY - Transport event.

          SUBROUTINE ASTRAN
```

```
    $INCLUDE COM.ICL

          ID = IPCURE ()
          IWORK = INT(RAT(ID,7))
          CALL ADDRAT(IPCURE(),6,1.0)
          TYPE=RAT(IPCURE(),1)
          OPER=RAT(IPCURE(),6)
          WRKSTN=RPV(ISYSOP(INT(TYPE),INT(OPER)),1)
          CALL SETRAT(IPCURE(),7,WRKSTN)
          II=INT(WRKSTN)

          IF(II.EQ.99)THEN
                  IPOS = LOCAT(ID,IASYOT(IWORK))
                  CALL ADD(ID,IOUT(2),0)
                  CALL REMOVE(IASYOT(IWORK),IPOS)
          ELSE
                  IPOS = LOCAT(ID,IASYOT(IWORK))
                  CALL ADD(ID,IASYIN(II),0)
                  CALL REMOVE(IASYOT(IWORK),IPOS)
          ENDIF

          RETURN
          END

C determine setter world.

          SUBROUTINE SETWLD

    $INCLUDE COM.ICL

          IF(IWORK.LE.3)THEN
                  JSET = 1
          ELSEIF(IWORK.LE.6)THEN
                  JSET = 4
          ELSE
                  JSET = IWORK
          ENDIF

          RETURN
          END

C deternine operator world.

          SUBROUTINE OPTWLD

    $INCLUDE COM.ICL
          IF(IWORK.LE.3)THEN
                  JOPT = 1
          ELSEIF(IWORK.LE.6)THEN
                  JOPT = 4
          ELSE
                  JOPT = IWORK
          ENDIF

          RETURN
          END

C Reset graphics.

          SUBROUTINE RESET

    $INCLUDE COM.ICL

          IF(IWORK.EQ.1)THEN
```

```
                CALL DIPBX
        ELSEIF(IWORK.EQ.2)THEN
                CALL AXLBX
        ELSEIF(IWORK.EQ.3)THEN
                CALL RADBX
        ELSEIF(IWORK.EQ.4)THEN
                CALL MSKBX
        ELSEIF(IWORK.EQ.5)THEN
                CALL SAWCC
        ELSEIF(IWORK.EQ.6)THEN
                CALL SAWOCC
        ELSEIF(IWORK.EQ.7)THEN
                CALL PI1BX
        ELSEIF(IWORK.EQ.8)THEN
                CALL FLSOBX
        ELSEIF(IWORK.EQ.9)THEN
                CALL MANBX
        ELSEIF(IWORK.EQ.10)THEN
                CALL PI2BX
        ELSEIF(IWORK.EQ.11)THEN
                CALL ATEBX
        ENDIF

        RETURN
        END

C Run Time interactions.

        SUBROUTINE COMAND

        COMMON /FLAG/IFLAG
        CHARACTER*3 WORD

   25   IF(IFLAG.EQ.2)THEN
                WORD='BAT'
                IFLAG=1
                GO TO 26
        ELSEIF(IFLAG.EQ.1)THEN
                WORD='CON'
                IFLAG=0
                GO TO 26
        ELSE
                CALL  TKEYB(WORD,1,-1,0,'Enter next
     &                                       command...')
        ENDIF

   26   IF(WORD.EQ.'SET')THEN
                CALL SETERS
        ELSEIF(WORD.EQ.'OPE')THEN
                CALL OPERS
        ELSEIF(WORD.EQ.'MAC')THEN
                CALL MACHIN
        ELSEIF(WORD.EQ.'SET')THEN
                CALL STOSET
        ELSEIF(WORD.EQ.'INS')THEN
                CALL INSPCT
        ELSEIF(WORD.EQ.'EXP')THEN
                CALL EXPARM
        ELSEIF(WORD.EQ.'COM')THEN
                CALL COMS
        ELSE
                CALL OPTCOM(WORD,*25,*30)
                RETURN
        ENDIF
```

```
   30     CALL DISTXT(1,-1,0,'Command "'//WORD//'"
     &    not known')
          CALL KBCANL
          GO TO 25

          RETURN
          END

          SUBROUTINE USECOM(WORD,*,*)

          CHARACTER*3 WORD
          RETURN 2
          END

C Switch comms on/off

          SUBROUTINE COMS

     $INCLUDE COM.ICL

          IF(IBABEL.EQ.0)THEN
                  CALL  IKEYB(INUM,1,-1,0,'Comms  are
     &    OFF: 1=ON, 0=OFF')
                  IF(INUM.EQ.1)THEN
                          IBABEL=1
                          COMMD='COMMS ARE ON'
                          CALL COMPRT(COMMD)
                          CALL    DISTXT(1,-1,0,'Comms
     &                     are ON.')
                  ENDIF
          ELSE
                  CALL  IKEYB(INUM,1,-1,0,'Comms  are
     &                      ON: 1=ON, 0=OFF')
                  IF(INUM.EQ.0)THEN
                          IBABEL=0
                          COMMD='COMMS ARE OFF'
                          CALL COMPRT(COMMD)
                          CALL    DISTXT(1,-1,0,'Comms
     &                                     are OFF.')
                  ENDIF
          ENDIF

          RETURN
          END

C Save model status.

          SUBROUTINE SAVER
     $INCLUDE COM.ICL
          IDAT(1)=IPER
          IDAT(2)=IDAY
          CALL SAVEBK(IDAT,8)
          RETURN
          END

C Restore model status.

          SUBROUTINE RESTR
     $INCLUDE COM.ICL
          CALL RESTBK(IDAT,8)
          IPER=IDAT(1)
          IDAY=IDAT(2)
          RETURN
```

```
      END

C Set initial stock levels.

      SUBROUTINE STOSET

$INCLUDE COM.ICL

      REAL LEVEL
      CALL  RKEYB(BSTK,1,-1,0,'What shall I set stock
     &      levels to ? ')

      DO 10 J = 1,255
            CALL SRPV(IBUFST(J),1,BSTK)
            LEVEL = BFSK
            CALL ABSROB(SLEV(J),LEVEL)
   10 CONTINUE

      RETURN
      END

C Set number of setters.

      SUBROUTINE SETERS

$INCLUDE COM.ICL

   10  CALL DISTXT(1,-1,0,'Setter world  defaults
     & are....')

      CALL DISTXT(1,-1,0,'IWDSET(1)
     &  ='//CFI(IAT(IWDSET(1),1),2)//
     & 'IWDSET(4) ='//CFI(IAT(IWDSET(4),1),2)//
     & ' IWDSET(10) ='//CFI(IAT(IWDSET(10),1),2))

      CALL  IKEYB(INUM,1,-1,0,'Which  do you wish  to
     &     change 1,4,10  or 0 (quit) ')

      IF(INUM.EQ.1.OR.INUM.EQ.4.OR.INUM.EQ.10)THEN

      CALL IKEYB(II,1,-1,0,'Enter number of Setters')

      IF(II.LT.1)THEN
      GO TO 10
      ELSE
      CALL SETIAT(IWDSET(INUM),1,II)
      CALL DISTXT(1,-1,0,'Setters updated ')
      GO TO 10
      ENDIF

      ENDIF

      RETURN
      END

C Set number of operators.

      SUBROUTINE OPERS

$INCLUDE COM.ICL

   10 CALL DISTXT(1,-1,0,'Operator world defaults
     &                                  are....')
      CAL TXLSTXT(1,-1,0,' IWDOPT(1) =
```

```
     &                    '//CFI(IAT(IWDOPT(1),1),2)//
     &        'IWDOPT(4) = '//CFI(IAT(IWDOPT(4),1),2)//
     &        'IWDOPT(7) = '//CFI(IAT(IWDOPT(7),1),2)//
     &        'IWDOPT(8) = '//CFI(IAT(IWDOPT(8),1),2) )

          CALL DISTXT(1,-1,0,' IWDOPT(9) =
     &                    '//CFI(IAT(IWDOPT(9),1),2)//
     &      'IWDOPT(10) = '//CFI(IAT(IWDOPT(10),1),2)//
     &      'IWDOPT(11) = '//CFI(IAT(IWDOPT(11),1),2) )

          CALL  IKEYB(INUM,1,-1,0,'Which do you  wish
     &          to change 1,4,7,8,9,10,11 or 0 (quit) ')

          IF(INUM.EQ.1.OR.INUM.EQ.4.OR.INUM.EQ.7
     &                  .OR.INUM.EQ.8.OR.INUM.EQ.9
     &                  .OR.INUM.EQ.10.OR.INUM.EQ.11)THEN

          CALL IKEYB(II,1,-1,0,'Enter operators ')

          IF(II.LT.1)THEN
          GO TO 10
          ELSE
          CALL SETIAT(IWDOPT(INUM),1,II)
          CALL DISTXT(1,-1,0,'Operators updated ')
          GO TO 10
          ENDIF

          ENDIF

          RETURN
          END

C Set number of machines.

          SUBROUTINE MACHIN

$INCLUDE COM.ICL

   10     CALL  DISTXT(1,-1,0,'M/C`s default  to  maximum
     &                                 shown on screen')
          CALL  IKEYB(IWORK,1,-1,0,'Which W/C do  you
     &                wish to change 1 to 11 or 0 (quit)')

          IF(IWORK.GT.0.AND.IWORK.LE.11.)THEN
          IMAX = IAT(IWLDMQ(IWORK),1)
          K = ISIZOF(IWLDMQ(IWORK))
          CALL  IKEYB(II,1,-1,0,'Enter number of machines
     &                                   0 = quit')

          IF(II.EQ.0.OR.II.GT.IMAX)THEN
          GO TO 40
          ELSEIF(II.GT.K)THEN
          KK = II - K

          DO 20 JJ = 1,KK

          CALL MAKEET(IMACH(IWORK,JJ),'MACH ',0,0)
          CALL ADD(IMACH(IWORK,JJ),IWLDMQ(IWORK),0)
          CALL SIPV(NMAC(1),IWORK,
     &         SIPV(NMAC(1),IWORK) + 1))

   20  CONTINUE

       CALL DISTXT(1,-1,0,'machines updated')
```

```
      GO TO 10

        ELSEIF(II.LT.K)THEN
        KK = K - II
        DO 30 JJ = 1,KK
        IDIS=IAT(MEMBER(IWL DMQ(IWORK),1),5)
        CALL SETCOL(IDIS,'KK')
        CALL RESET
        CALL REMOVE(IWLDMQ(IWORK),1)
        CALL SIPV(NMAC(1),IWORK,
     &       (IPV(NMAC(1),IWORK) - 1))

   30   CONTINUE
        CALL DISTXT(1,-1,0,'machines updated')
        GO TO 10
        ENDIF
        ENDIF

   40   RETURN
        END

C  Communication routines and graphics held in the following
C  include files.

     $INCLUDE COMMS.ICL
     $INCLUDE GRAPH.ICL

C Database Initialization and Loading.

C Part number translator.

        SUBROUTINE PRTNUM

     $INCLUDE COM.ICL

        OPEN(4,FILE='TRANSLT.DAT',STATUS='OLD',ERR=85)

   10   READ(4,15,END=100,ERR=90) J,TMSNUM
   15   FORMAT(I5,A20)

        CALL MAKEPT(NCNVRT(J),'T'//CFI(J,3),'T',20)
        CALL STPV(NCNVRT(J),1,TMSNUM)

        IF(J.EQ.255)THEN
                GO TO 100
        ELSE
                GO TO 10
        ENDIF

   85   CALL DISTXT(1,-1,0,'Cannot open TRANSLT.DAT
     &                               ')
        GO TO 999
   90   CALL DISTXT(1,-1,0,'ERROR reading
     &                        TRANSLT.DAT')
  100   CLOSE(4)
  999   RETURN
        END

C Julian - working day translator database.

        SUBROUTINE CALDAT

     $INCLUDE COM.ICL
```

```
      OPEN(4,FILE='CALEN87.DAT',STATUS='OLD',ERR=600)
 5    READ(4,7,END=610,ERR =595) JJ,II
 7    FORMAT(I3,I4)

      CALL SIPV(ICAL87,JJ,II)
      GO TO 5

 595 CALL DISTXT(1,-1,0,'ERROR reading CALEN87.DAT')
      GO TO 610
 600  CALL DISTXT(1,-1,0,'Cannot open CALEN87.DAT')
 610  CLOSE(4)

      RETURN
      END

C Experemental parameters.

      SUBROUTINE EXPARM

$INCLUDE COM.ICL
      REAL VALUE(6)
      CHARACTER*10 EXPER
      NNN = 10
   17 CALL SIPV(NAME,1,NNN)
      EXPER = 'EX'//CFI(NNN,2)
      OPEN(4,FILE=EXPER,STATUS='OLD',ERR=26)
      READ(4,20,END=25)VALUE(1),VALUE(2),VALUE(3),
&     VALUE(4),VALUE(5),VALUE(6),VALUE(7)
   20 FORMAT(7F9.3)
   25 CLOSE(4)
      GO TO 27
   26 CALL DISTXT(1,-1,0,'cannot open '//EXPER)
      GO TO 99
   27 CALL SRPV(IPLAN,5,(RPV(IPLAN,5)*VALUE(1)))
      CALL SRPV(ITRANS,1,VALUE(2))
      CALL SRPV(ITRANS,2,VALUE(3))
      CALL SRPV(ITRBAT,1,REAL(VALUE(4)))
      CALL SRPV(ITRBAT,2,REAL(VALUE(5)))

      IPRIOR = INT(VALUE(6))
      IDUR = 5
      ILEN = INT(VALUE(7))
      PER =REAL(IDUR)
      RLN =REAL(ILEN - 1)
      CALL SRPV(IPLAN,1,PER)
      CALL SRPV(IPLAN,2,RLN)
      CALL SCHEDL('ENDED',52800.0,IMACH(20,1))
      CALL SCHEDL('ENDED',64800.0,IMACH(20,1))
      CALL SCHEDL('ENDED',76800.0,IMACH(20,1))
      CALL SCHEDL('ENDED',88800.0,IMACH(20,1))
      CALL SCHEDL('ENDED',
&             REAL(IDUR*ILEN*480),IMACH(20,1))

      IST = 7
      CALL SRPV(IPLAN,3,REAL(IST*PER*480))
      NUM = 1500
      RLOW  = REAL(IST*IDUR*480)
      RHIGH = REAL(ILEN*IDUR*480)
      CREM = (RHIGH - RLOW) / NUM
      CALL SRPV(IPLAN,4,CREM)
      CALL SCHEDL('RECORD',RLOW,IMACH(20,1))
      RUM = 100.0
      CALL SRPV(ISAMPL,1,(RUM/100))
```

```
        RUM = 100.0
        CALL SRPV(ISAMPL,2,(RUM/100))

 99     RETURN
        END
```

C Load PCB database.

```
        SUBROUTINE FMSDAT

$INCLUDE COM.ICL

        REAL VALUE(3)

        OPEN(4,FILE='PCB.DAT',STATUS='OLD',ERR=85)

  5     READ(4,7,END=100,ERR=90) I

  7     FORMAT(I3)

        READ(4,7,END=100,ERR=90) IOPS
        CALL SETIAT (ITOPS,I,IOPS)

        CALL   TRACE('Loading   PCB.DAT;   PCB   No   =
     &                '//CFI(I,3))

        DO 40 J = 1,IOPS

        CALL MAKEPT(IPBDAT(I,J),'P'//CFI(I,3),'R',3)
        READ(4,15,ERR=90) VALUE(1),VALUE(2),VALUE(3)
 15     FORMAT(F9.3,F9.4,F9.4)
        VALUE(2) = VALUE(2)
        VALUE(3) = VALUE(3)

        DO 20 K = 1,3

        CALL SRPV(IPBDAT(I,J),K,VALUE(K))
 20     CONTINUE
 40     CONTINUE

        GO TO 5
 85     CALL DISTXT(1,-1,0,'Cannot open PCB.DAT ')
 90     CALL DISTXT(1,-1,0,'ERROR reading PCB.DAT')
100     CLOSE(4)

        RETURN
        END
```

C Load assembly operation and pick list databases.

```
        SUBROUTINE ASYDAT

$INCLUDE COM.ICL

  7     FORMAT(I3)
        OPEN(4,FILE='SYSPIC.DAT',STATUS='OLD',ERR=295)
                                   ) L

110     READ(4,7,END=310,ERR =300
        READ(4,120,ERR=300) VAL1,VAL2
        READ(4,120,ERR=300) VAL3,VAL4
        READ(4,120,ERR=300) VAL5,VAL6
120     FORMAT(2F9.4)

        DO 130 J = 1,3
```

```
      CALL MAKEPT(ISYDAT(L,J),'S'//CFI(L,2),'R',2)

130   CONTINUE

      CALL SRPV(ISYDAT(L,1),1,VAL1)
      CALL SRPV(ISYDAT(L,1),2,VAL2)
      CALL SRPV(ISYDAT(L,2),1,VAL3)
      CALL SRPV(ISYDAT(L,2),2,VAL4)
      CALL SRPV(ISYDAT(L,3),1,VAL5)
      CALL SRPV(ISYDAT(L,3),2,VAL6)

      K = (INT(VAL1)+3)

      DO 150 J = 4,K

      READ(4,140,END = 310,ERR=300) VAL7,VAL8
140   FORMAT(2F9.4)

      CALL MAKEPT(ISYDAT(L,J),'S'//CFI(L,2),'R',2)
      CALL SRPV(ISYDAT(L,J),1,VAL7)
      CALL SRPV(ISYDAT(L,J),2,VAL8)

150   CONTINUE
      GO TO 110

295   CALL DISTXT(1,-1,0,'Cannot open SYSPIC.DAT')
300   CALL DISTXT(1,-1,0,'ERROR reading SYSPIC.DAT')
310   CLOSE(4)

      OPEN(4,FILE='SYS.DAT',STATUS='OLD',ERR=600)
350   READ(4,360,END=610,ERR =600) L,J
360   FORMAT(2I4)


      DO 390 II = 1,J

      READ(4,370,ERR=595) VAL1,VAL2
370   FORMAT(2F9.4)

      CALL MAKEPT(ISYSOP(L,II),'OL'//CFI(L,2),'R',2)
      CALL SRPV(ISYSOP(L,II),1,VAL1)
      CALL SRPV(ISYSOP(L,II),2,VAL2)

390   CONTINUE

      GO TO 350

595   CALL DISTXT(1,-1,0,'ERROR reading SYSOPS.DAT')
      GO TO 610
600   CALL DISTXT(1,-1,0,'Cannot open SYSOPS.DAT')
610   CLOSE(4)

      RETURN
      END

      SUBROUTINE FKEY(NFK)
      RETURN
      END


      FUNCTION IO0104(NAME)
      CHARACTER NAME *(*)
      IF (NAME.EQ.'LST:')THEN
```

```
              I00104 = 2
              ELSE
              I00104 = 0
              ENDIF
              RETURN
              END
```

Listing of PCB facility initialization FMSINIT.ICL:

```
         SUBROUTINE FMSINT

$INCLUDE COM.ICL

    CALL LSTMAK
    CALL WC01
    CALL WC02
    CALL WC03
    CALL WC04
    CALL WC05
    CALL WC06
    CALL WC07
    CALL WC08
    CALL WC09
    CALL WC10
    CALL WC11
    CALL MAKELS(IBATWD,5,700,'BATW',  0,0,0,0,0,0, 0,0,0)

    DO 16 I = 1,700
    CALL MAKEET(IBAT,'BACH',0,10)
    CALL ADD (IBAT,IBATWD,0)
16  CONTINUE
    RETURN
    END

    SUBROUTINE LSTMAK

$INCLUDE COM.ICL

CALL MAKELS(IBATIN(1), 5,400,'BI1 ', 8 , 4 ,2, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(2), 5,450,'BI2 ', 16, 4, 2, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(3), 5,60,'BI3 ', 20, 4, 2, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(4), 5,100,'BI4 ',116,16, 3, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(5), 5,100,'BI5 ', 36, 1, 4, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(6), 5,50,'BI6 ', 45, 7, 4, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(7), 5,50,'BI7 ', 49, 6, 1, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(8), 5,50,'BI8 ', 54, 1, 2, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(9), 5,100,'BI9 ', 72, 2, 7, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(10),5,100,'BI10', 58, 7, 1, 3, 0,1,1,3,0)
CALL MAKELS(IBATIN(11),5,50,'BI11',102, 3, 3, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(1) ,5,100,'BO1 ',  9, 4, 4, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(2) ,5,100,'BO2 ', 17, 4, 4, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(3) ,5,50,'BO3 ', 21, 4, 4, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(4) ,5,50,'BO4 ', 31,16, 5, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(5) ,5,50,'BO5 ', 37, 1, 6, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(6) ,5,50,'BO6 ', 46, 7,10, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(7) ,5,50,'BO7 ', 50, 6, 3, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(8) ,5,50,'BO8 ', 55,20, 2, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(9) ,5,50,'BO9 ', 87,22, 4, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(10),5,60,'BO10', 59, 7, 3, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(11),5,30,'BO11',103, 3,10, 3, 0,1,1,3,0)
CALL MAKELS(IBAOUT(20),20 ,900,'BI20',  5,3,6,0,1,1, 9,3,0)
CALL MAKELS(IORDER,11,11,'ORDR',0,0,0,0,0,0,0,0,0)

     DO 15 JJ = 1,11
```

```
      CALL MAKEET(IJJJ,'WORK',0,1)
      CALL SETIAT(IJJJ,1,JJ)
      CALL ADD (IJJJ,IORDER,
15    CONTINUE
      CALL MAKELS(IOUT(1),10,150,'OUT1',13,19,3,-3,0,1,8,3,0)

      RETURN
      END

      SUBROUTINE WC01

$INCLUDE COM.ICL
     CALL MAKELS(IBASET(1,1), 1,1,'BS1 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IBAPRO(1,1), 1,1,'BP1 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IWLDMQ(1),1,1,'MW1 ',0,0,0,0,0,0,0,0,1)
     CALL SETIAT(IWLDMQ(1),1,1)
     CALL MAKELS(IMCSET(1,1), 1, 1,'MS1 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IMCPRO(1,1), 1, 1,'MP1 ',0,0,0,0,0,0,0,0,0)
     CALL MAKEET(IMACH(1,1),'MC1 ',0,5)
     CALL SETIAT(IMACH(1,1),1,1)
     CALL SETIAT(IMACH(1,1),2,1)
     CALL SETIAT(IMACH(1,1),5,6)
     CALL ADD(IMACH(1,1),IWLDMQ(1),0)
     CALL MAKEET(IWDSET(1),'SW1 ',0,2)
     CALL SETIAT(IWDSET(1),1,3)
     CALL MAKEET(IWDOPT(1),'OW1 ',0,2)
     CALL SETIAT(IWDOPT(1),1,3)

     RETURN
     END


     SUBROUTINE WC02

$INCLUDE COM.ICL

     CALL MAKELS(IBASET(2,1), 1,1,'BS2 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IBAPRO(2,1), 1,1,'BP2 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IWLDMQ(2),1,1,'MW2 ',0,0,0,0,0,0,0,0,1)
     CALL SETIAT(IWLDMQ(2),1,1)
     CALL MAKELS(IMCSET(2,1), 1, 1,'MS2 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IMCPRO(2,1), 1, 1,'MP2 ',0,0,0,0,0,0,0,0,0)
     CALL MAKEET(IMACH(2,1),'MC2 ',0,5)
     CALL SETIAT(IMACH(2,1),1,2)
     CALL SETIAT(IMACH(2,1),2,1)
     CALL SETIAT(IMACH(2,1),5,14)
     CALL ADD(IMACH(2,1),IWLDMQ(2),0)

     RETURN
     END

     SUBROUTINE WC03

$INCLUDE COM.ICL

     CALL MAKELS(IBASET(3,1), 1,1,'BS3 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IBAPRO(3,1), 1,1,'BP3 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IWLDMQ(3),1,1,'MW3 ',0,0,0,0,0,0,0,0,1)
     CALL SETIAT(IWLDMQ(3),1,1)
     CALL MAKELS(IMCSET(3,1), 1, 1,'MS3 ',0,0,0,0,0,0,0,0,0)
     CALL MAKELS(IMCPRO(3,1), 1, 1,'MP3 ',0,0,0,0,0,0,0,0,0)
     CALL MAKEET(IMACH(3,1),'MC3 ',0,5)
     CALL SETIAT(IMACH(3,1),1,3)
     CALL SETIAT(IMACH(3,1),2,1)
```

```
      CALL SETIAT(IMACH(3,1),5,18)
      CALL ADD(IMACH(3,1),IWLDMQ(3),0)

      RETURN
      END

      SUBROUTINE WC04
$INCLUDE COM.ICL

      DO 10 I = 1,9

   CALL MAKELS(IBASET(4,I), 1,1,'BS4'//CFI(I,1),0,0,0,0,0,0,0,0,0)
   CALL MAKELS(IBAPRO(4,I), 1,1,'BP4'//CFI(I,1),0,0,0,0,0,0,0,0,0)
   CALL MAKELS(IMCSET(4,I), 1,1,'MS4'//CFI(I,1),0,0,0,0,0,0,0,0,0)
   CALL MAKELS(IMCPRO(4,I), 1,1,'MP4'//CFI(I,1),0,0,0,0,0,0,0,0,0)

 10   CONTINUE
      CALL MAKELS(IWLDMQ(4),10,10,'MW4',0,0,0,0,0,0,0,0,1)
      CALL SETIAT(IWLDMQ(4),1,9)
      DO 20 J = 1,9
      CALL MAKEET(IMACH(4,J),'MC4'//CFI(J,1),0,5)
      CALL SETIAT(IMACH(4,J),1,4)
      CALL SETIAT(IMACH(4,J),2,J)
      CALL SETIAT(IMACH(4,J),5,21+J)
      CALL ADD(IMACH(4,J),IWLDMQ(4),0)
 20   CONTINUE

      CALL MAKEET(IWDSET(4),'SW4 ',0,2)
      CALL SETIAT(IWDSET(4),1,3)
      CALL MAKEET(IWDOPT(4),'OW4 ',0,2)
      CALL SETIAT(IWDOPT(4),1,12)

      RETURN
      END

      SUBROUTINE WC05

&INCLUDE COM.ICL
      CALL MAKELS(IWLDMQ(5),3,3,'MW5'1)
      CALL SETIAT(IWLDMQ(5),1,3)

      DO 10 J = 1,3
      CALL MAKELS(IBASET(5,J),1,1,'BS5'//CFI(J,1))
      CALL MAKELS(IBAPRO(5,J),1,1,'BP5'//CFI(J,1))
      CALL MAKELS(IMCSET(5,J),1, 1,'MS5'//CFI(J,1))
      CALL MAKELS(IMCPRO(5,J),1, 1,'MP5'//CFI(J,1))
      CALL MAKEET(IMACH(5,J),'MC5'//CFI(J,1),0,5)
      CALL SETIAT(IMACH(5,J),1,5)
      CALL SETIAT(IMACH(5,J),2,J)
      CALL SETIAT(IMACH(5,J),5,(31+J))
      CALL ADD(IMACH(5,J),IWLDMQ(5),0)

 10   CONTINUE

      RETURN
      END

      SUBROUTINE WC06

$INCLUDE COM.ICL

      CALL MAKELS(IWLDMQ(6),6,6,'MW6',0,0,0,0,0,0,0,0,1)
      CALL SETIAT(IWLDMQ(6),1,6)
      DO 10 J = 1,6
```

```
 CALL MAKELS(IBASET(6,J), 1,1,'BS6'//CFI(J,1),0,0,0,0,0,0,0,0,0)
 CALL MAKELS(IBAPRO(6,J), 1,1,'BP6'//CFI(J,1),0,0,0,0,0,0,0,0,0)
 CALL MAKELS(IMCSET(6,J), 1,1,'MS6'//CFI(J,1),0,0,0,0,0,0,0,0,0)
 CALL MAKELS(IMCPRO(6,J), 1,1,'MP6'//CFI(J,1),0,0,0,0,0,0,0,0,0)
 CALL MAKEET(IMACH(6,J),'MC6'//CFI(J,1),0,5)
 CALL SETIAT(IMACH(6,J),1,6)
 CALL SETIAT(IMACH(6,J),2,J)
 CALL SETIAT(IMACH(6,J),5,(37+J))
 CALL ADD(IMACH(6,J),IWLDMQ(6),0)

10    CONTINUE

      RETURN
      END

      SUBROUTINE WC07

$INCLUDE COM.ICL

      CALL MAKELS(IWLDMQ(7),2,2,'MW7 ',0,0,0,0,0,0,0,0,1)
      CALL SETIAT(IWLDMQ(7),1,2)
      DO 10 J = 1,2

CALL MAKELS(IBASET(7,J),1,1,'BS7'//CFI(J,1),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IBAPRO(7,J),1,1,'BP7'//CFI(J,1),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IMCSET(7,J),1,1,'MS7'//CFI(J,1),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IMCPRO(7,J),1,1,'MP7'//CFI(J,1),0,0,0,0,0,0,0,0,0)
CALL MAKEET(IMACH(7,J),'MC7'//CFI(J,1),0,5)
CALL SETIAT(IMACH(7,J),1,7)
CALL SETIAT(IMACH(7,J),2,J)
CALL ADD(IMACH(7,J),IWLDMQ(7),0)

 10   CONTINUE

      CALL SETIAT(IMACH(7,1),5,47)
      CALL SETIAT(IMACH(7,2),5,11)
      CALL MAKEET(IWDSET(7),'SW7 ',0,2)
      CALL SETIAT(IWDSET(7),1,2)
      CALL MAKEET(IWDOPT(7),'OW7 ',0,2)
      CALL SETIAT(IWDOPT(7),1,2)

      RETURN
      END

      SUBROUTINE WC08

$INCLUDE COM.ICL

      CALL MAKELS(IBASET(8,1), 1,1,'BS81',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IBAPRO(8,1), 1,1,'BP81',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IBASET(8,2), 1,1,'BS82',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IBAPRO(8,2), 1,1,'BP82',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IWLDMQ(8),2,2,'MW8',0,0,0,0,0,0,0,0,1)
      CALL SETIAT(IWLDMQ(8),1,2)
      CALL MAKELS(IMCSET(8,1), 1, 1,'MS81',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IMCPRO(8,1), 1, 1,'MP81',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IMCSET(8,2), 1, 1,'MS82',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IMCPRO(8,2), 1, 1,'MP82',0,0,0,0,0,0,0,0,0)
      CALL MAKEET(IMACH(8,1),'MC81',0,5)
      CALL SETIAT(IMACH(8,1),1,8)
      CALL SETIAT(IMACH(8,1),2,1)
      CALL SETIAT(IMACH(8,1),5,51)
      CALL ADD(IMACH(8,1),IWLDMQ(8),0)
```

```
      CALL MAKEET(IMACH(8,2),'MC82',0,5)
      CALL SETIAT(IMACH(8,2),1,8)
      CALL SETIAT(IMACH(8,2),2,2)
      CALL SETIAT(IMACH(8,2),5,52)
      CALL ADD(IMACH(8,2),IWLDMQ(8),0)
      CALL MAKEET(IWDSET(8),'SW8 ',0,2)
      CALL SETIAT(IWDSET(8),1,2)
      CALL MAKEET(IWDOPT(8),'OW8 ',0,2)
      CALL SETIAT(IWDOPT(8),1,5)

      RETURN
      END

      SUBROUTINE WC09

$INCLUDE COM.ICL
      DO 10 J = 1,20
CALL MAKELS(IBASET(9,J), 1,1,'BS'//CFI(J,2),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IBAPRO(9,J), 1,1,'BP'//CFI(J,2),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IMCSET(9,J), 1,1,'MS'//CFI(J,2),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IMCPRO(9,J), 1,1,'MP'//CFI(J,2),0,0,0,0,0,0,0,0,0)
10    CONTINUE

     CALL MAKELS(IWLDMQ(9),20,20,'MW 9',0,0,0,0,0,0,0,0,1)
     CALL SETIAT(IWLDMQ(9),1,20)
     DO 30 J = 1,10
     CALL MAKEET(IMACH(9,J),'M9'//CFI(J,2),0,5)
     CALL SETIAT(IMACH(9,J),1,9)
     CALL SETIAT(IMACH(9,J),2,J)
     CALL SETIAT(IMACH(9,J),5,(59+J))
     CALL ADD(IMACH(9,J),IWLDMQ(9),0)

 30   CONTINUE

      DO 40 J = 11,20
      CALL MAKEET(IMACH(9,J),'M9'//CFI(J,2),0,5)
      CALL SETIAT(IMACH(9,J),1,9)
      CALL SETIAT(IMACH(9,J),2,J)
      CALL SETIAT(IMACH(9,J),5,(63+J))
      CALL ADD(IMACH(9,J),IWLDMQ(9),0)

 40   CONTINUE

      CALL MAKEET(IWDSET(9),'SW9',0,2)
      CALL SETIAT(IWDSET(9),1,3)
      CALL MAKEET(IWDOPT(9),'OW9',0,2)
      CALL SETIAT(IWDOPT(9),1,20)

      RETURN
      END

      SUBROUTINE WC10

$INCLUDE COM.ICL

      CALL MAKELS(IBASET(10,1), 1,1,'BSA1',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IBAPRO(10,1), 1,1,'BPA1',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IBASET(10,2), 1,1,'BSA2',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IBAPRO(10,2), 1,1,'BPA2',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IBASET(10,3), 1,1,'BSA3',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IBAPRO(10,3), 1,1,'BPA3',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IWLDMQ(10),3,3,'MWB ',0,0,0,0,0,0,0,0,1)
      CALL SETIAT(IWLDMQ(10),1,3)
      CALL MAKELS(IMCSET(10,1), 1, 1,'MSA1',0,0,0,0,0,0,0,0,0)
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      CALL MAKELS(IMCPRO(10,1), 1, 1,'MPA1',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IMCSET(10,2), 1, 1,'MSA2',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IMCPRO(10,2), 1, 1,'MPA2',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IMCSET(10,3), 1, 1,'MSA3',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IMCPRO(10,3), 1, 1,'MPA3',0,0,0,0,0,0,0,0,0)
      CALL MAKEET(IMACH(10,1),'MCA1',0,5)
      CALL SETIAT(IMACH(10,1),1,10)
      CALL SETIAT(IMACH(10,1),2,1)
      CALL SETIAT(IMACH(10,1),5,56)
      CALL ADD(IMACH(10,1),IWLDMQ(10),0)
      CALL MAKEET(IMACH(10,2),'MCA2',0,5)
      CALL SETIAT(IMACH(10,2),1,10)
      CALL SETIAT(IMACH(10,2),2,2)
      CALL SETIAT(IMACH(10,2),5,88)
      CALL ADD(IMACH(10,2),IWLDMQ(10),0)
      CALL MAKEET(IMACH(10,3),'MCA3',0,5)
      CALL SETIAT(IMACH(10,3),1,10)
      CALL SETIAT(IMACH(10,3),2,3)
      CALL SETIAT(IMACH(10,3),5,89)
      CALL ADD(IMACH(10,3),IWLDMQ(10),0)
      CALL MAKEET(IWDSET(10),'SW10',0,2)
      CALL SETIAT(IWDSET(10),1,3)
      CALL MAKEET(IWDOPT(10),'OW10',0,2)
      CALL SETIAT(IWDOPT(10),1,3)
      RETURN
      END


      SUBROUTINE WC11

$INCLUDE COM.ICL
      CALL MAKELS(IWLDMQ(11),8,8,'MW E',0,0,0,0,0,0,0,0,1)
      CALL SETIAT(IWLDMQ(11),1,8)

      DO 10 J = 1,8
CALL MAKELS(IBASET(11,J),1,1,'BSB'//CFI(J,1),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IBAPRO(11,J),1,1,'BPB'//CFI(J,1),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IMCSET(11,J),1,1,'MSB'//CFI(J,1),0,0,0,0,0,0,0,0,0)
CALL MAKELS(IMCPRO(11,J),1,1,'MPB'//CFI(J,1),0,0,0,0,0,0,0,0,0)
CALL MAKEET(IMACH(11,J),'MCB'//CFI(J,1),0,5)
CALL SETIAT(IMACH(11,J),1,11)
CALL SETIAT(IMACH(11,J),2,J)
CALL SETIAT(IMACH(11,J),5,(91+J))
CALL ADD(IMACH(11,J),IWLDMQ(11),0)

10    CONTINUE
      CALL MAKEET(IWDSET(11),'SW11',0,2)
      CALL SETIAT(IWDSET(11),1,8)
      CALL MAKEET(IWDOPT(11),'OW11',0,2)
      CALL SETIAT(IWDOPT(11),1,8)

      RETURN
      END


      SUBROUTINE SYSLST

$INCLUDE COM.ICL

          ISLIST(1) = IASPLN
          ISLIST(2) = IASYIN(15)
          ISLIST(3) = IASYIN(16)
          ISLIST(4) = IASYIN(17)
          ISLIST(5) = IASYIN(18)
```

```
      ISLIST(6) = IASYIN(19)
      ISLIST(7) = IASYIN(20)
      ISLIST(8) = IASYIN(21)
      ISLIST(9) = IASYIN(22)
      ISLIST(10) = IASYOT(15)
      ISLIST(11) = IASYOT(16)
      ISLIST(12) = IASYOT(17)
      ISLIST(13) = IASYOT(18)
      ISLIST(14) = IASYOT(19)
      ISLIST(15) = IASYOT(20)
      ISLIST(16) = IASYOT(21)
      ISLIST(17) = IASYOT(22)
      ISLIST(18) = IWC(15,1)
      ISLIST(19) = IWC(16,1)
      ISLIST(20) = IWC(17,1)
      ISLIST(21) = IWC(18,1)
      ISLIST(22) = IWC(19,1)
      ISLIST(23) = IWC(20,1)
      ISLIST(24) = IWC(21,1)
      ISLIST(25) = IWC(22,1)
      ISLIST(26) = IOUT(2)

      RETURN
      END

      SUBROUTINE PCBLST

$INCLUDE COM.ICL

      IPLIST(1) = IBAOUT(20)
      IPLIST(2) = IBATIN(1)
      IPLIST(3) = IBATIN(2)
      IPLIST(4) = IBATIN(3)
      IPLIST(5) = IBATIN(4)
      IPLIST(6) = IBATIN(5)
      IPLIST(7) = IBATIN(6)
      IPLIST(8) = IBATIN(7)
      IPLIST(9) = IBATIN(8)
      IPLIST(10) = IBATIN(9)
      IPLIST(11) = IBATIN(10)
      IPLIST(12) = IBATIN(11)
      IPLIST(13) = IBAOUT(1)
      IPLIST(14) = IBAOUT(2)
      IPLIST(15) = IBAOUT(3)
      IPLIST(16) = IBAOUT(4)
      IPLIST(17) = IBAOUT(5)
      IPLIST(18) = IBAOUT(6)
      IPLIST(19) = IBAOUT(7)
      IPLIST(20) = IBAOUT(8)
      IPLIST(21) = IBAOUT(9)
      IPLIST(22) = IBAOUT(10)
      IPLIST(23) = IBAOUT(11)
      IPLIST(24) = IBASET(1,1)
      IPLIST(25) = IBASET(2,1)
      IPLIST(26) = IBASET(3,1)
      IPLIST(27) = IBASET(4,1)
      IPLIST(28) = IBASET(4,2)
      IPLIST(29) = IBASET(4,3)
      IPLIST(30) = IBASET(4,4)
      IPLIST(31) = IBASET(4,5)
      IPLIST(32) = IBASET(4,6)
      IPLIST(33) = IBASET(4,7)
      IPLIST(34) = IBASET(4,8)
      IPLIST(35) = IBASET(4,9)
```

```
IPLIST(36) = IBASET(5,1)
IPLIST(37) = IBASET(5,2)
IPLIST(38) = IBASET(5,3)
IPLIST(39) = IBASET(6,1)
IPLIST(40) = IBASET(6,2)
IPLIST(41) = IBASET(6,3)
IPLIST(42) = IBASET(6,4)
IPLIST(43) = IBASET(6,5)
IPLIST(44) = IBASET(6,6)
IPLIST(45) = IBASET(7,1)
IPLIST(46) = IBASET(7,2)
IPLIST(47) = IBASET(8,1)
IPLIST(48) = IBASET(8,2)
IPLIST(49) = IBASET(9,1)
IPLIST(50) = IBASET(9,2)
IPLIST(51) = IBASET(9,3)
IPLIST(52) = IBASET(9,4)
IPLIST(53) = IBASET(9,5)
IPLIST(54) = IBASET(9,6)
IPLIST(55) = IBASET(9,7)
IPLIST(56) = IBASET(9,8)
IPLIST(57) = IBASET(9,9)
IPLIST(58) = IBASET(9,10)
IPLIST(59) = IBASET(9,11)
IPLIST(60) = IBASET(9,12)
IPLIST(61) = IBASET(9,13)
IPLIST(62) = IBASET(9,14)
IPLIST(63) = IBASET(9,15)
IPLIST(64) = IBASET(9,16)
IPLIST(65) = IBASET(9,17)
IPLIST(66) = IBASET(9,18)
IPLIST(67) = IBASET(9,19)
IPLIST(68) = IBASET(9,20)
IPLIST(69) = IBASET(10,1)
IPLIST(70) = IBASET(10,2)
IPLIST(71) = IBASET(10,3)
IPLIST(72) = IBASET(11,1)
IPLIST(73) = IBASET(11,2)
IPLIST(74) = IBASET(11,3)
IPLIST(75) = IBASET(11,4)
IPLIST(76) = IBASET(11,5)
IPLIST(77) = IBASET(11,6)
IPLIST(78) = IBASET(11,7)
IPLIST(79) = IBASET(11,8)
IPLIST(80) = IBAPRO(1,1)
IPLIST(81) = IBAPRO(2,1)
IPLIST(82) = IBAPRO(3,1)
IPLIST(83) = IBAPRO(4,1)
IPLIST(84) = IBAPRO(4,2)
IPLIST(85) = IBAPRO(4,3)
IPLIST(86) = IBAPRO(4,4)
IPLIST(87) = IBAPRO(4,5)
IPLIST(88) = IBAPRO(4,6)
IPLIST(89) = IBAPRO(4,7)
IPLIST(90) = IBAPRO(4,8)
IPLIST(91) = IBAPRO(4,9)
IPLIST(92) = IBAPRO(5,1)
IPLIST(93) = IBAPRO(5,2)
IPLIST(94) = IBAPRO(5,3)
IPLIST(95) = IBAPRO(6,1)
IPLIST(96) = IBAPRO(6,2)
IPLIST(97) = IBAPRO(6,3)
IPLIST(98) = IBAPRO(6,4)
IPLIST(99) = IBAPRO(6,5)
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      IPLIST(100) = IBAPRO(6,6)
      IPLIST(101) = IBAPRO(7,1)
      IPLIST(102) = IBAPRO(7,2)
      IPLIST(103) = IBAPRO(8,1)
      IPLIST(104) = IBAPRO(8,2)
      IPLIST(105) = IBAPRO(9,1)
      IPLIST(106) = IBAPRO(9,2)
      IPLIST(107) = IBAPRO(9,3)
      IPLIST(108) = IBAPRO(9,4)
      IPLIST(109) = IBAPRO(9,5)
      IPLIST(110) = IBAPRO(9,6)
      IPLIST(111) = IBAPRO(9,7)
      IPLIST(112) = IBAPRO(9,8)
      IPLIST(113) = IBAPRO(9,9)
      IPLIST(114) = IBAPRO(9,10)
      IPLIST(115) = IBAPRO(9,11)
      IPLIST(116) = IBAPRO(9,12)
      IPLIST(117) = IBAPRO(9,13)
      IPLIST(118) = IBAPRO(9,14)
      IPLIST(119) = IBAPRO(9,15)
      IPLIST(120) = IBAPRO(9,16)
      IPLIST(121) = IBAPRO(9,17)
      IPLIST(122) = IBAPRO(9,18)
      IPLIST(123) = IBAPRO(9,19)
      IPLIST(124) = IBAPRO(9,20)
      IPLIST(125) = IBAPRO(10,1)
      IPLIST(126) = IBAPRO(10,2)
      IPLIST(127) = IBAPRO(10,3)
      IPLIST(128) = IBAPRO(11,1)
      IPLIST(129) = IBAPRO(11,2)
      IPLIST(130) = IBAPRO(11,3)
      IPLIST(131) = IBAPRO(11,4)
      IPLIST(132) = IBAPRO(11,5)
      IPLIST(133) = IBAPRO(11,6)
      IPLIST(134) = IBAPRO(11,7)
      IPLIST(135) = IBAPRO(11,8)
      IPLIST(136) = IOUT(1)
      RETURN
      END
```

Listing of the Assembly model initialization, ASSEMBLY.ICL:

```
        SUBROUTINE ASYINT

  $INCLUDE COM.ICL

      CALL LISTIO
      CALL WC15
      CALL WC16
      CALL WC17
      CALL WC18
      CALL WC19
      CALL WC20
      CALL WC21
      CALL WC22

      RETURN
      END

      SUBROUTINE LISTIO

  $INCLUDE COM.ICL

      CALL MAKELS(IPRODW,5,700,'PROW',0,0,0,0,0,0,0,0,0)
```

```
      DO 10 I = 1,700
      CALL MAKEET(IASY,'PROD',0,10)
      CALL ADD (IASY,IPRODW,0)
 10   CONTINUE

CALL MAKELS(IASPLN,10,600,'APLN',110, 2, 2, 0, 1,1,9,4,1)
CALL MAKELS(IASYIN(15),3,500,'AI15',118, 8, 2,0,1,1,3,3,0)
CALL MAKELS(IASYIN(16),3,500,'AI16',118, 8,11,0,1,1,3,3,0)
CALL MAKELS(IASYIN(17),3,300,'AI17',118, 8,15,0,1,1,3,3,0)
CALL MAKELS(IASYIN(18),3,500,'AI18',118, 8,21,0,1,1,3,3,0)
CALL MAKELS(IASYIN(19),3,300,'AI19',118, 8,25,0,1,1,3,3,0)
CALL MAKELS(IASYIN(20),3,300,'AI20',118, 8,29,0,1,1,3,3,0)
CALL MAKELS(IASYIN(21),3,300,'AI21',118, 8,33,0,1,1,3,3,0)
CALL MAKELS(IASYIN(22),3,300,'AI22',118, 8,37,0,1,1,3,3,0)
CALL MAKELS(IASYOT(15),3,200,'AO15',119,33, 2,0,1,1,3,3,0)
CALL MAKELS(IASYOT(16),3,200,'AO16',119,33,11,0,1,1,3,3,0)
CALL MAKELS(IASYOT(17),3,100,'AO17',119,33,15,0,1,1,3,3,0)
CALL MAKELS(IASYOT(18),3,100,'AO18',119,33,21,0,1,1,3,3,0)
CALL MAKELS(IASYOT(19),3,100,'AO19',119,33,25,0,1,1,3,3,0)
CALL MAKELS(IASYOT(20),3,100,'AO20',119,33,29,0,1,1,3,3,0)
CALL MAKELS(IASYOT(21),3,100,'AO21',119,33,33,0,1,1,3,3,0)
CALL MAKELS(IASYOT(22),3,100,'AO22',119,33,37,0,1,1,3,3,0)
CALL MAKELS(IASORD,8,8,'AORD',0,0,0,0,0,0,0,0,0)

      DO 15 JJ = 15,22
      CALL MAKEET(IKKK,'ASWC',0,1)
      CALL SETIAT(IKKK,1,JJ)
      CALL ADD (IKKK,IASORD,0)
 15   CONTINUE
      CALL MAKELS(OCUPYD,10,190,'OCPD',0,0,0,0,0,0,0,0,0)
      CALL MAKELS(IOUT(2),10,150,'OUT2',123,37,1,0,1,1,20,3,0)

      RETURN
      END

      SUBROUTINE WC15

$INCLUDE COM.ICL
      DO 10 I = 1,4
      CALL
      MAKELS(IWC(15,I),20,20,'W15'//CFI(I,1)
&                            ,121,12,(2*I),1,0,1,20,1,0)
      DO  5 J = 1,20
      CALL MAKEET(IASMAC,'  ',0,0)
      CALL ADD (IASMAC,IWC(15,I),0)
 5    CONTINUE
 10   CONTINUE

      RETURN
      END

      SUBROUTINE WC16

$INCLUDE COM.ICL
 CALL MAKELS(IWC(16,1),20,20,'W16 ',121,12,11,1,0,1,20,1,0)
      DO  5 J = 1,20
      CALL MAKEET(IASMAC,'  ',0,0)
      CALL ADD (IASMAC,IWC(16,1),0)
 5    CONTINUE

      RETURN
      END
```

```
      SUBROUTINE WC17

$INCLUDE COM.ICL
 CALL MAKELS(IWC(17,1),20,20,'W17 ',121,12,15,1,0,1,20,1,0)
      DO  5 J = 1,20
      CALL MAKEET(IASMAC,'   ',0,0)
      CALL ADD (IASMAC,IWC(17,1),0)
 5    CONTINUE

      RETURN
      END

      SUBROUTINE WC18

$INCLUDE COM.ICL

   CALL MAKELS(IWC(18,1),20,20,'W18 ',122,12,21,1,0,1,20,1,0)
      DO  5 J = 1,20
      CALL MAKEET(IASMAC,'   ',0,0)
      CALL ADD (IASMAC,IWC(18,1),0)
 5    CONTINUE

      RETURN
      END


      SUBROUTINE WC19

$INCLUDE COM.ICL

CALL MAKELS(IWC(19,1),20,20,'W19 ',122,12,25,1,0,1,20,1,0)
      DO  5 J = 1,20
      CALL MAKEET(IASMAC,'   ',0,0)
      CALL ADD (IASMAC,IWC(19,1),0)
 5    CONTINUE

      RETURN
      END


      SUBROUTINE WC20

$INCLUDE COM.ICL

CALL MAKELS(IWC(20,1),20,20,'W20 ',122,12,29,1,0,1,20,1,0)
      DO  5 J = 1,20
      CALL MAKEET(IASMAC,'   ',0,0)
      CALL ADD (IASMAC,IWC(20,1),0)
 5    CONTINUE

      RETURN
      END


      SUBROUTINE WC21

$INCLUDE COM.ICL

CALL MAKELS(IWC(21,1),20,20,'W211',122,12,33,1,0,1,20,1,0)
      DO  5 J = 1,20
      CALL MAKEET(IASMAC,'   ',0,0)
      CALL ADD (IASMAC,IWC(21,1),0)
 5    CONTINUE
```

```
      RETURN
      END

      SUBROUTINE WC22

$INCLUDE COM.ICL

CALL MAKELS(IWC(22,1),20,20,'W22 ',122,12,37,1,0,1,20,1,0)
      DO  5 J = 1,20
      CALL MAKEET(IASMAC,'   ',0,0)
      CALL ADD (IASMAC,IWC(22,1),0)
 5    CONTINUE
      RETURN
      END
```

Full listing of picture initialization, PINIT.ICL

```
      SUBROUTINE FMSPIC

$INCLUDE COM.ICL

      CALL SETPIC (2,2)
      CALL SETWND (17,6,2,1,1,1,64,41)
      CALL SETCOL (2,'GKD??')

      CALL SETPIC (3,3)
      CALL SETPIC (4,3)
      CALL SETPIC (5,3)
      CALL SETWND (10,18,3,1,1,1, 1, 6)
      CALL SETCOL ( 3,'WK???')
      CALL SETCOL ( 4,'CK???')
      CALL SETCOL ( 5,'YK???')

      CALL SETPIC (6,4)
      CALL SETPIC (7,4)
      CALL SETPIC (8,4)
      CALL SETPIC (9,4)
      CALL SETWND (35,4,4,1,1,1,12,7)
      CALL SETCOL (6,'RR')
      CALL SETCOL (7,'WK')
      CALL SETCOL (8,'YK')
      CALL SETCOL (9,'MK')

      CALL SETPIC (14,6)
      CALL SETPIC (15,6)
      CALL SETPIC (16,6)
      CALL SETPIC (17,6)
      CALL SETWND (6,4,6,1,1,1,12,12)
      CALL SETCOL (14,'RR')
      CALL SETCOL (15,'WK')
      CALL SETCOL (16,'YK')
      CALL SETCOL (17,'MK')

      CALL SETPIC (18,7)
      CALL SETPIC (19,7)
      CALL SETPIC (20,7)
      CALL SETPIC (21,7)
      CALL SETWND (6,4,7,1,1,1,10,17)
      CALL SETCOL (18,'RR')
      CALL SETCOL (19,'WK')
      CALL SETCOL (20,'YK')
      CALL SETCOL (21,'MK')
```

```
      CALL SETWND (18,7,8,1,1,1, 1,22)
      DO 5 IDIS =22,30
      CALL SETPIC (IDIS,8)
      CALL SETCOL (IDIS,'RR')
5     CONTINUE

      CALL SETPIC (115,8)
      CALL SETPIC (116,8)
      CALL SETCOL (115,'WK')
      CALL SETCOL (116,'YK')
      CALL SETPIC (31,8)
      CALL SETCOL (31,'MK')

      CALL SETWND (7,7,10,1,1,1, 1,34)
      DO 15 IDIS =32,34
      CALL SETPIC (IDIS,10)
      CALL SETCOL (IDIS,'RR')
15    CONTINUE
      CALL SETPIC (35,10)
      CALL SETPIC (36,10)
      CALL SETPIC (37,10)
      CALL SETCOL (35,'WK')
      CALL SETCOL (36,'YK')
      CALL SETCOL (37,'MK')

      CALL SETWND (9,13,11,1,1,1,9,29)
      DO 20 IDIS =38,43
      CALL SETPIC (IDIS,11)
      CALL SETCOL (IDIS,'RR')
20    CONTINUE
      CALL SETPIC (44,11)
      CALL SETPIC (45,11)
      CALL SETPIC (46,11)
      CALL SETCOL (44,'WK')
      CALL SETCOL (45,'YK')
      CALL SETCOL (46,'MK')

      CALL SETPIC (11,12)
      CALL SETPIC (47,12)
      CALL SETPIC (48,12)
      CALL SETPIC (49,12)
      CALL SETPIC (50,12)
      CALL SETWND (8, 3,12,1,1,1, 1,42)
      CALL SETCOL (11,'RR')
      CALL SETCOL (47,'RR')
      CALL SETCOL (48,'WK')
      CALL SETCOL (49,'YK')
      CALL SETCOL (50,'MK')

      CALL SETWND (22, 3,13,1,1,1,8,42)
      DO 25 IDIS =51,52
      CALL SETPIC (IDIS,13)
      CALL SETCOL (IDIS,'RR')
25    CONTINUE
      CALL SETPIC (53,13)
      CALL SETPIC (54,13)
      CALL SETPIC (55,13)
      CALL SETCOL (53,'WK')
      CALL SETCOL (54,'YK')
      CALL SETCOL (55,'MK')

      CALL SETPIC (88,14)
      CALL SETPIC (89,14)
      CALL SETPIC (56,14)
```

```
      CALL SETPIC (57,14)
      CALL SETPIC (58,14)
      CALL SETPIC (59,14)
      CALL SETWND (10, 3,14,1,1,1,32,42)
      CALL SETCOL (88,'RR')
      CALL SETCOL (89,'RR')
      CALL SETCOL (56,'RR')
      CALL SETCOL (57,'WK')
      CALL SETCOL (58,'YK')
      CALL SETCOL (59,'MK')

      CALL SETWND (32,14,15,1,1,1,17,28)
      DO 30 IDIS =60,69
      CALL SETPIC (IDIS,15)
      CALL SETCOL (IDIS,'RR')
3     CONTINUE

      DO 32 IDIS =74,83
      CALL SETPIC (IDIS,15)
      CALL SETCOL (IDIS,'RR')
35    CONTINUE

      CALL SETPIC (70,15)
      CALL SETPIC (71,15)
      CALL SETPIC (72,15)
      CALL SETPIC (73,15)
      CALL SETPIC (84,15)
      CALL SETPIC (85,15)
      CALL SETPIC (86,15)
      CALL SETPIC (87,15)

      CALL SETCOL (70,'WK')
      CALL SETCOL (71,'CK')
      CALL SETCOL (72,'YK')
      CALL SETCOL (73,'MK')
      CALL SETCOL (84,'WK')
      CALL SETCOL (85,'CK')
      CALL SETCOL (86,'YK')
      CALL SETCOL (87,'MK')

      CALL SETWND (22,14,18,1,1,1,20,13)
      DO 35 IDIS =92,99
      CALL SETPIC (IDIS,18)
      CALL SETCOL (IDIS,'RR???')
35    CONTINUE
      CALL SETPIC (100,18)
      CALL SETPIC (101,18)
      CALL SETPIC (102,18)
      CALL SETPIC (103,18)
      CALL SETCOL (100,'WK')
      CALL SETCOL (101,'CK')
      CALL SETCOL (102,'YK')
      CALL SETCOL (103,'MK')

      RETURN
      END

      SUBROUTINE ASYPIC

$INCLUDE COM.ICL
       IPIC=24
      CALL SETPIC (110,IPIC)
      CALL SETPIC (118,IPIC)
      CALL SETPIC (119,IPIC)
```

```
      CALL SETPIC (120,IPIC)
      CALL SETPIC (121,IPIC)
      CALL SETPIC (122,IPIC)
      CALL SETPIC (123,IPIC)
      CALL SETPIC (124,IPIC)
      CALL SETWND (39,40,IPIC,1,1,1,42,6)
      CALL SETCOL (110,'YK')
      CALL SETCOL (118,'YK')
      CALL SETCOL (119,'YK')
      CALL SETCOL (120,'CK')
      CALL SETCOL (121,'RC')
      CALL SETCOL (122,'CB')
      CALL SETCOL (123,'MW')
      CALL SETCOL (124,'WK')


      RETURN
      END

      SUBROUTINE OTHERS

$INCLUDE COM.ICL
      CALL SETPIC (12,9)
      CALL SETWND (9,3,9,1,1,1,32,6)
      CALL SETPIC (13,17)
      CALL SETWND (22,6,17,1,1,1,20,6)
      CALL SETPIC (105,19)
      CALL SETWND (12,5,19,1,1,1,37,7)
      CALL SETPIC (90,21)
      CALL SETWND (12,5,21,1,1,1,69,7)
      CALL SETPIC (91,22)
      CALL SETWND (16,3,22,1,1,1,42,45)
      CALL SETPIC (117,5)
      CALL SETWND (16,3,5,1,1,1,1,45)

      CALL SETPIC (104,23)
      CALL SETWND (1,43,23,1,1,1,41,6)
      CALL SETCOL (104,'CK')

      CALL SETPIC (106,19)
      CALL SETPIC (107,21)
      CALL SETPIC (112,17)

      CALL SETCOL (112,'WK')
      CALL SETCOL (106,'WK')
      CALL SETCOL (107,'WK')
      CALL SETCOL (12,'WK')
      CALL SETCOL (13,'MW')
      CALL SETCOL (105,'CK')
      CALL SETCOL (90,'CK')
      CALL SETCOL (91,'CKD')
      CALL SETCOL (117,'CKD')


      RETURN
      END
```

Common list include file COM.ICL.

```
COMMON /BIAS/ IORDER,IJJJ,IASORD,IKKK
COMMON /ENT1/ IBAT,ITRANS,ITRBAT,IMACH(20,20),ISETER(15),ITOPS
COMMON /ENT2/ IASY
COMMON /EXNAME/ NAME,IBABEL
```

```
      COMMON /FLAG/IFLAG
      COMMON /LIST1/ IBATWD,IBAEND,IBADAT,IBAOUT(20),IBATIN(20),
     & IBASET(20,20),IBAPRO(20,20),IWLDMQ(20),IMCSET(20,20),
     & IMCPRO(20,20),IMCAVA(20,20),IWDSET(20),IWDOPT(20),ISETT(20,20)
      COMMON /LIST2/IPRODW,IASPLN,IOUT(2),IWC(22,4),IASYIN(22),
     & IASYOT(22),IASMAC,IASEMQ,OCUPYD,ASYLAB
      COMMON /ORDER/ BORD,SORD
      COMMON /PACKET/ IPBDAT(255,30),ISYDAT(99,30),ISYSOP(99,30),
     & NCNVRT(255),IDAY,IPER,IYEAR,ICAL87,ICAL88,ICAL89,
     & IPER87,IPER88,IPER89
      COMMON /SAMPLE/ ISAMPL
      COMMON /SETOP/ JSET,JOPT
      COMMON /STAT/ IUTILZ(15),INPROG(2),INQUE(15),INMOVE(2),
     & IPLAN,ILATE(2),FLOTM(2),IBASIZ(2),BLED(255),BSIZE(255),
     & SLED(100), SSIZE(100),BLAT(255),SLAT(100)
      COMMON /STOR/ IBUFST(255),BLEV(255),SLEV(255),IACESS(255)
      COMMON /WIP/IWIP(2),NMAC(2)
      COMMON /WORK/ IWORK
      COMMON /STOC/ ISTK(2),ISTOCK
      COMMON /PARM/ IPRIOR,IRANG(200),INAME(2),IPLIST(136),ISLIST(26)
      COMMON /SAVR/IDAT(2)


      CHARACTER COMMD*80
      CHARACTER DSCOF*4
      CHARACTER CFI*20
      CHARACTER CFR*20
      CHARACTER ORDER*10,QUANT*13,BIN*8,PERD*2,TPV*20,CHAR*20,
     & TMSNUM*20,PRTNUM*20,T*20
      CHARACTER TOUT*80,DATE*6,PPLAN*80,START*8,FINISH*8
```

Full listing of the next day event include file NEWDAY.ICL

```
      SUBROUTINE ENDDAY

 $INCLUDE COM.ICL
      CALL DISTXT(1,-1,0,'End of day '//CFI(IDAY,1)//'.')
      CALL WIPCLS

      IF(IDAY.EQ.IAT(IASPLN,1))THEN
              CALL ENDPER
              CALL STPER
      ELSE
              CALL STTDAY
      ENDIF
      RETURN
      END

      SUBROUTINE STTDAY

 $INCLUDE COM.ICL

C.......Increment day counter.
      IDAY=IDAY+1

C.......Launch next assembly batches
      CALL RUNSYS

      RETURN
      END


      SUBROUTINE ENDPER
```

```
$INCLUDE COM.ICL

        CALL DISTXT(1,-1,0,'End of Period '//CFI(IPER,2)//'.')

        IF(IPER.EQ.39)CALL SHUT

C.......1.Write stock update from disc to TMS.

        CALL DISTXT(1,-1,0,'TMS: WIP update.')
        CALL WIPOUT

C.......2.Send MPS to TMS.

        CALL DISTXT(1,-1,0,'TMS: MPS update.')
        CALL NXTMPS

C.......3.Send SALES.(this automatically triggers an MRP run).

        CALL DISTXT(1,-1,0,'TMS: SALES update.')
        CALL SALES

        RETURN
        END

        SUBROUTINE STPER

$INCLUDE COM.ICL
        CHARACTER YELL*8

C.......Set period counter to the next period and IDAY to 1 .
        IPER = IPER+1
        IDAY =1
        CALL DRWTIM(TIM())
        CALL DISTXT(1,-1,0,'Start of Period '//CFI(IPER,2)//'.')

        IF(IYEAR.EQ.87)THEN
                NN = IPV(IPER87,IPER)
        ELSEIF(IYEAR.EQ.88)THEN
                NN = IPV(IPER88,IPER)
        ELSEIF(IYEAR.EQ.89)THEN
                NN = IPV(IPER89,IPER)
        ENDIF

        CALL SETIAT(IASPLN,1,NN)
        DO 10 II = 1,NN
             CALL SCHEDL('ENDDAY',II*480.0,IASPLN)
        10   CONTINUE

C.......Download WIP launches
        CALL WIPDWN
        CALL RUNBAT

C.......Download Suggested actions from TMS.
        CALL MSGDWN
        CALL RSCHED

C.......Update IPLAN,2
        IF(RPV(IPLAN,2).GT.0.0)THEN
           CALL SRPV(IPLAN,2,(RPV(IPLAN,2)-1.0))
        ENDIF

C.......Launch appropriate batches.
        CALL RUNSYS
```

```
      CALL DISTXT(1,-1,0,'Running.')

      RETURN
      END


      SUBROUTINE RUNSYS

$INCLUDE COM.ICL

      IF(ISIZOF(IASPLN).EQ.0)GO TO 99
      IPOS = 1
   25 LAUN = INT(RAT(MEMBER(IASPLN,IPOS),5))
      NOW = IFIX(TIM())

      IF(LAUN.LE.NOW)THEN
              I  = INT(RAT(MEMBER(IASPLN,IPOS),1))
              II = INT(RPV(ISYDAT(I,1),1)) + 3
              CALL AIPV(IACESS(I),1,1)
              J = 3
   30         J = J + 1
              JJ = INT(RPV(ISYDAT(I,J),1))
              IF(JJ.EQ.999)GO TO 53
              K  = INT(RPV(ISYDAT(I,J),2))
              KK = K*INT(RAT(MEMBER(IASPLN,IPOS),4))
              R  = RPV(ISYDAT(I,J),2)
              RR = R*RAT(MEMBER(IASPLN,IPOS),4)

              IF(RPV(IBUFST(JJ),1).LT.RR)THEN
              CALL AIPV(IACESS(I),2,1)
              CALL SETRAT(MEMBER(IASPLN,IPOS),5,0.0)
       CALL SETDSC(MEMBER(IASPLN,IPOS),'S'//CFI(I,2)//'*')

              IF(IPOS.EQ.ISIZOF(IASPLN))THEN
                        GO TO 99
              ELSE
                        IPOS = IPOS + 1
                        GO TO 25
              ENDIF
              ENDIF

              IF(J.LT.II)GO TO 30
              J = 3
   40         J = J + 1
              JJ = INT(RPV(ISYDAT(I,J),1))
              R  = RPV(ISYDAT(I,J),2)
              RR = R*RAT(MEMBER(IASPLN,IPOS),4)
              CALL ARPV(IBUFST(JJ),1,-RR)
              CALL ARPV(ISTK(1),1,-RR)
              CALL ABSROB(SLEV(JJ),RPV(IBUFST(JJ),1))

              IF(J.LT.II)THEN
                 GO TO 40
              ENDIF

   53         ITYP = I
              NOP  = 1
              IWORK=INT(RPV(ISYSOP(ITYP,NOP),1))
               WORK=    (RPV(ISYSOP(ITYP,NOP),1))
              RELE=TIME()
              CALL SETRAT(MEMBER(IASPLN,IPOS),5,RELE)
              CALL ADD(MEMBER(IASPLN,IPOS),IASYIN(IWORK),0)
              CALL REMOVE(IASPLN,IPOS)
          CALL ARPV(IWIP(2),1,RAT(MEMBER(IASYIN(IWORK),0),4))
```

```
          CALL ADDRAT(MEMBER(IASYIN(IWORK),0),6,1.0)
          CALL SETRAT(MEMBER(IASYIN(IWORK),0),7,WORK)
          IF(IPOS.GT.ISIZOF(IASPLN).OR.ISIZOF(IASPLN).EQ.0)THEN
          GO TO 99
          ENDIF

          GO TO 25

      ENDIF

 99   CALL DRAW (IASPLN)
      INSTOR = ISIZOF(IASPLN)
      CALL DISIV (108,6,9,INSTOR,3)

      RETURN
      END


      SUBROUTINE WIPCLS

$INCLUDE COM.ICL

      REAL LEVEL

      CHARACTER DAYOUT*10
      CHARACTER ACAB*10

      ISK = ISIZOF(IOUT(1)) + ISIZOF(IOUT(2))

      IF(IPER.LT.10)THEN
              WRITE(ACAB,2)'STKO',IPER,IDAY
  2           FORMAT(A4,I1,I1)
      ELSE
              WRITE(ACAB,4)'STK',IPER,IDAY
  4           FORMAT(A3,I2,I1)
      ENDIF

      READ(ACAB,6) DAYOUT
  6   FORMAT(A6)

      IF(ISK.LT.1)GO TO 150

      OPEN(4,FILE=DAYOUT,STATUS='NEW',ERR=10)
      GO TO 12

 10   CALL DISTXT(1,-1,0,'Cannot open '//DAYOUT)
      GO TO 800
 12   DO 100 K = 1,2

      IUPDAT = ISIZOF(IOUT(K))
      IF(IUPDAT.LT.1)GO TO 100

      DO 50 I = 1,IUPDAT
               J = INT(RAT(MEMBER(IOUT(K),1),1))
              JJ = INT(RAT(MEMBER(IOUT(K),1),4))
              RR =     RAT(MEMBER(IOUT(K),1),4)
              CALL ARPV(IWIP(K),1,-RR)
              CALL ARPV(ISTK(K),1,RR)
              CALL ARPV(IBUFST(J),1,RR)
              CALL ARPV(ISTOCK,1,RR)
              LEVEL= RPV(IBUFST(J),1)
              CALL ABSROB(SLEV(J),LEVEL)
      WRITE(4,22)'!P!',TPV(NCNVRT(J),1),CF1(JJ,13),'AS',
     & INT(RAT(MEMBER(IOUT(K),1),2)),'     ','FL18A','1'
```

```
22          FORMAT(A3,A20,A13,A2,I6,A4,A6,A8)

            IF(TIM().GT.RPV(IPLAN,3))THEN
               TYPE = REAL(J)
               SIZE = REAL(JJ)
               RELE = RAT(MEMBER(IOUT(K),1),5)/480
               COMP = TIM()/480
               FLOW = COMP - RELE
               DUE  = RAT(MEMBER(IOUT(K),1),8)/480
               TVAR = DUE - COMP
               CALL ABSROB(IFLOTM(K),FLOW)
               CALL ABSROB(IBASIZ(K),SIZE)
               CALL ABSROB(ILATE(K),TVAR)
               CALL ARPV(IPLAN,(6+K),SIZE)

               IF(K.EQ.1)THEN
                       CALL ABSROB(BLED(INT(TYPE)),FLOW)
                       CALL ABSROB(BSIZE(INT(TYPE)),SIZE)
                       CALL ABSROB(BLAT(INT(TYPE)),TVAR)
               ELSE
                       CALL ABSROB(SLED(INT(TYPE)),FLOW)
                       CALL ABSROB(SSIZE(INT(TYPE)),SIZE)
                       CALL ABSROB(SLAT(INT(TYPE)),TVAR)
               ENDIF
         ENDIF

      IF(K.EQ.1)THEN
          INUMB = 10
      ELSE
          INUMB = 10
      ENDIF

            DO 25 IK = 1,INUMB
                    CALL SETRAT(MEMBER(IOUT(K),1),IK,0.00)
25          CONTINUE

            IF(K.EQ.1)THEN
                    LISNAM = IBATWD
            ELSEIF(K.EQ.2)THEN
                    LISNAM = IPRODW
            ENDIF

            CALL ADD(MEMBER(IOUT(K),1),LISNAM,0)
            CALL REMOVE(IOUT(K),1)

 50   CONTINUE
100   CONTINUE
      GO TO 200
150   OPEN(4,FILE=DAYOUT,STATUS='NEW',ERR=10)
      WRITE(4,155) '!P!','NO WIP OUTPUT'
155   FORMAT(A3,A20)
200   CLOSE(4)
800   RETURN
      END

      SUBROUTINE RSCHED

$INCLUDE COM.ICL

      INTEGER SPRTNM(100),SIORD(100),SNWYER(100),
&   SNWDAY(100),SOLYER(100),
&   SOLDAY(100),BPRTNM(100),BIORD(100),BNWYER(100),BNWDAY(100),
&   BOLDAY(100),BOLYER(100)
      CHARACTER TX1*20,TX2*1,TX3*3,SMESGE(100)*1,
```

```
&  BMESGE(100)*1,DESC*4
      CHARACTER ACTFIL*10

      CALL DISTXT(1,-1,0,'Re-scheduling.')

      IB=0
      IS=0

      IF(IPER.LT.10)THEN
              ACTFIL='ACTNO'//CFI(IPER,1)
      ELSE
              ACTFIL='ACTN'//CFI(IPER,2)
      ENDIF

      OPEN(4,FILE=ACTFIL,STATUS='OLD',ERR=1)
      GO TO 5
  1   COMMD='Cannot open '//ACTFIL//'.'
      CALL COMPRT(COMMD)
      GO TO 999

  5   READ(4,10,ERR=990,END=15)TX1,IN1,IN2,TX2,
    & IN3,IN4,I5,I6,IN7,TX3
 10   FORMAT(A20,2X,I10,I6,A1,I2,I3,I2,I3,I12,A3)

      IF(TX2.NE.'C')THEN
              DO 11 IK = 1,255
                      IF(TX1.EQ.TPV(NCNVRT(IK),1)) GO TO 12
 11           CONTINUE
      IF(IK.GT.255)GO TO 5
 12           IF(IK.LT.100)THEN
                      IS=IS+1
                      SPRTNM(IS)=IK
                 SIORD(IS) =IN1
                 SMESGE(IS)=TX2
                 SNWYER(IS)=IN3
                 SNWDAY(IS)=IN4
                 SOLYER(IS)=IN5
                 SOLDAY(IS)=IN6
         ELSEIF(IK.LT.256)THEN
                 IB=IB+1
                 BPRTNM(IB)=IK
                 BIORD(IB) =IN1
                 BMESGE(IB)=TX2
                 BNWYER(IB)=IN3
                 BNWDAY(IB)=IN4
                 BOLYER(IB)=IN5
                 BOLDAY(IB)=IN6
         ENDIF
      ENDIF
      GO TO 5
 15   CLOSE(4)
      IE =IB+IS

      DO 40 IKI =1,26
      DESC = DSCOF(ISLIST(IKI))
      IF(ISIZOF(ISLIST(IKI)).EQ.0)GO TO 40
      IDI = ISIZOF(ISLIST(IKI))

      DO 35 IPOS =1, IDI

      IF(DSCOF(MEMBER(ISLIST(IKI),IPOS)).EQ.'    ')GO TO 35
              DO 30 KII = 1,IS

      IF(INT(RAT(MEMBER(ISLIST(IKI),IPOS),2)).EQ.SIORD(KII)
```

```
&             .AND.SMESGE(KII).EQ.'D')THEN
                   IYEARI = SNWYER(KII)
                   IDAYI  = SNWDAY(KII)
                   DUE    = REQIRD(IYEARI,IDAYI)

                   CALL SETRAT(MEMBER(ISLIST(IKI),IPOS),8,DUE)

        ELSEIF(INT(RAT(MEMBER(ISLIST(IKI),IPOS),2)).EQ.SIORD(KII)
&      .AND.SMESGE(KII).EQ.'E')THEN
                   IYEARI = SNWYER(KII)
                   IDAYI  = SNWDAY(KII)
                   DUE    = REQIRD(IYEARI,IDAYI)

                   CALL SETRAT(MEMBER(ISLIST(IKI),IPOS),8,DUE)
        ENDIF

  30             CONTINUE
  35    CONTINUE
  40    CONTINUE

        DO 240 IKI =1,136
        DESC = DSCOF(IPLIST(IKI))
        IF(ISIZOF(IPLIST(IKI)).EQ.0)GO TO 240
        IDI = ISIZOF(IPLIST(IKI))

        DO 235 IPOS =1,IDI

        DO 230 KII = 1,IB
        IF(INT(RAT(MEMBER(IPLIST(IKI),IPOS),2)).EQ.BIORD(KII).AND.
     &                 BMESGE(KII).EQ.'D')THEN
                       IYEARI = BNWYER(KII)
                       IDAYI  = BNWDAY(KII)
                       DUE    = REQIRD(IYEARI,IDAYI)

                CALL SETRAT(MEMBER(IPLIST(IKI),IPOS),8,DUE)

        ELSEIF(INT(RAT(MEMBER(IPLIST(IKI),IPOS),2)).EQ.BIORD(KII)
     &     .AND.BMESGE(KII).EQ.'E')THEN
                   IYEARI = BNWYER(KII)
                   IDAYI  = BNWDAY(KII)
                   DUE    = REQIRD(IYEARI,IDAYI)

                   CALL SETRAT(MEMBER(IPLIST(IKI),IPOS),8,DUE)
        ENDIF
 230    CONTINUE
 235    CONTINUE
 240    CONTINUE
        GO TO 999
 990    CALL DISTXT(1,-1,0,'Error reading '//ACTFIL)
        GO TO 999
 999    RETURN
        END

        SUBROUTINE RUNBAT

$INCLUDE COM.ICL

        REAL ORDNUM,BQUAN,TYPE
        REAL LAUN,DUE,RELESE,REQIRD
        REAL RINC
        CHARACTER ORDERS*9,DUM*2

        IF(IPER.LT.10)THEN
           CALL DISTXT(1,-1,0,'Opening ORDERO'//CFI(IPER,1))
```

```
         ORDERS = 'ORDERO'//CFI(IPER,1)
      ELSE
         CALL DISTXT(1,-1,0,'Opening ORDER'//CFI(IPER,2))
         ORDERS = 'ORDER'//CFI(IPER,2)
      ENDIF

      OPEN(4,FILE=ORDERS,STATUS='OLD',ERR=3)
      GO TO 5

 3    COMMD='Can not open '//ORDERS//'.'
      CALL COMPRT(COMMD)

      GO TO 800

 5    READ(4,7,END=100,ERR=150) DUM,JORDER,PRTNUM,
     &   IQUAN,IYEARO,IDAYO,IYEARI,IDAYI

 7    FORMAT(A2,I10,A20,I8,4X,I2,I3,I2,I3)

      BQUAN=REAL(IQUAN)
      BBAT = 1.0

      DO 10 IK = 1,255
         IF(PRTNUM.EQ.TPV(NCNVRT(IK),1)) GO TO 15
10    CONTINUE

      COMMD = 'Part number '//PRTNUM//' not recognised !!!'
      OPEN(5,FILE='LST:',STATUS='NEW',ERR=5)
      WRITE(5,11)COMMD
11    FORMAT(A80)
      CLOSE(5)
      GO TO 5

15    IF(IK.LE.99)THEN
              INAME(1) =  IPRODW
              INAME(2) =  IASPLN
      ELSE
              INAME(1) =  IBATWD
              INAME(2) =  IBAOUT(20)
      ENDIF

      IF(IK.LE.99)THEN
         TRB = RPV(ITRBAT,2)
         TTRB = 1.5*RPV(ITRBAT,2)
      ELSE
         TRB = RPV(ITRBAT,1)
         TTRB = 1.5*RPV(ITRBAT,1)
      ENDIF

      LAUN     = RELESE(IYEARO,IDAYO)
      DUE      = REQIRD(IYEARI,IDAYI)
      TYPE     = REAL(IK)
      VAL2     = BQUAN
      ORDNUM   = REAL(JORDER)

 30   IF(VAL2.GT.TTRB)THEN
         CALL SETRAT(MEMBER(INAME(1),1),1,TYPE)
         CALL SETRAT(MEMBER(INAME(1),1),2,ORDNUM)
         CALL SETRAT(MEMBER(INAME(1),1),3,BBAT)
         CALL SETRAT(MEMBER(INAME(1),1),4,TRB)
         CALL SETRAT(MEMBER(INAME(1),1),5,LAUN)
         CALL SETRAT(MEMBER(INAME(1),1),7,20.0)
         CALL SETRAT(MEMBER(INAME(1),1),8,DUE)
```

```
         IF(IPRIOR.EQ.1)THEN
 CALL SETRAT(MEMBER(INAME(1),1),10,DUE/IAT(ITOPS,INT(TYPE)))
         ENDIF

         IF(TYPE.LT.100.0)THEN
CALL SETDSC(MEMBER(INAME(1),1),'S'//CFI(INT(TYPE),2))
         ELSE
CALL SETDSC(MEMBER(INAME(1),1),CFI(INT(TYPE),3))
         ENDIF

         CALL ADD(MEMBER(INAME(1),1),INAME(2),0)
         CALL REMOVE(INAME(1),1)

         IF(IK.GE.100)THEN
         RINC=RAT(MEMBER(INAME(2),0),5)-TIME()

         IF(RINC.LE.0.0)THEN
                         RINC=0.0
         ENDIF
         CALL SCHEDL('TRNSPT',RINC,MEMBER(INAME(2),0))
         ENDIF
         IF(ISIZOF(INAME(2)).GT.1)THEN
                 ISERC = ISIZOF(INAME(2)) - 1
                 DO 40 IKJ = ISERC,1,-1

         IF(RAT(MEMBER(INAME(2),IKJ),5).GT.
    &    RAT(MEMBER(INAME(2),IKJ+1),5))THEN
         CALL TRACE('IASPLN SWAPPED = '//CFI(IKJ,3))
         CALL SWAP(MEMBER(INAME(2),IKJ+1),
    &    INAME(2),IKJ,IKJ+1)
         ENDIF
40       CONTINUE
         ENDIF

         VAL2 = VAL2-TRB
         BBAT = BBAT + 1.0
         GO TO 30
      ELSE
         CALL SETRAT(MEMBER(INAME(1),1),1,TYPE)
         CALL SETRAT(MEMBER(INAME(1),1),2,ORDNUM)
         CALL SETRAT(MEMBER(INAME(1),1),3,BBAT)
         CALL SETRAT(MEMBER(INAME(1),1),4,VAL2)
         CALL SETRAT(MEMBER(INAME(1),1),5,LAUN)
         CALL SETRAT(MEMBER(INAME(1),1),7,20.0)
         CALL SETRAT(MEMBER(INAME(1),1),8,DUE)


   IF(IPRIOR.EQ.1)THEN
   CALL SETRAT(MEMBER(INAME(1),1),10,DUE/IAT(ITOPS,INT(TYPE)))
   ENDIF

   IF(TYPE.LT.100.0)THEN
    CALL SETDSC(MEMBER(INAME(1),1),'S'//CFI(INT(TYPE),2))
   ELSE
    CALL SETDSC(MEMBER(INAME(1),1),CFI(INT(TYPE),3))
   ENDIF

         CALL ADD(MEMBER(INAME(1),1),INAME(2),0)
         CALL REMOVE(INAME(1),1)

         IF(IK.GE.100)THEN
                 RINC=RAT(MEMBER(INAME(2),0),5)-TIME()
                 IF(RINC.LE.0.0)THEN
                         RINC=0.0
                 ENDIF
```

```
    CALL SCHEDL('TRNSPT',RINC,MEMBER(INAME(2),0))

    ENDIF

    IF(ISIZOF(INAME(2)).GT.1)THEN
                  ISERC = ISIZOF(INAME(2)) - 1
                  DO 50 IKJ = ISERC,1,-1

    IF(RAT(MEMBER(INAME(2),IKJ),5).GT.
&   RAT(MEMBER(INAME(2),IKJ+1),5))THEN
    CALL TRACE('IASPLN SWAPPED = '//CFI(IKJ,3))
    CALL SWAP(MEMBER(INAME(2),IKJ+1),
&   INAME(2),IKJ,IKJ+1)
    ENDIF
 50        CONTINUE
           ENDIF

     ENDIF

C.......Get next WIP order.
        GO TO 5
  100   CLOSE(4)
        GO TO 800
  150   CALL DISTXT(1,-1,0,'ERROR reading '//ORDERS//'.')
  800   RETURN
        END

        FUNCTION RELESE(IYEARO,IDAYO)

$INCLUDE COM.ICL

        IF(IYEAR.EQ.IYEARO.AND.IYEAR.EQ.87)THEN
           RELESE = REAL(480*(IPV(ICAL87,IDAYO)))-480.0
        ELSEIF(IYEAR.EQ.IYEARO.AND.IYEAR.EQ.88)THEN
           RELESE = REAL(480*(IPV(ICAL88,IDAYO)))-480.0
        ELSEIF(IYEAR.EQ.IYEARO.AND.IYEAR.EQ.89)THEN
           RELESE = REAL(480*(IPV(ICAL89,IDAYO)))-480.0
        ELSEIF(IYEAR.LT.IYEARO.AND.IYEAR.EQ.87)THEN
           RELESE = REAL((251+IDAYO)*480) -480.0
        ELSEIF(IYEAR.LT.IYEARO.AND.IYEAR.EQ.88)THEN
           RELESE = REAL((500+IDAYO)*480) -480.0
        ELSEIF(IYEAR.LT.IYEARO.AND.IYEAR.EQ.89)THEN
           RELESE = REAL((748+IDAYO)*480) -480.0
        ELSE
           RELESE=0.1
        ENDIF

        IF(RELESE.LT.0.0.OR.RELESE.LT.TIME())THEN
           RELESE = TIME()
        ENDIF

        RETURN
        END

        FUNCTION REQIRD(IYEARI,IDAYI)

$INCLUDE COM.ICL

        IF(IYEAR.EQ.IYEARI.AND.IYEAR.EQ.87)THEN
           REQIRD = REAL(480*(IPV(ICAL87,IDAYI)))-480.0
        ELSEIF(IYEAR.EQ.IYEARI.AND.IYEAR.EQ.88)THEN
           REQIRD = REAL(480*(IPV(ICAL88,IDAYI)))-480.0
        ELSEIF(IYEAR.EQ.IYEARI.AND.IYEAR.EQ.89)THEN
```

```
      REQIRD = REAL(480*(IPV(ICAL89,IDAYI)))-480.0
   ELSEIF(IYEAR.LT.IYEARI.AND.IYEAR.EQ.87)THEN
      REQIRD = REAL((251+IDAYI)*480)-480.0
   ELSEIF(IYEAR.LT.IYEARI.AND.IYEAR.EQ.88)THEN
      REQIRD = REAL((500+IDAYI)*480)-480.0
   ELSEIF(IYEAR.LT.IYEARI.AND.IYEAR.EQ.89)THEN
      REQIRD = REAL((748+IDAYI)*480)-480.0
   ELSE
      REQIRD=0.1
   ENDIF
   IF(REQIRD.LT.0.0)THEN
      REQIRD = 0.0
   ENDIF
   RETURN
   END
```

Experement end point include file ENEDE.ICL

```
      SUBROUTINE ENDED

$INCLUDE COM.ICL

      CHARACTER*6 TT
      REAL STKOUT

      CALL DISTXT(1,-1,0,'SAVING RESULTS')

C.......Output results to disk

      JJ = IPV(NAME,1)
      TT = 'STAT'//CFI(IPER,2)

      OPEN(4,FILE=TT,STATUS='NEW')
      WRITE(4,7) '     '
      WRITE(4,7) '     '
    7 FORMAT(A)
    8 FORMAT(6F10.3)
    6 FORMAT(8F7.3)


      WRITE(4,7) ' EXPERIMENT:    '
      WRITE(4,7) ' ---------------      '
      WRITE(4,7) '     '
      WRITE(4,7) '     '
      WRITE(4,7) ' PARAMETER VALUES:-    '
      WRITE(4,7) ' -----------------    '
      WRITE(4,7) '     '
      WRITE(4,7) '      PCBT/B    SYST/B      PCBTT       SYSTT
     LOAD'
      WRITE(4,7) '       ------    ------     -----       -----
     ----'

      AA = RPV(ITRBAT,1)
      BB = RPV(ITRBAT,2)
      CC = RPV(ITRANS,1)
      DD = RPV(ITRANS,2)
      EE = RPV(IPLAN,5)

      WRITE(4,9) AA,BB,CC,DD,EE
    9 FORMAT(F10.2,F10.2,F10.2,F10.2,F10.2)
      CALL TRACE ('RESULTS FILE HEADER WRITTEN')

      WRITE(4,7) '     '
      WRITE(4,7) '     '
```

```
      WRITE(4,7) '  EXPERIMENTAL RESULTS FOR: '//TT
      WRITE(4,7) '  ------------------------------ '

      WRITE(4,7) '     '
      WRITE(4,7) '     '

      CALL ANALTS(IBASIZ(1),R1,R2,RMIN,RMAX,RMEAN,R3,R4,DUR)
      CALL ANLTS(IBASIZ(2),RR1,RR2,RRMIN,RRMAX,
&        RRMEAN,RR3,RR4,DUR)

      WRITE(4,7) '     '
      WRITE(4,7) 'SUMMARIZED:    PCB BATCH SIZE      SYS BATCH
                  SIZE  '
      WRITE(4,7)                 '-----------    -------------
                  --------------  '
      WRITE(4,7) '     '
      WRITE(4,7) '     MIN       MEAN      MAX MIN       MEAN
                     MAX'
      WRITE(4,7)   '         ---       ----      ---       ---
                  ----      ---'

      WRITE(4,8) RMIN,RMEAN,RMAX,RRMIN,RRMEAN,RRMAX

      CALL ANALTS(INPROG(1),R1,R2,RMIN,RMAX,RMEAN,R3,R4,DUR)
      CALL ANALTS(INPROG(2),RR1,RR2,RRMIN,RRMAX,
                  RRMEAN,RR3,RR4,DUR)

      WRITE(4,7) '     '
      WRITE(4,7) 'SUMMARIZED:     PCB WIP               SYS WIP
      WRITE(4,7) '-----------     -------------   '
      WRITE(4,7) '     '
      WRITE(4,7)  '       MIN         MEAN        MAX         MIN
                      MEAN        MAX'
      WRITE(4,7)   '        ---         ----        ---         ---
                      ----        ---'

      WRITE(4,8) RMIN,RMEAN,RMAX,RRMIN,RRMEAN,RRMAX

      CALL ANALTS(IFLOTM(1),R1,R2,RMIN,RMAX,RMEAN,R3,R4,DUR)
      CALL ANALTS(IFLOTM(2),RR1,RR2,RRMIN,
                  RRMAX,RRMEAN,RR3,RR4,DUR)

      WRITE(4,7) '     '
      WRITE(4,7) 'SUMMARIZED:   PCB FLOW              SYS FLOW
      WRITE(4,7) '-----------   --------              --------
      WRITE(4,7) '     '
      WRITE(4,7) '    MIN    MEAN    MAX    STD    MIN     MEAN
                     MAX    STD'
      WRITE(4,7)  '     ---    ----    ---    ---    ---     ----
                     ---    ---'

      WRITE(4,6) RMIN,RMEAN,RMAX,R3,RRMIN,RRMEAN,RRMAX,RR3

      CALL ANALTS(ILATE(1),R1,R2,RMIN,RMAX,
                  RMEAN,R3,R4,DUR)
      CALL ANALTS(ILATE(2),RR1,RR2,RRMIN,
                  RRMAX,RRMEAN,RR3,RR4,DUR)

      WRITE(4,7) '     '
      WRITE(4,7)  'SUMMARIZED:    PCB D/D ACCURACY          SYS
                  D/D ACCURACY '
      WRITE(4,7)                '-----------   ---------------
                  ---------------- '
      WRITE(4,7) '     '
```

```
      WRITE(4,7) '  MIN     MEAN     MAX     STD     MIN MEAN   MAX
                 STD'
      WRITE(4,7)  '  ---    ----    ---    ---    ---    ----
                 ---    ---'

      WRITE(4,6) RMIN,RMEAN,RMAX,R3,RRMIN,RRMEAN,RRMAX,RR3

      WRITE(4,7) '      '
      WRITE(4,7) '         W/C UTILIZATION DATA  '
      WRITE(4,7) '         --------------------  '
      WRITE(4,7) '      '
      WRITE(4,7) '      W/C    MIN    MEAN     MAX  '
      WRITE(4,7) '      ---    ---    ----     ---  '


      DO 11 II = 1,11


              CALL ANALTS(IUTILZ(II),R1,R2,RMIN,
                       RMAX,RMEAN,R3,R4,DUR)
              WRITE(4,10) II,RMIN,RMEAN,RMAX
10            FORMAT(I8,F8.2,F8.2,F8.2)

11    CONTINUE

      WRITE(4,7) '      '
      WRITE(4,7) '         W/C INPUT QUEUE DATA  '
      WRITE(4,7) '         --------------------  '
      WRITE(4,7) '      '
      WRITE(4,7) '      W/C    MIN    MEAN     MAX  '
      WRITE(4,7) '      ---    ---    ----     ---  '

14    DO 13 II = 1,11

              CALL ANALTS(INQUE(II),R1,R2,RMIN,
                       RMAX,RMEAN,R3,R4,DUR)

              WRITE(4,12) II,RMIN,RMEAN,RMAX
12            FORMAT(I8,F8.2,F8.2,F8.2)
13    CONTINUE


      WRITE(4,7) '      '
      WRITE(4,7) '    INDIVIDUAL WIP & STOCK DATA:- '
      WRITE(4,7) '    -----------------------------    '
      WRITE(4,7) '      '
      WRITE(4,7)  '              BATCH SIZES             FLOW
                 TIMES
   &    LATENESS '
      WRITE(4,7)          '                             -----------
                 -----------
   &   ------------'
      WRITE(4,7) '      '
      WRITE(4,7)  '   TYPE     MIN    MEAN      MAX      MIN
                 MEAN     MAX    MIN    MEAN MAX '
      WRITE(4,7)    '    ----    ---    ----    ---    ---
                    ----    ---
   &  ---    ----     --- '
      DO 20 II = 1,99

      CALL ANALTS(SLED(II),R1,R2,RMIN,RMAX,RMEAN,R3,R4,DUR)
      CALL ANALTS(SSIZE(II),S1,S2,SMIN,SMAX,SMEAN,S3,S4,DUR)
      CALL ANALTS(SLAT(II),S1,S2,RRMIN,RRMAX,RRMEAN,S3,S4,DUR)
```

```
      NNMIN = INT(RRMIN)
      NNMEAN = INT(RRMEAN)
      NNMAX = INT(RRMAX)

      IF(SMEAN.EQ.0.0)GOTO 20

      WRITE(4,15) II,SMIN,SMEAN,SMAX,RMIN,
&   RMEAN,RMAX,NNMIN,NNMEAN,NNMAX
  15 FORMAT(I8,F8.2,F8.2,F8.2,F8.2,
           F8.2,F8.2,1X,I4,5X,I4,5X,I4)

  20  CONTINUE

      DO 27 II = 100,255

      CALL ANALTS(BLED(II),R1,R2,RMIN,RMAX,RMEAN,R3,R4,DUR)
      CALL ANALTS(BSIZE(II),S1,S2,SMIN,SMAX,SMEAN,S3,S4,DUR)
      CALL ANALTS(BLAT(II),S1,S2,RRMIN,RRMAX,RRMEAN,S3,S4,DUR)
      NNMIN = INT(RRMIN)
      NNMEAN = INT(RRMEAN)
      NNMAX = INT(RRMAX)

      IF(SMEAN.EQ.0.0)GOTO 27

      WRITE(4,25) II,SMIN,SMEAN,SMAX,RMIN,RMEAN,
                        RMAX,NNMIN,NNMEAN,NNMAX
  25  FORMAT(I8,F8.2,F8.2,F8.2,F8.2,F8.2,
                        F8.2,1X,I4,5X,I4,5X,I4)

  27  CONTINUE

      WRITE(4,7) '      '
      WRITE(4,7) '      '
      WRITE(4,7) 'SYSTEM LAUNCH ATTEMPTS:                  STOCK
                                  LEVEL INFO`M:'
      WRITE(4,7) '      '
      WRITE(4,7) '                LAUNCH '
      WRITE(4,7)  '      TYPE      ATTEMPTS    % STOCKOUT      MIN
                                   MEAN      MAX'
      WRITE(4,7)  '      ----      ------    ----------      ---
                                   ----      ---'

      DO 125 II = 1,99

         CALL ANALTS(SLEV(II),S1,S2,RMIN,RMAX,RMEAN,S3,S4,DUR)
         ILNC =  IPV(IACESS(II),1)
         ISTO =  IPV(IACESS(II),2)

         IF(ILNC.EQ.0)THEN
                 STKOUT = 0
                 GOTO 122
         ENDIF

         STKOUT =  (REAL(ISTO)/REAL(ILNC))
         STKOUT  = STKOUT*100

 122     NNMIN = INT(RMIN)
         NNMEAN = INT(RMEAN)
         NNMAX = INT(RMAX)

         IF(NNMEAN.EQ.0)GOTO 125

         WRITE(4,123) II,ILNC,STKOUT,NNMIN,NNMEAN,NNMAX
 123     FORMAT(5X,I3,7X,I4,6X,F7.2,6X,I4,5X,I4,5X,I4)
```

```
 125    CONTINUE

        WRITE(4,7) '       '
        WRITE(4,7) '       '
        WRITE(4,7) ' INDIVIDUAL PCB STOCK LEVEL INFO`M:      '
        WRITE(4,7) '       '

        DO 126 II = 100,255
        CALL ANALTS(SLEV(II),S1,S2,RRMIN,RRMAX,RRMEAN,S3,S4,DUR)

           NNMIN = INT(RRMIN)
           NNMEAN = INT(RRMEAN)
           NNMAX = INT(RRMAX)

           IF(NNMEAN.EQ.0)GOTO 126

           WRITE(4,127) II,NNMIN,NNMEAN,NNMAX
 127       FORMAT(5X,I3,30X,I4,5X,I4,5X,I4)

 126       CONTINUE

        CLOSE(4)
        IF(IPER.GT.39)CALL SHUT
        RETURN
        END
```

Comminication Routines, COMMS.ICL

```
        SUBROUTINE WIPOUT

$INCLUDE COM.ICL

        CHARACTER DAYOUT*10
        CHARACTER ACAB*10

        IF(IBABEL.EQ.0)RETURN
        COMMD = 'HELL TEST/TEST'
        CALL COMPRT(COMMD)
        CALL COMOPN(COMMD)
        COMMD = 'ASP/PINNACLE'
        CALL COMPRT(COMMD)
        CALL COMOPN(COMMD)
  10    COMMD = 'R $TMSOBJ/ASP010'
        CALL COMPRT(COMMD)
        CALL COMUP(COMMD)

        IREC = 0

        IF(IYEAR.EQ.87.AND.IPER.LT.2)THEN
           NIJ=1
        ELSEIF(IYEAR.EQ.87)THEN
           NIJ=IPV(IPER87,IPER)
        ELSEIF(IYEAR.EQ.88.AND.IPER.EQ.1)THEN
           NIJ=IPV(IPER87,52)
        ELSEIF(IYEAR.EQ.88.AND.IPER.GT.1)THEN
           NIJ=IPV(IPER88,IPER)
        ELSEIF(IYEAR.EQ.89.AND.IPER.EQ.1)THEN
           NIJ=IPV(IPER88,51)
        ELSEIF(IYEAR.EQ.89.AND.IPER.GT.1)THEN
           NIJ=IPV(IPER89,IPER)
        ENDIF

        DO 150 LJK = 1,NIJ
        IF(IPER.LT.10)THEN
```

```
           WRITE(ACAB,20)'STKO',IPER,LJK
 20             FORMAT(A4,I1,I1)
        ELSE
           WRITE(ACAB,25)'STK',IPER,LJK
 25             FORMAT(A3,I2,I1)
        ENDIF

        READ(ACAB,30) DAYOUT
 30     FORMAT(A6)
        OPEN(4,FILE=DAYOUT,STATUS='OLD',ERR=135)
129     READ(4,130,END=140) TOUT
130     FORMAT(A80)
        COMMD = TOUT
        CALL COMPRT(COMMD)
        CALL COMUP(COMMD)
        IREC = IREC + 1
        GO TO 129
135     CALL DISTXT(1,-1,0,'Cannot open '//DAYOUT)
        GO TO 191
145     CLOSE(4)
150     CONTINUE

C.......Test for correct number of records.

        IF(IREC.LT.10)THEN
           WRITE(ACAB,160)'!Z!000',IREC
160             FORMAT(A6,I1)
        ELSEIF(IREC.LT.100)THEN
                WRITE(ACAB,170)'!Z!00',IREC
170              FORMAT(A5,I2)
        ELSEIF(IREC.LT.1000)THEN
           WRITE(ACAB,180)'!Z!0',IREC
180             FORMAT(A4,I3)
        ENDIF

        READ(ACAB,185)COMMD
185     FORMAT(A7)

        CALL COMPRT(COMMD)
        CALL COMUP(COMMD)

C.......Test for correct number of records.

        COMMD = '!E!'
        CALL COMPRT(COMMD)
        CALL COMUP(COMMD)

        GO TO 191

190     CALL DISTXT(1,-1,0,'cannot write to '//DAYOUT)
191     RETURN
        END

        SUBROUTINE NXTMPS

$INCLUDE COM.ICL

        CHARACTER MPSUP*9
        CHARACTER ACAB*10

        IF(IBABEL.EQ.0)RETURN

C.......Determine next MPS.
```

```
      IF(IPER.LT.10)THEN
         MPSUP = 'MPS0'//CFI(IPER,1)
      ELSE
         MPSUP = 'MPS'//CFI(IPER,2)
      ENDIF

C.......Call MPS update programme

      COMMD = 'HELL TEST/TEST'
      CALL COMPRT(COMMD)
      CALL COMOPN(COMMD)

      COMMD = 'ASP/PINNACLE'
      CALL COMPRT(COMMD)
      CALL COMOPN(COMMD)

      COMMD = 'R $TMSOBJ/ASP020'
      CALL COMPRT(COMMD)
      CALL COMUP(COMMD)

C.......Output MPS update to TMS.

      IREC=0
      OPEN(4,FILE=MPSUP,STATUS='OLD',ERR=235)
  229 READ(4,230,END=240) TOUT
  230 FORMAT(A80)

      CALL INQUAN(TOUT)
      IREC=IREC+1
      COMMD = TOUT
      CALL COMPRT(COMMD)
      CALL COMUP(COMMD)

      GO TO 229
  235 CALL DISTXT(1,-1,0,'Cannot open '//MPSUP//'....')

      GO TO 246
  240 CALL DISTXT(1,-1,0,MPSUP//' upload completed....')

  245 CLOSE(4)

C.......Test for correct number of records.

      IF(IREC.LT.10)THEN
         WRITE(ACAB,160)'!Z!000',IREC
  160          FORMAT(A6,I1)
      ELSEIF(IREC.LT.100)THEN
         WRITE(ACAB,170)'!Z!00',IREC
  170          FORMAT(A5,I2)
      ELSEIF(IREC.LT.1000)THEN
         WRITE(ACAB,180)'!Z!0',IREC
  180          FORMAT(A4,I3)
      ENDIF

      READ(ACAB,185)COMMD
  185 FORMAT(A7)

      CALL COMPRT(COMMD)
      CALL COMUP(COMMD)

C.......Test for correct number of records.

      COMMD = '!E!'
      CALL COMPRT(COMMD)
```

```
      CALL COMUP(COMMD)

C.......NOTE: !E! automatically triggers an MRP run.

  246 RETURN
      END

      SUBROUTINE INQUAN(TOUT)

$INCLUDE COM.ICL

      CHARACTER INCDEM*80
      CHARACTER AAA*3
      CHARACTER AAJJ*20
      WRITE(INCDEM,10)TOUT
   10 FORMAT(A80)

      READ(INCDEM,20)AAA,AAJJ,IPERID,IQUAN
   20 FORMAT(A3,A20,I2,1X,I5)

      IQUAN=INT(REAL(IQUAN)*RPV(IPLAN,5))

      WRITE(INCDEM,30)AAA,AAJJ,IPERID,IQUAN
   30 FORMAT(A3,A20,I2,1X,I5)

      READ(INCDEM,40)TOUT
   40 FORMAT(A80)

      RETURN
      END


      SUBROUTINE SALES

$INCLUDE COM.ICL

      CHARACTER SALEUP*9
      CHARACTER ACAB*10

      IF(IBABEL.EQ.0)RETURN

C.......Determine next SALES.

      IF(IPER.LT.10)THEN
              SALEUP = 'SALE0'//CFI(IPER,1)
      ELSE
              SALEUP = 'SALE'//CFI(IPER,2)
      ENDIF

C.......Call SALES update programme

      COMMD = 'HELL TEST/TEST'
      CALL COMPRT(COMMD)
      CALL COMOPN(COMMD)

      COMMD = 'ASP/PINNACLE'
      CALL COMPRT(COMMD)
      CALL COMOPN(COMMD)

      COMMD = 'R $TMSOBJ/ASP030'
      CALL COMPRT(COMMD)
      CALL COMUP(COMMD)

C.......Output SALES update to TMS.
```

```
      IREC=0
      OPEN(4,FILE=SALEUP,STATUS='OLD',ERR=235)

 229  READ(4,230,END=240) TOUT
 230  FORMAT(A80)

      CALL INCSAL(TOUT)

      IREC=IREC+1
      COMMD = TOUT
      CALL COMPRT(COMMD)
      CALL COMUP(COMMD)

      GO TO 229
 235  CALL DISTXT(1,-1,0,'Cannot open '//SALEUP//'....')

      GO TO 246
 240  CALL DISTXT(1,-1,0,SALEUP//' upload completed....')

 245  CLOSE(4)

C.......Test for correct number of records.

      IF(IREC.LT.10)THEN
         WRITE(ACAB,160)'!Z!000',IREC
 160          FORMAT(A6,I1)
      ELSEIF(IREC.LT.100)THEN
              WRITE(ACAB,170)'!Z!00',IREC
 170          FORMAT(A5,I2)
      ELSEIF(IREC.LT.1000)THEN
              WRITE(ACAB,180)'!Z!0',IREC
 180          FORMAT(A4,I3)
      ENDIF

      READ(ACAB,185)COMMD
 185  FORMAT(A7)

      CALL COMPRT(COMMD)
      CALL COMUP(COMMD)

C.......Test for correct number of records.

      COMMD = '!E!'
      CALL COMPRT(COMMD)
      CALL COMUP(COMMD)

C.......NOTE: !E! automatically triggers an MRP run.

 246  RETURN
      END

      SUBROUTINE INCSAL(TOUT)

$INCLUDE COM.ICL

      CHARACTER INCDEM*80
      CHARACTER AAA*3
      CHARACTER AAJJ*20
      CHARACTER DUM*2

      WRITE(INCDEM,10)TOUT
  10  FORMAT(A80)
```

```
      READ(INCDEM,20)AAA,AAJJ,DUM,IQUAN
   20 FORMAT(A3,A20,A2,I9)

      IQUAN=INT(REAL(IQUAN)*RPV(IPLAN,5))

      WRITE(INCDEM,30)AAA,AAJJ,DUM,IQUAN
   30 FORMAT(A3,A20,A2,I9)

      READ(INCDEM,40)TOUT
   40 FORMAT(A80)

      RETURN
      END

      SUBROUTINE MSGDWN

$INCLUDE COM.ICL

      CHARACTER ACAB*10
      CHARACTER ACTFIL*10

      IF(IBABEL.EQ.0)RETURN

C.......Download Action messages to disc from TMS.

      IF(IPER.LT.10)THEN
              ACTFIL='ACTNO'//CFI(IPER,1)
      ELSE
              ACTFIL='ACTN'//CFI(IPER,2)
      ENDIF

      OPEN(4,FILE=ACTFIL,STATUS='NEW',ERR=35)

C.......Call order update programme

      COMMD = 'HELL TEST/TEST'
      CALL COMPRT(COMMD)
      CALL COMOPN(COMMD)

      COMMD = 'ASP/PINNACLE'
      CALL COMPRT(COMMD)
      CALL COMOPN(COMMD)

      COMMD = 'R $TMSOBJ/ASP050'
      CALL COMPRT(COMMD)
      CALL COMDWN(COMMD)

C.......Send ready prompt to the Borroughs

      IREC = 0

   20  COMMD = '!C!'
       CALL COMDWN(COMMD)
       ILEN = LEN(COMMD) - 2

          DO 25 NN = 1,ILEN
                  IF(COMMD(NN:NN+2).EQ.'!Z!') GO TO 40
   25           CONTINUE

      WRITE(4,30) COMMD(4:)
   30 FORMAT(A64)

      IREC = IREC + 1
           GO TO 20
```

```
   35   CALL DISTXT(1,-1,0,'Cannot open '//ACTFIL)

        GO TO 99
   40   CLOSE(4)

C.......Test for correct number of records.
        IF(IREC.LT.10)THEN
           WRITE(ACAB,160)'!Z!000',IREC
  160           FORMAT(A6,I1)
        ELSEIF(IREC.LT.100)THEN
           WRITE(ACAB,170)'!Z!00',IREC
  170           FORMAT(A5,I2)
        ELSEIF(IREC.LT.1000)THEN
           WRITE(ACAB,180)'!Z!0',IREC
  180           FORMAT(A4,I3)
        ENDIF

        READ(ACAB,185)COMMD
  185   FORMAT(A7)

        CALL COMPRT(COMMD)
        CALL COMDWN(COMMD)

   99   RETURN
        END


        SUBROUTINE WIPDWN

$INCLUDE COM.ICL

        CHARACTER ORDERS*9
        CHARACTER ACAB*10

        IF(IBABEL.EQ.0)RETURN

C.......Download WIP orders to disc from TMS.
C.......Determine next SALES.

        IF(IPER.LT.10)THEN
                ORDERS = 'ORDER0'//CFI(IPER,1)
        ELSE
                ORDERS = 'ORDER'//CFI(IPER,2)
        ENDIF

        OPEN(4,FILE=ORDERS,STATUS='NEW',ERR=35)

C.......Call order update programme

        COMMD = 'HELL TEST/TEST'
        CALL COMPRT(COMMD)
        CALL COMOPN(COMMD)

        COMMD = 'ASP/PINNACLE'
        CALL COMPRT(COMMD)
        CALL COMOPN(COMMD)

        COMMD = 'R $TMSOBJ/ASP040'
        CALL COMPRT(COMMD)
        CALL COMDWN(COMMD)

C.......Send ready prompt to the Borroughs

        IREC = 0
```

```
   20   COMMD = '!C!'

        CALL COMDWN(COMMD)

        ILEN = LEN(COMMD) - 2

                DO 25 NN = 1,ILEN
                        IF(COMMD(NN:NN+2).EQ.'!Z!') GO TO 40
   25           CONTINUE

        WRITE(4,30) COMMD(4:57)
   30   FORMAT(A54)

        IREC = IREC + 1

        GO TO 20

   35   CALL DISTXT(1,-1,0,'Cannot open '//ORDERS//'....')

        GO TO 99

   40   CLOSE(4)

C.......Test for correct number of records.

        IF(IREC.LT.10)THEN
                WRITE(ACAB,160)'!Z!000',IREC
  160           FORMAT(A6,I1)
        ELSEIF(IREC.LT.100)THEN
                WRITE(ACAB,170)'!Z!00',IREC
  170           FORMAT(A5,I2)
        ELSEIF(IREC.LT.1000)THEN
                WRITE(ACAB,180)'!Z!0',IREC
  180           FORMAT(A4,I3)
        ENDIF

        READ(ACAB,185)COMMD
  185   FORMAT(A7)

        CALL COMPRT(COMMD)
        CALL COMDWN(COMMD)

        CALL DISTXT(1,-1,0,'WIP order download completed....')

   99   RETURN
        END


        SUBROUTINE COMOPN(COMMD)

$INCLUDE COM.ICL

        CHARACTER TXT*100
        TXT = COMMD
        DO 5 L = LEN(TXT),1,-1
        IF(TXT(L:L).NE.' ') GO TO 8
    5   CONTINUE
    8   TXT = TXT(:L)

C.......Send outgoing text.

        CALL DISTXT(1,-1,0,TXT)
    9   CALL SENDTX(TXT)
```

```
C.......Use  outgoing  text  to determine how to
C.......read incoming text.

        IF(TXT(:4).EQ.'HELL')THEN
   10           CALL GETTEX(TXT,ILEN)
                ILEN = ILEN - 3
                DO 15 NN = 1,ILEN

                   IF(TXT(NN:NN+3).EQ.'#ENT')THEN
                            GO TO 100
                   ELSEIF(TXT(NN:NN+3).EQ.'#LOG')THEN
                            TXT='HELL TEST/TEST'
                            GO TO 9
                   ENDIF

   15           CONTINUE
                GO TO 10
                 ELSEIF(TXT(:4).EQ.'ASP/')THEN
   20           CALL GETTEX(TXT,ILEN)
                ILEN = ILEN - 2
                DO 25 NN = 1,ILEN
                   IF(TXT(NN:NN+2).EQ.'#SE') GO TO 100
   25           CONTINUE
                GO TO 20
             ENDIF
  100   COMMD = TXT
        CALL COMPRT(COMMD)

        RETURN
        END


        SUBROUTINE COMDWN(COMMD)

$INCLUDE COM.ICL

        CHARACTER TXT*100
        TXT = COMMD

C.......Send outgoing text.

        CALL DISTXT(1,-1,0,COMMD(:60))
        CALL SENDTX(TXT)

C.......Use  outgoing  text  to determine how to
C.......read incoming text.

        IF(TXT(:9).EQ.'R $TMSOBJ')THEN
   30           CALL GETTEX(TXT,ILEN)
                ILEN = ILEN - 2
            DO 35 NN = 1,ILEN
                   IF(TXT(NN:NN+2).EQ.'!C!') GO TO 100
   35           CONTINUE
                GO TO 30
        ELSEIF(TXT(:3).EQ.'!C!')THEN
   40           CALL GETTEX(TXT,ILEN)
                ILEN = ILEN - 2
                DO 45 NN = 1,ILEN
        IF(TXT(NN:NN+2).EQ.'!P!'.OR.TXT(NN:NN+2).EQ.'!Z!')THEN
        GO TO 100
        ENDIF
   45           CONTINUE
                GO TO 40
```

```
      ELSEIF(TXT(:3).EQ.'!Z!')THEN
 50           CALL GETTEX(TXT,ILEN)
              ILEN = ILEN - 2
      DO 55 NN = 1,ILEN
              IF(TXT(NN:NN+2).EQ.'#ET')THEN
              GO TO 100
              ENDIF
 55           CONTINUE
      GO TO 50

      ENDIF

 100  COMMD = TXT
      CALL DISTXT(1,-1,0,COMMD(:60))

      RETURN
      END


      SUBROUTINE COMUP(COMMD)

$INCLUDE COM.ICL

      CHARACTER TXT*100
      TXT = COMMD
C.......Send outgoing text.
      CALL DISTXT(1,-1,0,COMMD(:60))
      CALL SENDTX(TXT)
C.......Use  outgoing  text  to determine how to  read  incoming
C.......text.

      IF(TXT(:9).EQ.'R $TMSOBJ')THEN
 30           CALL GETTEX(TXT,ILEN)
              ILEN = ILEN - 2
              DO 35 NN = 1,ILEN
              IF(TXT(NN:NN+2).EQ.'!C!') GO TO 100
 35           CONTINUE
              GO TO 30
      ELSEIF(TXT(:3).EQ.'!P!')THEN
 40           CALL GETTEX(TXT,ILEN)
              ILEN = ILEN - 2
              DO 45 NN = 1,ILEN
              IF(TXT(NN:NN+2).EQ.'!C!')THEN
                 GO TO 100
              ENDIF
 45           CONTINUE
              GO TO 40
      ELSEIF(TXT(:3).EQ.'!Z!')THEN
 50           CALL GETTEX(TXT,ILEN)
              ILEN = ILEN - 2
              DO 55 NN = 1,ILEN
                 IF(TXT(NN:NN+2).EQ.'!Z!')THEN
                           GO TO 100
                 ENDIF
 55           CONTINUE
              GO TO 50
      ELSEIF(TXT(:3).EQ.'!E!')THEN
 60           CALL GETTEX(TXT,ILEN)
              ILEN = ILEN - 2
              DO 65 NN = 1,ILEN
                 IF(TXT(NN:NN+2).EQ.'#ET')THEN
                           GO TO 100
                 ENDIF
 65           CONTINUE
```

```
            GO TO 60
        ENDIF
  100   COMMD = TXT
        CALL DISTXT(1,-1,0,COMMD(:60))

        RETURN
        END


        SUBROUTINE COMPRT(COMMD)

$INCLUDE COM.ICL

        CHARACTER TXT*100

        TXT = COMMD

C.......Send outgoing text to the printer, for validation.

        OPEN(5,FILE='LST:',STATUS='NEW',ERR=99)
             WRITE(5,10)TXT
   10   FORMAT(A80)
        CLOSE(5)
        GO TO 100
   99   CALL DISTXT(1,-1,0,'ERROR opening LST:')
  100   RETURN
        END

        SUBROUTINE SENDTX(TXT)

        INTEGER*2 IARR(300)

        CHARACTER TXT*(*)

        DO 10 L = LEN(TXT),1,-1
           IF(TXT(L:L).NE.' ') GO TO 20
   10   CONTINUE
        L = 0
   20   JJ = 0
        DO 30 II = 1,L
                 JJ = JJ + 1
                IARR(JJ) = ICHAR(TXT(II:II))
   30   CONTINUE
        IARR(JJ+1) = 13
        IARR(JJ+2) = 0
        CALL TALK01(IARR)

        RETURN
        END


        SUBROUTINE GETTEX(TXT,ILEN)

        INTEGER*2 IARR(300)
        CHARACTER TXT*(*)

        CALL TALK00(IARR)

        DO 20 II = 1,300
                IF(IARR(II).EQ.0) THEN
                        ILEN = II - 1
                        TXT = TXT(:ILEN)
                        RETURN
                ENDIF
```

```
      TXT(II:II) = CHAR(IARR(II))
20    CONTINUE

      RETURN
      END


      SUBROUTINE TALK00(IARR)

      INTEGER*2 IARR(*)

      IC = 0
10    I = ITKGET()
      IF(I.EQ.0) GO TO 10
      IF(I.GT.127) I = I - 128
      IF(I.LT.32) THEN
              IF(I.EQ.3.AND.IC.GT.0)THEN
                      IC=IC+1
                      IARR(IC)=0
                      RETURN
              ENDIF
              GO TO 10
      ENDIF
      IF(I.LT.0)THEN
              I = I + 128
              I = MOD(I,128)
      ENDIF
      IC = IC + 1
      IARR(IC) = I
      GO TO 10
      END

      SUBROUTINE TALK01(IARR)

      INTEGER*2 IARR(*)
      INTEGER*1 JJ

      IC = 0
10    IC = IC + 1
      JJ = IARR(IC)
      IF(JJ.EQ.0) GO TO 20
      CALL ITKPUT(JJ)
      IF(JJ.EQ.13) JJ = 10
      GO TO 10
20    RETURN
      END
```

Record event include file RECORD.ICL

```
      SUBROUTINE RECORD

$INCLUDE COM.ICL
      IUT = 0
      DO 10 II = 1,3
         IUT = ISIZOF(IMCPRO(II,1))
         RR   = REAL(IUT)
         RMAC = REAL(IPV(NMAC(1),II))
         RUT  = 100.0*(RR/RMAC)
         CALL ABSROB(IUTILZ(II),RUT)
10    CONTINUE
      II = 4
      IUT = 0
      DO 20 JJ = 1,9
```

```
         IUT = IUT + ISIZOF(IMCPRO(II,JJ))
 20   CONTINUE
      RR   = REAL(IUT)
      RMAC = REAL(IPV(NMAC(1),II))
      RUT  = 100.0*(RR/RMAC)
      CALL ABSROB(IUTILZ(II),RUT)
      II = 5
      IUT = 0
      DO 30 JJ = 1,3
         IUT = IUT + ISIZOF(IMCPRO(II,JJ))
 30   CONTINUE
      RR   = REAL(IUT)
      RMAC = REAL(IPV(NMAC(1),II))
      RUT  = 100.0*(RR/RMAC)
      CALL ABSROB(IUTILZ(II),RUT)
      II = 6
      IUT = 0
      DO 40 JJ = 1,6
         IUT = IUT + ISIZOF(IMCPRO(II,JJ))
 40   CONTINUE
      RR   = REAL(IUT)
      RMAC = REAL(IPV(NMAC(1),II))
      RUT  = 100.0*(RR/RMAC)
      CALL ABSROB(IUTILZ(II),RUT)
      II = 7
      IUT = 0
      DO 50 JJ = 1,2
         IUT = IUT + ISIZOF(IMCPRO(II,JJ))
 50   CONTINUE
      RR   = REAL(IUT)
      RMAC = REAL(IPV(NMAC(1),II))
      RUT  = 100.0*(RR/RMAC)
      CALL ABSROB(IUTILZ(II),RUT)
      II = 8
      IUT = 0
      DO 60 JJ = 1,2
         IUT = IUT + ISIZOF(IMCPRO(II,JJ))
 60   CONTINUE
      RR   = REAL(IUT)
      RMAC = REAL(IPV(NMAC(1),II))
      RUT  = 100.0*(RR/RMAC)
      CALL ABSROB(IUTILZ(II),RUT)
      II = 9
      IUT = 0
      DO 70 JJ = 1,20
         IUT = IUT + ISIZOF(IMCPRO(II,JJ))
 70   CONTINUE
         RR   = REAL(IUT)
         RMAC = REAL(IPV(NMAC(1),II))
         RUT  = 100.0*(RR/RMAC)
         CALL ABSROB(IUTILZ(II),RUT)
         II = 10
         IUT = 0
      DO 80 JJ = 1,3
         IUT = IUT + ISIZOF(IMCPRO(II,JJ))
 80   CONTINUE
      RR   = REAL(IUT)
      RMAC = REAL(IPV(NMAC(1),II))
      RUT  = 100.0*(RR/RMAC)
      CALL ABSROB(IUTILZ(II),RUT)
      II = 11
      IUT = 0
      DO 90 JJ = 1,8
         IUT = IUT + ISIZOF(IMCPRO(II,JJ))
```

```
 90    CONTINUE
         RR   = REAL(IUT)
         RMAC = REAL(IPV(NMAC(1),II))
         RUT  = 100.0*(RR/RMAC)
         CALL ABSROB(IUTIL"(II),RUT)
         CALL ABSROB(INPROG(1),RPV(IWIP(1),1))
         CALL ABSROB(INPROG(2),RPV(IWIP(2),1))
       DO 110 JJ =1,11
          AA=0
          KK = ISIZOF(IBATIN(JJ))
          IF(KK.GT.0)THEN
             DO 100 LL =1,KK
                 AA = AA+RAT(MEMBER(IBATIN(JJ),LL),4)
100          CONTINUE
          CALL ABSROB(INQUE(JJ),AA)
          ELSE
          CALL ABSROB(INQUE(JJ),0.0)
          ENDIF
110    CONTINUE
       BB=0
       DO 130 JJ =1,11
          KK = ISIZOF(IBAOUT(JJ))
          IF(KK.GT.0)THEN
                  DO 120 LL =1,KK
                          BB = BB+RAT(MEMBER(IBAOUT(JJ),LL),2)
120                    CONTINUE
          ENDIF
130    CONTINUE
       CALL ABSROB(INMOVE(1),BB)
       CALL SCHEDL('RECORD',RPV(IPLAN,4),IMACH(20,1))
       CALL DONTC
       RETURN
       END
```

Statistics Initialization.

```
       DO 5 J = 1,11
          IF(J.LT.10)THEN
                  CALL MAKETS(INQUE(J),'QU '//CFI(J,1))
          ELSE
                  CALL MAKETS(INQUE(J),'QU'//CFI(J,2))
          ENDIF
 5     CONTINUE

       DO 10 J = 1,11
          IF(J.LT.10)THEN
                  CALL MAKETS(IUTILZ(J),'Ut '//CFI(J,1))
          ELSE
                  CALL MAKETS(IUTILZ(J),'Ut'//CFI(J,2))
          ENDIF
10     CONTINUE

       CALL MAKETS(IFLOTM(1),'BFLO')
       CALL MAKETS(IFLOTM(2),'SFLO')
       CALL MAKETS(IBASIZ(1),'BSIZ')
       CALL MAKETS(IBASIZ(2),'SSIZ')
       CALL MAKETS(ILATE(1),'BLAT')
       CALL MAKETS(ILATE(2),'SLAT')

       DO 7 ITY = 1,99
       CALL MAKETS(SLAT(ITY),'L '//CFI(ITY,2))
 7     CONTINUE

       DO 8 ITT = 100,255
       CALL MAKETS(BLAT(ITT),'L'//CFI(ITT,3))
```

```
 8      CONTINUE
        CALL MAKETS(INMOVE(1),´BMOV´)
        CALL MAKETS(INMOVE(2),´SMOV´)
        CALL MAKETS(INPROG(1),´BWIP´)
        CALL MAKETS(INPROG(2),´SWIP´)
        DO 11 JJ = 1,99
        CALL MAKETS(SLED(JJ),´SF´//CFI(JJ,2))
11      CONTINUE

        DO 12 JJ = 100,255
        CALL MAKETS(BLED(JJ),´F´//CFI(JJ,3))
12      CONTINUE
        DO 13 JJ = 1,99
        CALL MAKETS(SSIZE(JJ),´SS´//CFI(JJ,2))
13      CONTINUE

        DO 14 JJ = 100,255
        CALL MAKETS(BSIZE(JJ),´S´//CFI(JJ,3))
14      CONTINUE
        DO 25 JJ = 1,99
        CALL MAKEPT(IACESS(JJ),´A´//CFI(JJ,2),´I´,3)
25      CONTINUE
        DO 16 JJ = 1,255
        CALL MAKETS(SLEV(JJ),´L´//CFI(JJ,3))
16      CONTINUE
```

Appendix 3 FCL's Historical Uncertain MPSs.

Uncertain MPS: Product 1.

Demand Periods.

	per	11	15	19	24	28	32	37	41	45	49	53
U	2	0	0	45	85							
p	3	0	0	45	85							
d	4	0	0	45	85							
a	5	0	0	45	85							
t	6	0	0	45	85							
e	7	0	0	45	85							
	8	0	0	45	85							
P	9	0	0	45	85							
e	10	0	0	45	85							
r	11	0	0	45	85	100						
i	12		0	45	85	100						
o	13		0	45	85	100						
d	14		0	45	85	100						
	15		0	45	85	100	100					
	16			45	85	100	100					
	17			45	85	100	100					
	18			45	85	100	100					
	19			45	85	100	100	0				
	20				85	100	100	0				
	21				85	100	100	0				
	22				85	120	90	0				
	23				85	120	90	0				
	24				85	120	90	0	85			
	25					120	90	0	85			
	26					100	100	0	100			
	27					100	100	0	100			
	28					100	100	0	100	60		
	29						100	0	100	60		
	30						100	0	100	60		
	31						100	0	100	60		
	32						100	0	100	60	90	
	33							0	100	60	90	
	34							0	100	60	90	
	35							0	90	70	90	
	36							0	90	70	90	
	37							0	85	70	90	80
	38								85	70	90	80
	39								85	80	90	80
	40								85	80	85	80
	41								85	80	85	80
	42									80	85	80
	43									80	85	80

Uncertain MPS: Product 5.

per	11	15	19	24	28	32	37	41	45	49	53
2	51	0	0	0	0	0	0	0			
3	51	0	0	0	0	0	0	0			
4	51	0	0	0	0	0	0	0			
5	51	0	0	0	0	0	0	0			
6	51	0	0	0	0	0	0	0			
7	51	0	0	0	0	0	0	0			
8	51	0	0	0	0	0	0	0			
9	51	0	0	0	0	0	0	0			
10	51	0	0	0	0	0	0	0			
11	51	0	0	0	0	0	0	0			
12		0	50	0	0	0	0	0			
13		0	50	0	0	0	0	0			
14		0	0	20	0	0	0	0	20	0	20
15		0	0	20	0	0	0	0	20	0	20
16			0	20	0	15	0	0	20	0	20
17			0	20	0	15	0	0	20	0	20
18			0	80	0	15	0	0	20	0	20
19			0	80	0	15	0	0	20	0	20
20				50	0	15	0	0	20	0	20
21				50	0	15	0	0	0	20	0
22				30	0	15	0	0	0	20	0
23				30	0	15	0	0	0	20	0
24				30	0	15	0	0	0	20	0
25					0	15	0	0	0	20	0
26					0	15	0	0	0	40	0
27					0	35	0	0	0	40	0
28					0	35	0	0	0	40	0
29						35	0	0	0	40	0
30						35	0	20	0	20	0
31						35	0	20	0	20	0
32						35	0	10	0	20	0
33							0	10	0	20	0
34							0	10	0	30	0
35							0	10	0	30	0
36							0	20	0	30	0
37							0	20	0	30	0
38								30	0	30	0
39								30	0	20	0
40								20	0	20	0
41								20	0	20	0
42									0	20	0
43									0	20	0

Uncertain MPS: Product 10.

per	11	15	19	24	28	32	37	41	45	49	53
2	200	200	200	100							
3	200	200	200	100							
4	200	200	200	100							
5	200	200	200	100							
6	200	200	200	100							
7	200	200	200	100							
8	200	200	200	100							
9	200	200	200	100							
10	200	200	200	100							
11	200	200	200	100							
12		100	165	100							
13		145	165	200							
14		145	165	200							
15		145	150	200	100						
16			150	300	100						
17			150	300	50						
18			150	300	50						
19			150	300	100	100					
20				300	100	100					
21				300	100	100					
22				300	100	100					
23				300	100	100					
24				300	100	100	0				
25					100	100	0				
26					100	260	0				
27					100	260	50				
28					100	260	50	20			
29						260	50	20			
30						260	30	20			
31						260	30	20			
32						260	30	20	125		
33							30	20	125		
34							30	20	125		
35							30	15	125		
36							30	15	100		
36							30	15	100	100	
37								15	100	100	
38								15	100	100	
39								15	120	100	
40								15	120	100	100
41									120	100	100
42									120	100	100
43											

Uncertain MPS: Product 12.

per	11	15	19	24	28	32	37	41	45	49	53
2	50	50	0	75	75						
3	50	50	0	75	75						
4	50	50	0	75	75						
5	50	50	0	75	75						
6	50	50	0	75	75						
7	50	50	0	75	75						
8	50	50	0	75	75						
9	50	50	0	75	75						
10	50	50	0	75	75						
11	50	50	0	75	75	50					
12		50	0	75	75	50					
13		50	0	75	75	50					
14		50	0	75	75	50					
15		50	50	75	100	100	0				
16			50	75	100	100	40				
17			50	75	100	100	40				
18			50	100	100	100	40				
19			50	100	100	100	40	0			
20				100	100	100	40	20			
21				100	150	50	40	20			
22				100	150	50	40	20			
23				100	150	50	40	20			
24				100	150	50	20	10	0		
25					150	50	20	10	0		
26					150	50	20	10	0		
27					150	50	20	10	0		
28					150	50	10	10	0	75	
29						50	10	10	0	75	
30						50	10	20	75	75	
31						50	10	20	75	75	
32						50	20	20	75	175	75
33							20	20	75	175	75
34							20	20	75	175	75
35							20	20	75	175	75
36							20	20	50	100	25
37							20	20	50	100	25
38								20	50	100	25
39								20	50	100	25
40								20	50	100	25
41								20	75	100	25
42									75	100	25
43									75	100	25

Uncertain MPS: Product 16.

per	11	15	19	24	28	32	37	41	45	49	53
2	200	200	100								
3	200	200	100								
4	200	200	100								
5	200	200	100								
6	200	200	100								
7	200	200	100								
8	200	200	100								
9	200	200	100								
10	200	200	100								
11	200	200	100	100							
12		200	100	150							
13		100	100	150							
14		100	100	150							
15		100	100	150	100						
16			100	150	100						
17			100	0	250						
18			100	0	250						
19			100	0	250	150					
20				0	250	150					
21				0	180	150					
22				0	180	150					
23				0	180	150					
24				0	180	150					
25					180	200					
26					180	200					
27					180	200					
28					180	230					
29						230					
30						230					
31						230					
32						230					
33											
34											
35											
36											
37											
38											
39											
40											
41											
42											
43											

Uncertain MPS: Product 18.

per	11	15	19	24	28	32	37	41	45	49	53
2	4	3	2	5	6	6	0	0			
3	4	3	2	5	6	6	0	0			
4	4	3	2	5	6	6	0	0			
5	4	3	2	5	6	6	0	0			
6	4	3	2	5	6	6	0	0			
7	4	3	2	5	6	6	0	0			
8	4	3	2	5	6	6	0	0			
9	4	3	2	5	6	6	0	0			
10	4	3	2	5	6	6	0	0			
11	4	3	2	5	6	6	0	0			
12		3	2	5	6	6	0	0			
13		3	2	0	8	9	0	0			
14		3	2	0	8	9	0	0	5	6	5
15		3	2	0	8	9	0	0	5	6	5
16			2	0	8	9	5	0	5	6	5
17			2	0	8	9	5	0	5	6	5
18			2	0	8	9	5	0	5	6	5
19			2	0	8	9	5	0	5	6	5
20				4	8	9	5	0	5	6	5
21				4	5	9	4	0	5	6	5
22				4	5	9	4	0	3	6	0
23				4	5	9	4	5	3	6	0
24				4	5	9	4	5	3	6	0
25					5	9	4	5	3	6	0
26					5	9	4	5	3	6	0
27					5	9	4	5	3	6	0
28					5	9	4	5	3	6	0
29						9	4	5	3	6	0
30						9	4	5	3	6	5
31						9	4	5	3	6	5
32						9	4	5	3	6	5
33							4	5	3	6	5
34							4	5	3	6	5
35							4	5	3	1	5
36							4	5	3	1	5
37							4	5	3	1	5
38								5	3	1	5
39								5	3	1	5
40								5	3	1	5
41								5	3	1	5
42									3	1	5
43									3	1	5

Uncertain MPS: Product 37.

per	11	15	19	24	28	32	37	41	45	49	53
2	60	0	0								
3	60	0	0								
4	60	0	0								
5	60	0	0								
6	60	0	0								
7	60	0	0								
8	60	0	0								
9	60	0	0								
10	60	0	0								
11	60	0	0	0							
12		0	0	0							
13		0	0	0							
14		0	0	0							
15		0	0	0	60						
16			0	0	60						
17			0	0	60						
18			0	0	60						
19			0	0	60	20					
20				0	60	20					
21				0	60	10					
22				0	50	10					
23				0	50	10	10				
24					50	10	10				
25					50	10	10				
26					50	10	10				
27					50	20	10				
28					50	20	10	60			
29						20	10	60			
30						20	10	60			
31						20	10	60			
32						20	10	60	20		
33							15	40	10		
34							15	40	10		
35							15	40	10		
36							15	40	10		
37							15	40	10	20	
38								70	10	20	
39								70	10	20	
40								70	10	20	
41								70	10	20	
42									10	20	20
43									10	20	20

Uncertain MPS: Product 41.

per	11	15	19	24	28	32	37	41	45	49	53
2	20	16	16								
3	20	16	16								
4	20	16	16								
5	20	16	16								
6	20	16	16								
7	20	16	16								
8	20	16	16								
9	20	16	16								
10	20	16	16								
11	20	16	16	4							
12		16	16	4							
13		16	16	4							
14		16	16	4							
15		16	16	4	0						
16			16	4	0						
17			16	4	0						
18			16	4	0						
19			16	4	0	0					
20				4	0	0					
21				0	0	0					
22				0	0	0					
23				0	0	0					
24				0	0	0	1				
25					0	0	1				
26					0	0	1				
27					0	0	1				
28					0	0	1	1			
29						0	1	1			
30						0	1	1			
31						0	1	1			
32						0	1	1	0		
33							1	1	0		
34							1	1	0		
35							1	1	0		
36							1	1	0		
37							1	1	0		
38								1	0		
39								1	0		
40								1	0		
41								1	0		
42								1	0		
43								1	0		

Uncertain MPS: Product 47.

per	11	15	19	24	28	32	37	41	45	49	53
2	2	2	2	2	0	0					
3	2	2	2	2	0	0					
4	2	2	2	2	0	0					
5	2	2	2	2	0	0					
6	2	2	2	2	0	0					
7	2	2	2	2	0	0					
8	2	2	2	2	0	0					
9	2	2	2	2	0	0					
10	2	2	2	2	0	0					
11	2	2	2	2	0	0	0				
12		2	2	2	0	0	0				
13		2	2	3	0	0	0				
14		2	2	3	0	0	0				
15		2	2	3	0	2	0	0			
16			2	3	0	0	0	0			
17			2	3	0	0	0	0			
18			2	3	0	0	0	0			
19			2	3	0	0	0	0	4		
20				3	0	0	0	0	4		
21				2	0	2	2	0	4		
22				2	0	2	2	0	4		
23				2	0	2	2	0	4		
24				2	0	2	2	0	4	3	
25					0	2	2	0	4	3	
26					0	2	2	0	4	3	
27					0	2	2	0	4	3	
28					0	2	2	0	4	3	2
29						2	2	0	4	3	2
30						2	2	0	2	3	2
31						2	2	0	2	3	2
32						2	2	0	2	3	2
33							2	0	2	3	2
34							1	0	3	3	4
35							1	0	3	3	4
36							1	0	3	3	4
37							1	0	3	3	4
38								0	4	4	5
39								0	4	4	5
40								0	4	4	5
41								0	4	4	5
42								0	4	4	5
43								0	4	4	5

Uncertain MPS: Product 56.

per	11	15	19	24	28	32	38	41	45	49	53
2	60	0	0								
3	60	0	0								
4	60	0	0								
5	60	0	0								
6	60	0	0								
7	60	0	0								
8	60	0	0								
9	60	0	0								
10	60	0	0								
11	60	0	0	0							
12		0	0	0							
13		0	0	0							
14		0	0	0							
15		0	0	0	60						
16			0	0	60						
17			0	0	60						
18			0	0	60						
19			0	0	60	20					
20				0	60	20					
21				0	60	20					
22				0	60	20					
23				0	60	20	10				
24					30	30	15				
25					30	30	15				
26					30	30	15				
27					30	30	15				
28					30	30	15	10			
29						30	10	10			
30						30	10	10			
31						30	10	10			
32						30	10	10	5		
33							10	5	5		
34							20	5	5		
35							20	5	5		
36							20	5	5		
37							20	5	5	10	
38								5	5	10	
39								5	10	10	
40								5	10	10	
41								5	10	10	10
42									10	10	10
43									10	10	10

Uncertain MPS: Product 67.

per	11	15	19	24	28	32	38	41	45	49	53
2	0	0	6	6							
3	0	0	6	6							
4	0	0	6	6							
5	0	0	6	6							
6	0	0	6	6							
7	0	0	6	6							
8	0	0	6	6							
9	0	0	6	6							
10	0	0	6	6							
11	0	0	6	6	6						
12		0	6	6	6						
13		0	6	6	6						
14		0	6	6	6						
15		0	6	6	6	6					
16			6	6	6	6					
17			0	6	0	0					
18			0	6	0	0					
19			0	6	0	0	0				
20				6	3	3	4				
21				6	3	3	4				
22				6	3	3	4				
23				6	3	3	4	3			
24					3	3	4	3			
25					3	3	4	3			
26					3	3	4	3			
27					3	8	4	4			
28					3	8	5	5	6		
29						8	5	5	6		
30						8	5	5	6		
31						8	5	5	6		
32						8	5	5	6	6	
33							5	5	6	6	
34							6	3	6	6	
35							6	3	6	6	
36							6	3	6	6	
37							6	3	6	6	6
38								6	6	0	6
39								6	6	0	6
40								6	6	0	6
41								6	6	0	6
42									6	0	6
43									6	0	6

Uncertain MPS: Product 68.

per	11	15	19	24	28	32	38	41	45	49	53
2	5	0	36	0							
3	5	0	36	0							
4	5	0	36	0							
5	5	0	36	0							
6	5	0	36	0							
7	5	0	36	0							
8	5	0	36	0							
9	5	0	36	0							
10	5	0	36	0							
11	5	0	36	0	0						
12		4	48	0	18						
13		9	48	0	18						
14		9	48	0	18						
15		9	48	0	18	7					
16			48	0	18	7					
17			48	0	18	7					
18			48	0	18	7					
19			48	0	18	7	0				
20				2	16	7	7				
21				2	16	7	7				
22				2	16	7	7				
23				2	17	7	8				
24					17	6	8	3			
25					17	6	8	3			
26					17	6	8	3			
27					17	6	8	3			
28					17	6	8	3	1		
29						5	5	3	2		
30						5	5	3	2		
31						5	5	3	2		
32						5	5	7	2	7	
33							5	7	0	7	
34							7	7	0	7	
35							7	7	0	7	
36							7	7	0	7	
37							7	7	0	7	3
38								6	3	7	7
39								6	3	7	7
40								6	3	7	7
41								6	3	7	7
42									3	7	7
43									3	7	7

Uncertain MPS: Product 70.

per	11	15	19	24	28	32	38	41	45	49	53
2	0	0	14	0	0	0	0	0			
3	0	0	14	0							
4	0	0	14	0							
5	0	0	14	0							
6	0	0	14	0							
7	0	0	14	0							
8	0	0	14	0							
9	0	0	14	0							
10	0	0	14	0							
11	0	0	14	0	0						
12		0	14	0	0						
13		0	14	0	0						
14		0	14	0	0						
15		0	15	0	15	0					
16			15	15	0	15					
17			15	15	0	15					
18			15	15	0	15					
19			15	15	0	15	0				
20				0	15	15	0				
21				0	15	15	0				
22				0	15	15	0				
23				0	15	15	0				
24					15	10	10	10			
25					15	10	10	10			
26					15	10	10	10			
27					15	10	10	10			
28					15	10	10	10	10		
29						15	15	15	10		
30						15	15	15	10		
31						15	15	15	10		
32						15	15	15	10	15	
33							10	12	8	10	
34							10	12	8	10	
35							10	10	8	10	
36							10	10	8	10	
37							10	10	8	10	15
38								15	8	10	10
39								15	15	10	10
40								15	15	10	10
41								15	15	10	10
42									15	10	10
43									15	10	10

Uncertain MPS: Product 201.

per	11	15	19	23	28	32	37	41	45	49	53
2	10	0									
3	10	0									
4	10	0									
5	10	0									
6	10	0									
7	10	0									
8	10	0									
9	10	0									
10	10	0									
11	10	0	0								
12		0	0								
13		0	0								
14		0	0								
15		0	0	220							
16			10	220							
17			10	220							
18			10	220							
19			10	220	220						
20				220	220						
21				220	220						
22				220	350						
23				220	350						
24					350	200					
25					350	200					
26					220	200					
27					220	400					
28					220	400	0				
29						400	0				
30						350	0				
31						350	0				
32						350	0	150			
33							0	150			
34							0	150			
35							0	150			
36							0	200			
37							0	200	150		
38								200	150		
39								300	150		
40								300	150		
41								300	150	300	
42									150	300	
43									150	300	

Uncertain MPS: Product 202.

per	11	15	19	23	28	32	37	41	45	49	53
2	10	0									
3	10	0									
4	10	0									
5	10	0									
6.	10	0									
7	10	0									
8	10	0									
9	10	0									
10	10	0									
11	10	0	0								
12		0	0								
13		0	0								
14		0	0								
15		0	0	220							
16			10	220							
17			10	220							
18			10	220							
19			10	220	220						
20				220	220						
21				220	220						
22				220	220						
23				220	220						
24					220	400					
25					220	400					
26					220	400					
27					220	400					
28					220	400	0				
29						350	0				
30						350	0				
31						350	0				
32						350	0	200			
33							0	200			
34							0	200			
35							0	150			
36							0	150			
37							0	150	0		
38								150	0		
39								300	0		
40								300	0		
41								300	0	300	
42									0	300	
43									0	300	

Uncertain MPS: Product 225.

per	11	15	19	23	28	32	37	41	45	49	53
2	0	0									
3	0	0									
4	0	0									
5	0	0									
6	0	0									
7	0	0									
8	0	0									
9	0	0									
10	0	0									
11	0	0	0								
12		0	0								
13		0	0								
14		0	0								
15		0	0	0							
16			0	0							
17			0	0							
18			0	0							
19			0	0	0						
20				0	0						
21				0	0						
22				0	0						
23				0	0						
24					50	50					
25					50	50					
26					50	50					
27					50	50					
28					50	50	50				
29						0	50				
30						0	50				
31						0	50				
32						0	50	50			
33							50	0			
34							50	0			
35							50	0			
36							50	0			
37							50	0	50		
38								0	50		
39								0	50		
40								0	50		
41								0	50	0	
42									50	0	
43									50	0	

Uncertain MPS: Product 226.

per	11	15	19	23	28	32	37	41	45	49	53
2	0	0									
3	0	0									
4	0	0									
5	0	0									
6	0	0									
7	0	0									
8	0	0									
9	0	0									
10	0	0									
11	0	0	0								
12		0	0								
13		0	0								
14		0	0								
15		0	0	0							
16			0	0							
17			0	0							
18			0	0							
19			0	0	0						
20				0	0						
21				0	0						
22				0	0						
23				0	0	550					
24					0	550					
25					0	550					
26					0	550					
27					0	550					
28					0	550	0				
29						550	550				
30						550	550				
31						550	550				
32						550	550	50			
33							550	50			
34							550	50			
35							550	50			
36							550	50			
37							550	150	0		
38							550	150	0		
39							550	150	0		
40							550	150	0		
41							550	150	0	150	
42								50	100	50	
43								50	100	50	

Appendix 4 Original Deterministic MPS.

Part no. Original MPS. Week no --->	5	6	7	8	9	10	11	12	13
1	0	0	0	0	0	0	0	0	45
5	51	0	0	0	0	0	0	0	0
10	200	0	0	0	200	0	0	0	200
12	50	0	0	0	50	0	0	0	0
16	200	0	0	0	200	0	0	0	100
18	4	0	0	0	3	0	0	0	2
37	60	0	0	0	0	0	0	0	0
41	20	0	0	0	16	0	0	0	16
47	2	0	0	0	2	0	0	0	2
56	60	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	6
68	0	0	0	0	0	0	0	0	36
70	0	0	0	0	0	0	0	0	14
201	10	0	0	0	0	0	0	0	0
202	10	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0
Total	667	0	0	0	471	0	0	0	421

Part no. Original MPS. Week no --->	14	15	16	17	18	19	20	21	22
1	0	0	0	0	85	0	0	0	100
5	0	0	0	0	0	0	0	0	0
10	0	0	0	0	100	0	0	0	100
12	0	0	0	0	75	0	0	0	75
16	0	0	0	0	100	0	0	0	0
18	0	0	0	0	5	0	0	0	6
37	0	0	0	0	0	0	0	0	10
41	0	0	0	0	4	0	0	0	0
47	0	0	0	0	2	0	0	0	0
56	0	0	0	0	0	0	0	0	10
67	0	0	0	0	6	0	0	0	6
68	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0
201	0	0	0	0	1020	0	0	0	0
202	0	0	0	0	1020	0	0	0	0
225	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	2417	0	0	0	307

Part no. Original MPS. Week no --->

Part no.	23	24	25	26	27	28	29	30	31
1	0	0	0	100	0	0	0	0	0
5	0	0	0	0	0	0	0	0	15
10	0	0	0	100	0	0	0	0	50
12	0	0	0	50	0	0	0	0	40
16	0	0	0	0	0	0	0	0	0
18	0	0	0	6	0	0	0	0	5
37	0	0	0	10	0	0	0	0	10
41	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0
56	0	0	0	10	0	0	0	0	10
67	0	0	0	6	0	0	0	0	0
68	0	0	0	7	0	0	0	0	7
70	0	0	0	15	0	0	0	0	15
201	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	0	0	0
225	0	0	0	50	0	0	0	0	50
226	0	0	0	550	0	0	0	0	550
Total	0	0	0	904	0	0	0	0	752

Part no. Original MPS. Week no --->

Part no.	LOAD	MEAN	Std.	CV	CV+25%	CV-25%
1	330	8.25	25.75	3.12	3.90	2.34
5	66	1.65	8.24	5.00	6.24	3.75
10	950	23.75	57.00	2.40	3.00	1.80
12	340	8.50	20.89	2.46	3.07	1.84
16	600	15.00	47.70	3.18	3.97	2.38
18	31	.78	1.78	2.30	2.87	1.72
37	90	2.25	9.61	4.27	5.34	3.20
41	56	1.40	4.61	3.29	4.11	2.47
47	8	.20	.60	3.00	3.75	2.25
56	90	2.25	9.61	4.27	5.34	3.20
67	24	.60	1.80	3.00	3.75	2.25
68	50	1.25	5.77	4.62	5.77	3.46
70	44	1.10	3.87	3.51	4.39	2.64
201	1030	25.75	159.22	6.18	7.73	4.64
202	1030	25.75	159.22	6.18	7.73	4.64
225	100	2.50	10.90	4.36	5.45	3.27
226	1100	27.50	119.87	4.36	5.45	3.27
Total	5939					

Appendix 5. Deterministic MPS +25% Load.

Part no. Original MPS + 25% Load. Week no --->	5	6	7	8	9	10	11	12	13
1	0	0	0	0	0	0	0	0	56
5	64	0	0	0	0	0	0	0	0
10	250	0	0	0	250	0	0	0	250
12	63	0	0	0	63	0	0	0	0
16	250	0	0	0	250	0	0	0	125
18	5	0	0	0	4	0	0	0	3
37	75	0	0	0	0	0	0	0	0
41	25	0	0	0	20	0	0	0	20
47	3	0	0	0	3	0	0	0	3
56	75	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	8
68	0	0	0	0	0	0	0	0	45
70	0	0	0	0	0	0	0	0	18
201	13	0	0	0	0	0	0	0	0
202	13	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0
Total	834	0	0	0	589	0	0	0	526

Part no. Original MPS + 25% Load. Week no --->	14	15	16	17	18	19	20	21	22
1	0	0	0	0	106	0	0	0	125
5	0	0	0	0	0	0	0	0	0
10	0	0	0	0	125	0	0	0	125
12	0	0	0	0	94	0	0	0	94
16	0	0	0	0	125	0	0	0	0
18	0	0	0	0	6	0	0	0	8
37	0	0	0	0	0	0	0	0	13
41	0	0	0	0	5	0	0	0	0
47	0	0	0	0	3	0	0	0	0
56	0	0	0	0	0	0	0	0	13
67	0	0	0	0	8	0	0	0	8
68	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0
201	0	0	0	0	1275	0	0	0	0
202	0	0	0	0	1275	0	0	0	0
225	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	3021	0	0	0	384

Part no. Original MPS + 25% Load. Week no --->

	23	24	25	26	27	28	29	30	31
1	0	0	0	125	0	0	0	0	0
5	0	0	0	0	0	0	0	0	19
10	0	0	0	125	0	0	0	0	63
12	0	0	0	63	0	0	0	0	50
16	0	0	0	0	0	0	0	0	0
18	0	0	0	8	0	0	0	0	6
37	0	0	0	13	0	0	0	0	13
41	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0
56	0	0	0	13	0	0	0	0	13
67	0	0	0	8	0	0	0	0	0
68	0	0	0	9	0	0	0	0	9
70	0	0	0	19	0	0	0	0	19
201	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	0	0	0
225	0	0	0	63	0	0	0	0	63
226	0	0	0	688	0	0	0	0	688
Total	0	0	0	1130	0	0	0	0	940

Part no. Original MPS + 25% Load. Week no --->

	LOAD	MEAN	Std.	CV	CV+25%	CV-25%
1	413	10.31	32.19	3.12	3.90	2.34
5	83	2.06	10.30	5.00	6.24	3.75
10	1188	29.69	71.24	2.40	3.00	1.80
12	425	10.63	26.12	2.46	3.07	1.84
16	750	18.75	59.62	3.18	3.97	2.38
18	39	.97	2.23	2.30	2.87	1.72
37	113	2.81	12.02	4.27	5.34	3.20
41	70	1.75	5.76	3.29	4.11	2.47
47	10	.25	.75	3.00	3.75	2.25
56	113	2.81	12.02	4.27	5.34	3.20
67	30	.75	2.25	3.00	3.75	2.25
68	63	1.56	7.21	4.62	5.77	3.46
70	55	1.38	4.83	3.51	4.39	2.64
201	1288	32.19	199.02	6.18	7.73	4.64
202	1288	32.19	199.02	6.18	7.73	4.64
225	125	3.13	13.62	4.36	5.45	3.27
226	1375	34.38	149.84	4.36	5.45	3.27
Total	7424					

Appendix 6 Deterministic MPS -25% Load.

Part no.	5	6	7	8	9	10	11	12	13
1	0	0	0	0	0	0	0	0	34
5	38	0	0	0	0	0	0	0	0
10	150	0	0	0	150	0	0	0	150
12	38	0	0	0	38	0	0	0	0
16	150	0	0	0	150	0	0	0	75
18	3	0	0	0	2	0	0	0	2
37	45	0	0	0	0	0	0	0	0
41	15	0	0	0	12	0	0	0	12
47	2	0	0	0	2	0	0	0	2
56	45	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	5
68	0	0	0	0	0	0	0	0	27
70	0	0	0	0	0	0	0	0	11
201	8	0	0	0	0	0	0	0	0
202	8	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0
Total	500	0	0	0	353	0	0	0	316

Part no. Original MPS - 25% Load. Week no --->

Part no.	14	15	16	17	18	19	20	21	22
1	0	0	0	0	64	0	0	0	75
5	0	0	0	0	0	0	0	0	0
10	0	0	0	0	75	0	0	0	75
12	0	0	0	0	56	0	0	0	56
16	0	0	0	0	75	0	0	0	0
18	0	0	0	0	4	0	0	0	5
37	0	0	0	0	0	0	0	0	8
41	0	0	0	0	3	0	0	0	0
47	0	0	0	0	2	0	0	0	0
56	0	0	0	0	0	0	0	0	8
67	0	0	0	0	5	0	0	0	5
68	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0
201	0	0	0	0	765	0	0	0	0
202	0	0	0	0	765	0	0	0	0
225	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	1813	0	0	0	230

Part no. Original MPS - 25% Load. Week no --->

Part no.	23	24	25	26	27	28	29	30	31
1	0	0	0	75	0	0	0	0	0
5	0	0	0	0	0	0	0	0	11
10	0	0	0	75	0	0	0	0	38
12	0	0	0	38	0	0	0	0	30
16	0	0	0	0	0	0	0	0	0
18	0	0	0	5	0	0	0	0	4
37	0	0	0	8	0	0	0	0	8
41	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0
56	0	0	0	8	0	0	0	0	8
67	0	0	0	5	0	0	0	0	0
68	0	0	0	5	0	0	0	0	5
70	0	0	0	11	0	0	0	0	11
201	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	0	0	0
225	0	0	0	38	0	0	0	0	38
226	0	0	0	413	0	0	0	0	413
Total	0	0	0	678	0	0	0	0	564

Part no. Original MPS - 25% Load. Week no --->

Part no.	LOAD	MEAN	Std.	CV	CV+25%	CV-25%
1	248	6.19	19.31	3.12	3.90	2.34
5	50	1.24	6.18	5.00	6.24	3.75
10	713	17.81	42.75	2.40	3.00	1.80
12	255	6.38	15.67	2.46	3.07	1.84
16	450	11.25	35.77	3.18	3.97	2.38
18	23	.58	1.34	2.30	2.87	1.72
37	68	1.69	7.21	4.27	5.34	3.20
41	42	1.05	3.46	3.29	4.11	2.47
47	6	.15	.45	3.00	3.75	2.25
56	68	1.69	7.21	4.27	5.34	3.20
67	18	.45	1.35	3.00	3.75	2.25
68	38	.94	4.33	4.62	5.77	3.46
70	33	.83	2.90	3.51	4.39	2.64
201	773	19.31	119.41	6.18	7.73	4.64
202	773	19.31	119.41	6.18	7.73	4.64
225	75	1.88	8.17	4.36	5.45	3.27
226	825	20.63	89.90	4.36	5.45	3.27
Total	4454					

Appendix 7. Deterministic MPS +25% Lumpiness.

Part no.	Original MPS +25% CV. 5	6	7	8	9	10	11	12	Week no. ---> 13
1	0	0	0	0	0	0	0	0	130
5	66	0	0	0	0	0	0	0	0
10	300	0	0	0	100	0	0	0	310
12	100	0	0	0	0	0	0	0	0
16	324	0	0	0	76	0	0	0	200
18	6	0	0	0	1	0	0	0	1
37	77	0	0	0	0	0	0	0	0
41	32	0	0	0	4	0	0	0	19
47	4	0	0	0	0	0	0	0	2
56	8	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	12
68	0	0	0	0	0	0	0	0	46
70	0	0	0	0	0	0	0	0	25
201	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0
tot	917	0	0	0	181	0	0	0	745

Part no.	Original MPS +25% CV. 14	15	16	17	18	19	20	Week no. ---> 21
1	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
12	0	0	0	0	120	0	0	0
16	0	0	0	0	0	0	0	0
18	0	0	0	0	6	0	0	0
37	0	0	0	0	0	0	0	0
41	0	0	0	0	1	0	0	0
47	0	0	0	0	2	0	0	0
56	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
201	0	0	0	0	1030	0	0	0
202	0	0	0	0	1030	0	0	0
225	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0
total	0	0	0	0	2189	0	0	0

Part no.	Original MPS +25% CV.				Week no.		--->			
	22	23	24	25	26	27	28	29	30	31
1	160	0	0	0	40	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	140	0	0	0	0	0	0	0	0	100
12	30	0	0	0	65	0	0	0	0	25
16	0	0	0	0	0	0	0	0	0	0
18	9	0	0	0	0	0	0	0	0	8
37	0	0	0	0	8	0	0	0	0	5
41	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	77	0	0	0	0	5
67	6	0	0	0	6	0	0	0	0	0
68	0	0	0	0	1	0	0	0	0	3
70	0	0	0	0	0	0	0	0	0	19
201	0	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	0	0	0	0
225	0	0	0	0	61	0	0	0	0	39
226	0	0	0	0	953	0	0	0	0	147
total	345	0	0	0	1211	0	0	0	0	351

Part no.	Original MPS +25% CV.		
	LOAD	MEAN	Std.
1	330	8.25	32.16
5	66	1.65	10.30
10	950	23.75	71.26
12	340	8.50	26.11
16	600	15.00	59.53
18	31	.78	2.21
37	90	2.25	12.06
41	56	1.40	5.75
47	8	.20	.75
56	90	2.25	12.06
67	24	.60	2.24
68	50	1.25	7.18
70	44	1.10	4.84
201	1030	25.75	160.81
202	1030	25.75	160.81
225	100	2.50	11.17
226	1100	27.50	149.96
total	5939		

Appendix 8. Deterministic MPS -25% Lumpiness.

MPS Item	Period Numbers (weeks) --> 5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	40	0	5	0	0
5	39	0	7	0	5	0	0	0	0	0	0
10	0	155	45	0	115	0	85	0	155	0	0
12	0	40	0	10	0	45	0	5	0	0	0
16	100	0	100	0	100	0	0	100	0	0	0
18	0	4	0	0	3	0	0	4	0	0	0
37	39	0	0	0	0	0	0	0	21	0	0
41	14	6	0	11	0	5	0	12	0	4	0
47	0	1	0	1	0	1	0	1	0	1	0
56	39	0	0	0	0	0	0	0	0	21	0
67	0	0	0	0	4	0	0	0	2	0	0
68	0	0	23	0	0	0	13	0	0	0	0
70	0	0	0	12	0	0	0	0	2	0	0
201	0	0	100	0	0	137	0	0	0	0	0
202	0	0	100	0	0	137	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0	0

MPS Item	Period Numbers (weeks) --> 16	17	18	19	20	21	22	23	24	25
1	0	0	25	0	5	60	0	0	35	0
5	0	0	0	0	0	0	0	0	4	0
10	0	80	0	20	0	0	80	0	20	0
12	35	0	0	40	0	0	35	0	0	40
16	0	0	100	0	0	0	0	0	0	0
18	3	0	0	0	2	0	2	0	2	0
37	0	0	0	0	0	0	10	0	0	0
41	0	0	4	0	0	0	0	0	0	0
47	1	0	2	0	0	0	0	0	0	0
56	0	0	0	0	0	10	0	0	0	0
67	0	0	4	0	0	2	0	2	0	4
68	0	0	0	0	0	0	0	0	0	0
70	0	6	0	0	0	0	0	0	0	9
201	40	0	753	0	0	0	0	0	0	0
202	40	0	753	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	23	0
226	0	0	0	0	0	0	0	400	0	150

MPS Item	26	27	28	29	30	31	32	33	34	LOAD	MEAN	td.
	Period Numbers (weeks) -->											
1	81	0	19	0	0	0	0	0	0	330	8.25	19.30
5	0	0	4	0	0	4	0	0	3	66	1.65	6.21
10	80	0	20	0	0	50	0	0	0	950	23.75	42.69
12	0	10	0	40	0	40	0	0	0	340	8.50	15.66
16	0	0	0	0	0	0	0	0	0	600	15.00	35.71
18	2	0	0	4	0	3	0	2	0	31	.78	1.33
37	0	0	0	10	0	10	0	0	0	90	2.25	7.18
41	0	0	0	0	0	0	0	0	0	56	1.40	3.45
47	0	0	0	0	0	0	0	0	0	8	.20	.46
56	10	0	0	0	0	0	10	0	0	90	2.25	7.18
67	0	1	0	0	5	0	0	0	0	24	.60	1.34
68	4	0	0	10	0	0	0	0	0	50	1.25	4.33
70	0	0	0	0	6	0	0	9	0	44	1.10	2.89
201	0	0	0	0	0	0	0	0	0	1030	25.75	119.46
202	0	0	0	0	0	0	0	0	0	1030	25.75	119.46
225	27	0	0	0	39	11	0	0	0	100	2.50	8.14
226	0	0	0	376	0	0	174	0	0	1100	27.50	89.99

Appendix 9 Deterministic 52 period Original MPSs.

Part No.	New MPS (Original load & cv). Week no --->									
	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	51	0	0	0	0	0
10	0	0	0	0	200	0	0	0	200	0
12	0	0	0	0	50	0	0	0	50	0
16	0	0	0	0	200	0	0	0	200	0
18	0	0	0	0	4	0	0	0	3	0
37	0	0	0	0	60	0	0	0	0	0
41	0	0	0	0	20	0	0	0	16	0
47	0	0	0	0	2	0	0	0	2	0
56	0	0	0	0	60	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0
201	0	0	0	0	10	0	0	0	400	0
202	0	0	0	0	10	0	0	0	400	0
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0
Load	0	0	0	0	667	0	0	0	1271	0

Part No.	New MPS (Original load & cv). Week no --->									
	16	17	18	19	20	21	22	23	24	25
1	0	0	45	0	0	0	0	85	0	0
5	0	0	0	0	0	0	0	0	0	0
10	0	0	200	0	0	0	0	100	0	0
12	0	0	0	0	0	0	0	75	0	0
16	0	0	100	0	0	0	0	100	0	0
18	0	0	2	0	0	0	0	5	0	0
37	0	0	0	0	0	0	0	0	0	0
41	0	0	16	0	0	0	0	4	0	0
47	0	0	2	0	0	0	0	2	0	0
56	0	0	0	0	0	0	0	0	0	0
67	0	0	6	0	0	0	0	6	0	0
68	0	0	36	0	0	0	0	0	0	0
70	0	0	14	0	0	0	0	0	0	0
201	0	0	0	0	0	0	0	320	0	0
202	0	0	0	0	0	0	0	320	0	0
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0
Load	0	0	421	0	0	0	0	1017	0	0

Part No.	New MPS (Original load & cv). Week no --->									
	26	27	28	29	30	31	32	33	34	35
1	0	100	0	0	0	100	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	0	100	0	0	0	100	0	0	0	0
12	0	75	0	0	0	50	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
18	0	6	0	0	0	6	0	0	0	0
37	0	10	0	0	0	10	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0
56	0	10	0	0	0	10	0	0	0	0
67	0	6	0	0	0	6	0	0	0	0
68	0	0	0	0	0	7	0	0	0	0
70	0	0	0	0	0	15	0	0	0	0
201	0	300	0	0	0	0	0	0	0	0
202	0	300	0	0	0	0	0	0	0	0
225	0	0	0	0	0	50	0	0	0	0
226	0	0	0	0	0	550	0	0	0	0
Load	0	907	0	0	0	904	0	0	0	0

Part No.	New MPS (Original load & cv). Week no --->									
	36	37	38	39	40	41	42	43	44	45
1	0	0	0	0	85	0	0	0	80	0
5	15	0	0	0	0	0	0	0	20	0
10	50	0	0	0	100	0	0	0	100	0
12	40	0	0	0	75	0	0	0	75	0
16	0	0	0	0	0	0	0	0	0	0
18	5	0	0	0	6	0	0	0	5	0
37	10	0	0	0	10	0	0	0	10	0
41	0	0	0	0	4	0	0	0	4	0
47	0	0	0	0	0	0	0	0	0	0
56	10	0	0	0	10	0	0	0	10	0
67	0	0	0	0	6	0	0	0	6	0
68	7	0	0	0	7	0	0	0	7	0
70	15	0	0	0	15	0	0	0	10	0
201	0	0	0	0	300	0	0	0	0	0
202	0	0	0	0	300	0	0	0	0	0
225	50	0	0	0	0	0	0	0	50	0
226	550	0	0	0	0	0	0	0	150	0
Load	752	0	0	0	918	0	0	0	527	0

Part No. New MPS (Original load & cv). Week no --->

Part No.	46	47	48	49	50	51	52	CV
1	0	0	85	0	0	0	80	2.76
5	0	0	0	0	0	0	20	3.76
10	0	0	100	0	0	0	100	1.99
12	0	0	75	0	0	0	75	1.98
16	0	0	0	0	0	0	0	3.47
18	0	0	6	0	0	0	5	1.89
37	0	0	10	0	0	0	10	3.31
41	0	0	4	0	0	0	4	2.83
47	0	0	0	0	0	0	0	3.28
56	0	0	10	0	0	0	10	3.31
67	0	0	6	0	0	0	6	2.21
68	0	0	7	0	0	0	7	3.36
70	0	0	15	0	0	0	10	2.43
201	0	0	300	0	0	0	0	2.90
202	0	0	300	0	0	0	0	2.90
225	0	0	0	0	0	0	50	3.28
226	0	0	0	0	0	0	150	3.82
Load	0	0	918	0	0	0	527	1.91

Appendix 10. Deterministic 52 period MPS with "Grouped" demands.

Part No.	Grouped MPS. Week no --->									
	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	51	0	0	0
10	0	0	0	0	0	200	0	0	0	200
12	0	0	0	0	50	0	0	0	50	0
16	0	0	0	200	0	0	0	200	0	0
18	0	0	0	0	0	4	0	0	0	3
37	0	0	0	0	60	0	0	0	0	0
41	0	0	0	20	0	0	0	16	0	0
47	0	0	0	0	0	2	0	0	2	0
56	0	0	0	0	60	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0
201	0	0	0	0	0	10	0	0	0	0
202	0	0	0	0	0	10	0	0	400	0
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0
Load	0	0	0	220	170	226	51	216	452	203

Part No.	Grouped MPS. Week no --->									
	16	17	18	19	20	21	22	23	24	25
1	0	0	0	45	0	0	0	0	85	0
5	0	0	0	0	0	0	0	0	0	0
10	0	0	0	200	0	0	100	0	0	0
12	0	0	0	0	0	0	0	0	75	0
16	0	0	100	0	0	0	0	0	0	100
18	0	2	0	0	0	0	0	5	0	0
37	0	0	0	0	0	0	0	0	0	0
41	0	0	0	16	0	4	0	0	0	0
47	0	0	2	0	0	0	0	2	0	0
56	0	0	0	0	0	0	0	0	0	0
67	0	0	0	0	6	0	0	6	0	0
68	0	0	0	36	0	0	0	0	0	0
70	0	0	14	0	0	0	0	0	0	0
201	400	0	0	0	0	320	0	0	0	300
202	0	0	0	0	0	0	0	0	320	0
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0
Load	400	2	116	297	6	324	100	13	480	400

Part No. Grouped MPS. Week no --->

Part No.	26	27	28	29	30	31	32	33	34	35
1	0	0	100	0	0	0	0	100	0	0
5	0	0	0	0	0	0	0	0	0	0
10	100	0	0	0	0	0	100	0	0	50
12	0	75	0	0	50	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
18	0	6	0	0	0	6	0	0	0	0
37	0	0	10	0	10	0	0	0	10	0
41	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0
56	0	10	0	0	0	0	0	10	0	0
67	0	6	0	0	0	6	0	0	0	0
68	0	0	0	0	7	0	0	0	0	0
70	0	0	0	0	15	0	0	0	0	0
201	0	0	0	0	0	0	0	0	0	0
202	0	0	0	300	0	0	0	0	0	0
225	0	0	0	0	0	0	0	50	0	50
226	0	0	0	0	0	550	0	0	0	0
Load	100	97	110	300	82	562	100	160	10	100

Part No. Grouped MPS. Week no --->

Part No.	36	37	38	39	40	41	42	43	44	45
1	0	0	0	0	0	85	0	0	0	0
5	0	0	15	0	0	0	0	20	0	0
10	0	0	0	100	0	0	0	0	100	0
12	0	40	0	0	75	0	0	0	0	75
16	0	0	0	0	0	0	0	0	0	0
18	5	0	0	0	6	0	0	0	5	0
37	0	0	0	0	0	10	0	0	0	0
41	0	0	0	0	4	0	0	0	4	0
47	0	0	0	0	0	0	0	0	0	0
56	10	0	0	0	10	0	0	10	0	0
67	0	0	0	0	6	0	0	0	6	0
68	7	0	0	0	7	0	0	0	7	0
70	0	0	15	0	0	0	15	0	10	0
201	0	300	0	0	0	0	0	0	0	0
202	0	0	0	0	300	0	0	0	0	0
225	0	0	0	0	0	0	0	50	0	0
226	0	550	0	0	0	0	0	0	150	0
Load	22	890	30	100	408	95	15	80	282	75

Part No. Grouped MPS. Week no --->

Part No.	46	47	48	49	50	51	52	CV
1	80	0	85	0	0	80	0	2.26
5	0	0	0	0	0	0	20	3.76
10	0	0	100	0	0	0	100	1.99
12	0	0	0	0	75	0	75	1.98
16	0	0	0	0	0	0	0	3.47
18	0	6	0	0	5	0	0	1.89
37	10	0	10	0	0	0	10	3.31
41	0	4	0	0	0	4	0	2.83
47	0	0	0	0	0	0	0	3.28
56	0	0	0	10	0	10	0	3.31
67	0	0	6	0	0	0	6	2.21
68	0	0	7	0	0	0	7	3.36
70	0	0	0	15	0	0	10	2.43
201	300	0	0	0	0	0	0	2.90
202	0	0	300	0	0	0	0	2.90
225	0	0	0	0	0	0	50	3.28
226	0	0	0	0	150	0	0	3.82
Load	390	10	508	25	230	94	278	1.00

Appendix 11. Deterministic 52 period Smooth MPS.

Part No	Smoothed MPS. Week no --->									
	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0	0	0
5	0	0	0	10	10	10	10	11	0	0
10	0	0	0	40	40	40	40	40	40	40
12	0	0	0	10	10	10	10	10	10	10
16	0	0	0	40	40	40	40	40	80	40
18	0	0	0	5	0	0	0	0	5	0
37	0	0	0	0	10	10	10	10	10	10
41	0	0	0	5	5	5	5	5	5	5
47	0	0	0	0	2	0	0	0	2	0
56	0	0	0	10	10	10	10	10	10	0
67	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	5	5
70	0	0	0	0	5	0	5	0	5	0
201	0	0	0	0	40	40	40	40	40	40
202	0	0	0	0	40	40	40	40	40	40
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	40	40	40	40	40	40	40
Load	0	0	0	160	252	245	250	246	292	230

Part No	Smoothed MPS. Week no --->									
	16	17	18	19	20	21	22	23	24	25
1	10	10	15	10	15	10	20	25	15	20
5	0	0	0	0	0	0	0	0	0	0
10	40	40	80	40	40	40	40	40	40	20
12	10	10	0	10	10	10	10	10	10	15
16	40	40	20	20	20	20	20	20	20	20
18	0	0	0	0	2	0	0	3	0	0
37	0	0	0	0	0	0	0	0	0	2
41	2	5	5	5	0	2	0	2	0	0
47	0	0	2	0	0	0	0	2	0	0
56	0	0	0	0	0	0	0	0	0	0
67	3	0	3	0	0	3	0	3	0	3
68	5	5	5	5	6	0	0	0	0	0
70	5	0	5	5	0	5	0	5	0	5
201	40	40	40	40	40	40	40	40	40	40
202	40	40	40	40	40	40	40	40	40	40
225	0	0	0	0	0	0	0	0	0	0
226	40	40	40	40	40	40	40	40	40	40
Load	235	230	255	215	213	210	210	230	205	205

Part No Smoothed MPS. Week no --->

Part No	26	27	28	29	30	31	32	33	34	35
1	20	20	20	20	20	20	20	20	20	0
5	0	0	0	0	0	0	0	0	5	0
10	20	20	20	20	20	20	20	20	20	20
12	20	20	15	20	20	10	10	10	10	10
16	20	20	0	0	0	0	0	0	0	0
18	0	3	0	0	0	3	0	0	0	5
37	4	4	0	2	4	4	2	2	2	2
41	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0
56	5	0	5	0	5	0	5	0	5	0
67	0	3	0	3	0	3	0	0	0	0
68	0	0	0	3	0	4	0	0	3	0
70	0	5	0	5	0	5	5	0	5	0
201	40	40	40	40	40	40	0	40	40	40
202	40	40	40	40	40	40	0	40	40	40
225	0	0	10	10	10	10	10	10	10	10
226	40	40	40	40	0	40	0	40	0	40
Load	209	215	190	203	159	199	72	182	160	167

Part No Smoothed MPS. Week no --->

Part No	36	37	38	39	40	41	42	43	44	45
1	0	10	10	10	15	20	20	20	20	20
5	5	0	5	0	0	0	5	5	5	0
10	20	30	20	20	20	20	20	20	20	20
12	10	10	20	20	20	15	20	20	20	20
16	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	5	0	0	5	2	0
37	2	4	2	2	2	4	2	2	2	4
41	0	0	0	2	1	1	0	1	1	1
47	0	0	0	0	0	0	0	0	0	0
56	5	0	5	0	5	0	5	0	5	0
67	0	0	3	0	3	0	3	3	0	0
68	4	0	3	0	4	0	3	0	4	0
70	0	0	5	0	0	0	5	0	4	0
201	0	40	40	40	40	30	40	40	40	40
202	0	40	40	40	40	30	40	40	40	40
225	10	10	0	0	0	10	10	10	10	10
226	0	40	0	40	0	40	0	40	40	40
Load	56	184	153	174	155	170	173	206	213	195

Part No Smoothed MPS. Week no --->

Part No	46	47	48	49	50	51	52	CV
1	20	20	20	20	25	40	40	.72
5	5	0	0	5	5	5	5	1.53
10	20	20	20	40	20	20	100	.60
12	20	20	20	20	20	30	25	.49
16	0	0	0	0	0	0	0	1.42
18	0	5	2	2	2	2	2	1.56
37	2	2	2	4	2	2	2	1.11
41	2	1	2	1	1	0	2	1.26
47	0	0	0	0	0	0	0	3.28
56	5	0	5	0	5	0	5	1.28
67	3	0	3	0	3	0	3	1.39
68	3	0	4	0	3	0	4	1.26
70	0	0	5	0	0	0	5	1.22
201	40	40	40	40	40	40	40	.38
202	40	40	40	40	40	40	40	.38
225	0	0	10	10	10	10	10	1.16
226	0	40	40	40	40	40	0	.59
Load	160	188	213	222	216	229	283	.35

Appendix 12. Deterministic 52 Period Moderate MPS.

Part No. Moderarte MPS. Week no --->

Part No.	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	26	0	25	0	0	0
10	0	0	0	0	100	0	100	0	100	0
12	0	0	0	0	25	0	25	0	25	0
16	0	0	0	0	100	0	100	0	100	0
18	0	0	0	0	2	0	2	0	2	0
37	0	0	0	0	30	0	30	0	0	0
41	0	0	0	0	10	0	10	0	8	0
47	0	0	0	0	1	0	1	0	1	0
56	0	0	0	0	30	0	30	0	0	0
67	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0
201	0	0	0	0	5	0	5	0	200	0
202	0	0	0	0	5	0	5	0	200	0
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0
Load	0	0	0	0	334	0	333	0	636	0

Part No. Moderarte MPS. Week no --->

Part No.	16	17	18	19	20	21	22	23	24	25
1	0	0	20	0	0	25	0	45	0	40
5	0	0	0	0	0	0	0	0	0	0
10	100	0	100	0	0	0	0	50	0	50
12	25	0	0	0	0	40	0	35	0	40
16	100	0	50	0	50	0	0	50	0	50
18	2	0	1	0	0	3	0	2	0	3
37	0	0	0	0	0	0	0	0	0	0
41	8	0	8	0	8	0	0	2	0	2
47	1	0	1	0	1	0	1	1	0	1
56	0	0	0	0	0	0	0	0	0	0
67	0	0	3	0	3	0	0	3	0	3
68	0	0	18	0	18	0	0	0	0	0
70	0	0	7	0	7	0	0	0	0	0
201	200	0	0	0	0	0	0	160	0	160
202	200	0	0	0	0	0	0	160	0	160
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0
Load	636	0	208	0	87	68	1	508	0	509

Part No.	Moderarte MPS. Week no --->									
	26	27	28	29	30	31	32	33	34	35
1	0	50	0	50	0	50	0	50	0	0
5	0	0	0	0	0	0	0	0	8	0
10	0	50	0	50	0	50	0	0	75	0
12	0	35	0	25	0	25	0	20	0	0
16	0	0	0	0	0	0	0	0	0	0
18	0	3	0	3	0	3	0	0	3	0
37	0	5	0	5	0	5	0	5	0	0
41	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0
56	0	5	0	5	0	5	0	5	0	0
67	0	3	0	3	0	3	0	3	0	0
68	0	0	0	0	0	4	0	3	0	0
70	0	0	0	0	0	7	0	8	0	0
201	0	150	0	150	0	0	0	0	0	0
202	0	150	0	150	0	0	0	0	0	0
225	0	0	0	0	0	25	0	25	0	0
226	0	0	0	0	0	275	0	275	0	0
Load	0	451	0	441	0	452	0	394	86	0

Part No.	Moderarte MPS. Week no --->									
	36	37	38	39	40	41	42	43	44	45
1	0	0	0	0	40	0	45	0	40	0
5	7	0	0	0	0	0	0	0	10	0
10	75	0	50	0	50	0	50	0	50	0
12	20	0	40	0	35	0	40	0	35	0
16	0	0	0	0	0	0	0	0	0	0
18	2	0	0	0	3	0	3	0	3	0
37	5	0	0	0	5	0	5	0	5	0
41	0	0	0	0	2	0	2	0	2	0
47	0	0	0	0	0	0	0	0	0	0
56	5	0	5	0	5	0	5	0	5	0
67	0	0	0	0	3	0	3	0	3	0
68	4	0	3	0	4	0	3	0	4	0
70	7	0	8	0	7	0	8	0	5	0
201	0	0	0	0	150	0	150	0	0	0
202	0	0	0	0	150	0	150	0	0	0
225	25	0	25	0	0	0	0	0	25	0
226	275	0	275	0	0	0	0	0	75	0
Load	425	0	406	0	454	0	464	0	262	0

Part No. Moderarte MPS. Week no --->

	46	47	48	49	50	51	52	CV
1	40	0	40	0	45	0	80	1.55
5	10	0	0	0	0	0	20	2.72
10	50	0	50	0	50	0	100	1.27
12	40	0	35	0	0	0	75	1.34
16	0	0	0	0	0	0	0	2.35
18	2	0	3	0	3	0	5	1.25
37	0	0	5	0	0	0	10	2.56
41	2	0	2	0	2	0	4	1.89
47	0	0	0	0	0	0	0	2.05
56	5	0	5	0	5	0	10	2.26
67	3	0	3	0	3	0	6	1.52
68	3	0	4	0	3	0	7	2.31
70	5	0	7	0	8	0	10	1.65
201	0	0	150	0	150	0	0	1.93
202	0	0	150	0	150	0	0	1.93
225	25	0	0	0	0	0	50	2.52
226	75	0	0	0	0	0	150	2.66
Load	260	0	454	0	419	0	527	1.17

Appendix 13 Deterministic 52 Period Lumpy MPS.

Part No.	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	51	0	0	0	0	0
10	0	0	0	0	400	0	0	0	0	0
12	0	0	0	0	100	0	0	0	0	0
16	0	0	0	0	400	0	0	0	0	0
18	0	0	0	0	7	0	0	0	0	0
37	0	0	0	0	60	0	0	0	0	0
41	0	0	0	0	36	0	0	0	0	0
47	0	0	0	0	4	0	0	0	0	0
56	0	0	0	0	60	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0
201	0	0	0	0	410	0	0	0	0	0
202	0	0	0	0	410	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0
Load	0	0	0	0	1938	0	0	0	0	0

Part No. Lumpy MPS. Week no --->

Part No.	16	17	18	19	20	21	22	23	24	25
1	0	0	130	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	0	0	300	0	0	0	0	0	0	0
12	0	0	75	0	0	0	0	0	0	0
16	0	0	200	0	0	0	0	0	0	0
18	0	0	7	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0
41	0	0	20	0	0	0	0	0	0	0
47	0	0	4	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0
67	0	0	12	0	0	0	0	0	0	0
68	0	0	36	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0
201	0	0	320	0	0	0	0	0	0	0
202	0	0	320	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0
Load	0	0	1424	0	0	0	0	0	0	0

Part No. Lumpy MPS. Week no --->

Part No.	26	27	28	29	30	31	32	33	34	35
1	0	200	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	0	200	0	0	0	0	0	0	0	0
12	0	125	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
18	0	12	0	0	0	0	0	0	0	0
37	0	20	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0
56	0	20	0	0	0	0	0	0	0	0
67	0	12	0	0	0	0	0	0	0	0
68	0	7	0	0	0	0	0	0	0	0
70	0	15	0	0	0	0	0	0	0	0
201	0	300	0	0	0	0	0	0	0	0
202	0	300	0	0	0	0	0	0	0	0
225	0	50	0	0	0	0	0	0	0	0
226	0	550	0	0	0	0	0	0	0	0
Load	0	1811	0	0	0	0	0	0	0	0

Part No. Lumpy MPS. Week no --->

Part No.	36	37	38	39	40	41	42	43	44	45
1	85	0	0	0	0	0	0	0	165	0
5	15	0	0	0	0	0	0	0	20	0
10	150	0	0	0	0	0	0	0	200	0
12	115	0	0	0	0	0	0	0	150	0
16	0	0	0	0	0	0	0	0	0	0
18	11	0	0	0	0	0	0	0	11	0
37	20	0	0	0	0	0	0	0	20	0
41	4	0	0	0	0	0	0	0	8	0
47	0	0	0	0	0	0	0	0	0	0
56	20	0	0	0	0	0	0	0	20	0
67	6	0	0	0	0	0	0	0	12	0
68	14	0	0	0	0	0	0	0	14	0
70	30	0	0	0	0	0	0	0	25	0
201	300	0	0	0	0	0	0	0	300	0
202	300	0	0	0	0	0	0	0	300	0
225	50	0	0	0	0	0	0	0	50	0
226	550	0	0	0	0	0	0	0	150	0
Load	1670	0	0	0	0	0	0	0	1445	0

Part No. Lumpy MPS. Week no --->

	46	47	48	49	50	51	52	CV
1	0	0	0	0	0	0	80	3.09
5	0	0	0	0	0	0	20	3.76
10	0	0	0	0	0	0	100	2.89
12	0	0	0	0	0	0	75	2.71
16	0	0	0	0	0	0	0	5.01
18	0	0	0	0	0	0	5	2.74
37	0	0	0	0	0	0	10	3.55
41	0	0	0	0	0	0	4	3.90
47	0	0	0	0	0	0	0	4.74
56	0	0	0	0	0	0	10	3.55
67	0	0	0	0	0	0	6	3.05
68	0	0	0	0	0	0	7	3.58
70	0	0	0	0	0	0	10	3.55
201	0	0	0	0	0	0	0	2.93
202	0	0	0	0	0	0	0	2.93
225	0	0	0	0	0	0	50	3.28
226	0	0	0	0	0	0	150	3.82
Load	0	0	0	0	0	0	527	2.76

Appendix 14 Deterministic Production Plans (39 periods).

period	smooth MPS cv=.35 min=20	moderate MPS cv=1.17 min=20	original MPS cv=1.91 min=20	lumpy MPS cv=2.76 min=20
1	1177.506	753.9184	655.3236	899.4559
2	238.3046	115.2956	244.1322	109.8499
3	313.609	394.1102	472.3439	709.7654
4	631.7025	507.7801	249.684	1689.933
5	625.4501	529.833	1313.611	1143.702
6	1011.464	655.6979	315.2866	448.3505
7	855.3021	1079.45	599.6532	1000.979
8	1316.656	1458.228	2201.115	2770.923
9	1490.034	1457.121	2568.555	3111.62
10	1517.568	1439.62	226.8435	62.4003
11	1306.854	1343.678	552.2655	416.7346
12	1529.19	799.319	1820.786	797.1271
13	1642.357	1510.811	2672.024	1542.544
14	1355.384	1089.819	365.6254	1230.61
15	1100.101	1871.478	1298.395	2579.487
16	919.6139	892.844	1089.925	2173.244
17	1602.846	1214.96	1397.009	1047.937
18	886.6719	996.3055	383.0585	0
19	1228.072	708.4231	595.7594	0
20	1374.918	1279.692	1317.962	0
21	485.1013	1356.671	658.4033	963.0739
22	1400.332	517.3264	1564.203	417.2277
23	1179.834	956.916	969.9929	2244.502
24	943.065	1419.664	1245.687	2506.836
25	967.8351	706.1715	791.7548	1436.996
26	807.0755	1281.657	1313.211	1729.021
27	1424.801	910.3154	1071.3	0
28	795.4591	1343.907	1363.892	14.9507
29	784.181	929.3975	800.0701	118.478
30	1146.054	1120.01	689.6394	174.4327
31	933.3729	674.4245	635.238	1307.989
32	528.3857	642.6073	228.2464	874.2811
33	697.9203	804.6583	333.598	1627.356
34	1337.438	601.7471	1029.808	1553.978
35	812.7092	1111.097	1326.239	1597.912
36	1332.547	797.6905	572.579	26.8131
37	1015.838	1435.447	1514.136	191.3444
38	982.8113	909.7811	885.4607	319.327
39	1307.185	1451.62	1520.605	558.7167

Periods 7-39				
Total	37007.5133	36112.8572	35603.0401	34396.8413
Mean	1121.439797	1094.329006	1078.880003	1042.328524
st.d.	306.6422670	324.1628860	611.7699963	917.1260307
c.v	.2734362271	.2962206833	.5670417420	.8798819272

period	←---------Original MPS ------------→			
		9.	8.	10.
	min=0	min=10	min=20	min=30
1	655.3236	655.3236	655.3236	655.3236
2	244.1322	244.1322	244.1322	244.1322
3	472.3439	472.3439	472.3439	540.0838
4	195.4526	214.414	249.684	284.954
5	1267.023	1274.97	1313.611	1373.244
6	269.7241	276.0131	315.2866	346.1325
7	586.5151	583.7712	599.6532	669.8462
8	2250.059	2535.316	2201.115	2138.353
9	2547.882	215.6491	2568.555	2667.593
10	215.5409	531.8978	226.8435	161.8302
11	536.7885	1844.408	552.2655	388.9191
12	1870.602	2665.28	1820.786	1797.164
13	2646.019	426.252	2672.024	2628.654
14	406.7803	1304.145	365.6254	385.4633
15	1305.68	1189.184	1298.395	1318.983
16	1168.713	1412.371	1089.925	1092.956
17	1413.981	340.4025	1397.009	1401.656
18	373.5091	563.1886	383.0585	404.844
19	579.4429	1342.278	595.7594	557.8341
20	1342.875	1342.278	1317.962	1315.062
21	680.2234	675.3492	658.4033	641.4563
22	1551.79	1553.402	1564.203	1632.076
23	995.1889	987.1217	969.9929	970.2141
24	1257.177	1257.562	1245.687	1240.276
25	759.5557	762.5829	791.7548	791.6515
26	1275.381	1280.761	1313.211	1330.036
27	1068.153	1070.363	1071.3	1121.066
28	1365.641	1366.71	1363.892	1359.392
29	892.9918	892.9918	800.0701	768.8802
30	689.6394	689.6394	689.6394	692.5524
31	605.2118	594.0179	635.238	686.4879
32	217.444	209.9294	228.2464	259.6204
33	418.341	358.8742	333.598	360.6284
34	985.5268	980.6527	1029.808	948.8823
35	1310.074	1315.454	1326.239	1343.618
36	553.6288	555.8393	572.579	496.9094
37	1397.962	1442.64	1514.136	1471.588
38	983.2563	986.2835	885.4607	1038.389
39	1500.608	1489.415	1520.605	1574.768

Periods 7-39				
Total	35752.18	34766.010	35603.04	35657.650
Mean	1083.399	1053.5155	1078.880	1080.5348
st.d.	607.8653	578.33591	611.7700	619.09078
c.v	.5610722	.54895816	.5670417	.57294846

period	<-----------Smooth MPS------------->			
	min=0	min=10	min=20	min=30
1	737.8749	1162.678	1177.506	737.875
2	561.4979	188.4809	238.3046	454.4593
3	154.6109	287.034	313.609	319.8536
4	635.1575	662.4232	631.7025	306.4207
5	696.3193	639.6612	625.4501	757.8074
6	572.2366	886.2598	1011.464	654.5821
7	1146.563	932.1496	855.3021	820.9703
8	1367.154	1424.59	1316.656	976.8075
9	1625.291	1541.662	1490.034	1348.921
10	1528.289	1453.8	1517.568	1528.707
11	1518.37	1371.526	1306.854	1351.236
12	1543.889	1557.854	1529.19	1236.891
13	1707.478	1758.322	1642.357	1393.43
14	1445.663	1379.041	1355.384	1763.937
15	1274.307	1114.264	1100.101	1316.122
16	926.409	960.4725	919.6139	1026.193
17	1490.62	1643.048	1602.846	957.1016
18	1025.615	903.3939	886.6719	1593.945
19	1322.469	1269.849	1228.072	879.5115
20	1138.673	1374.761	1374.918	1249.506
21	706.7039	477.3583	485.1013	1360.84
22	1410.08	1391.445	1400.332	471.2546
23	1076.346	1129.162	1179.834	1358.909
24	1000.016	943.4482	943.065	1214.414
25	981.0446	953.1873	967.8351	998.6474
26	901.1189	864.421	807.0755	854.8863
27	1404.231	1451.272	1424.801	920.0999
28	895.0146	848.8202	795.4591	1390.72
29	815.3753	787.7059	784.181	753.5052
30	1170.323	1158.462	1146.054	720.6693
31	916.7059	923.176	933.3729	1123.267
32	763.5054	660.5278	528.3857	812.3856
33	709.7515	660.0325	697.9203	562.7866
34	1363.45	660.315	1337.438	650.8093
35	808.8534	851.3125	812.7092	1461.817
36	1369.882	1352.405	1332.547	880.8122
37	1100.142	1043.516	1015.838	1530.802
38	1263.128	1049.041	982.8113	1051.067
39	1252.548	1212.507	1307.185	1032.922

Periods 7-39				
Total	38969.01	37102.85	37007.51	36593.89
Mean	1180.879	1124.329	1121.440	1108.906
st.d.	278.4629	316.4277	306.6423	314.8933
c.v	.2358099	.2814370	.2734362	.2839675

period	Moderate MPS min=0	Lumpy MPS min=0	Original MPS OP=2/5	Moderate MPS min=20	min=10
1	753.9184	899.4559	899.4559	735.91	817.6871
2	115.2956	109.8499	0	81.76	961.015
3	394.1102	709.7654	96.8686	214.075	671.277
4	507.7801	1689.933	1262.347	653.419	164.087
5	529.833	1143.702	165.905	133.69	941.1401
6	655.6979	448.3505	229.5512	796.733	1597.723
7	1079.45	1000.979	665.4218	362.724	1402.813
8	1458.228	2770.923	2725.01	2089.084	1073.102
9	1457.121	3111.62	2152.42	1191.739	1334.523
10	1439.62	62.4003	222.1779	1757.832	1357.442
11	1343.678	416.7346	751.4071	1348.878	1047.465
12	799.319	797.1271	1742.496	972.136	1721.681
13	1510.811	1542.544	2712.408	1469.658	1098.357
14	1089.819	1230.61	436.8348	1043.389	1482.07
15	1871.478	2579.487	966.4096	1818.556	630.347
16	892.844	2173.244	1790.161	986.272	828.4875
17	1214.96	1047.937	705.1458	656.49	438.8375
18	996.3055	0	623.6917	1199.84	1388.161
19	708.4231	0	452.2596	722.94	1105.72
20	1279.692	0	864.0574	692.25	1084.731
21	1356.671	963.0739	2562.266	1732.277	890.521
22	517.3264	417.2277	301.6132	503.311	659.291
23	956.916	2244.502	666.3417	1059.104	1302.814
24	1419.664	2506.836	704.8562	1204.312	590.281
25	706.1715	1436.996	1534.37	929.958	1028.638
26	1281.657	1729.021	1428.953	1060.09	1307.816
27	910.3154	0	748.1104	1160.625	900.341
28	1343.907	14.9507	653.2187	1023.924	919.471
29	929.3975	118.478	1864.399	1329.763	682.451
30	1120.01	174.4327	964.9415	701.625	1378.185
31	674.4245	1307.989	408.8345	1204.153	685.6789
32	642.6073	874.2811	46.5752	728.169	939.5491
33	804.6583	1627.356	460.0244	653.217	371.7288
34	601.7471	1553.978	1052.396	731.516	1054.081
35	1111.097	1597.912	1339.221	1025.447	1012.74
36	797.6905	26.8131	205.5381	572.822	1115.559
37	1435.447	191.3444	723.8332	1110.893	846.472
38	909.7811	319.327	2016.877	1177.054	1519.651
39	1451.62	558.7167	1415.989	1097.519	787.847

Periods 7-39					
Total	36112.86	34396.84	35908.26	35317.57	33986.85
Mean	1094.329	1042.329	1088.129	1070.229	1029.905
st.d.	324.1629	917.1260	736.7093	388.8656	320.4452
c.v	.2962207	.8798819	.6770423	.3633479	.3111407

Appendix 15. Grouped Original Uncertain MPS.

Grouped Uncertain MPS: Product 1.

	per	12	16	20	25	29	33	38	42	46	50	54
	3	0	0	45	85							
G'p 1	4	0	0	45	85							
	5	0	0	45	85							
	6	0	0	45	85							
	7	0	0	45	85							
	8	0	0	45	85							
	9	0	0	45	85							
	10	0	0	45	85							
	11	0	0	45	85							
	12	0	0	45	85	100						
	13		0	45	85	100						
	14		0	45	85	100						
	15		0	45	85	100						
	16		0	45	85	100	100					
	17			45	85	100	100					
	18			45	85	100	100					
	19			45	85	100	100					
	20			45	85	100	100	0				
	21				85	100	100	0				
	22				85	100	100	0				
	23				85	120	90	0				
	24				85	120	90	0				
	25				85	120	90	0	85			
	26					120	90	0	85			
	27					100	100	0	100			
	28					100	100	0	100			
	29					100	100	0	100	60		
	30						100	0	100	60		
	31						100	0	100	60		
	32						100	0	100	60		
	33						100	0	100	60	90	
	34							0	100	60	90	
	35							0	100	60	90	
	36							0	90	70	90	
	37							0	90	70	90	
	38							0	85	70	90	80
	39								85	70	90	80
	40								85	80	90	80
	41								85	80	85	80
	42								85	80	85	80
	43									80	85	80
	44									80	85	80

Grouped Uncertain MPS: Product 5.

per	13	17	21	26	30	34	39	43	47	51	55
4	51	0	0	0	0	0	0	0			
5	51	0	0	0	0	0	0	0			
6	51	0	0	0	0	0	0	0			
7	51	0	0	0	0	0	0	0			
8	51	0	0	0	0	0	0	0			
9	51	0	0	0	0	0	0	0			
10	51	0	0	0	0	0	0	0			
11	51	0	0	0	0	0	0	0			
12	51	0	0	0	0	0	0	0			
13	51	0	0	0	0	0	0	0			
14		0	50	0	0	0	0	0			
15		0	50	0	0	0	0	0			
16		0	0	20	0	0	0	0	20	0	20
17		0	0	20	0	0	0	0	20	0	20
18			0	20	0	15	0	0	20	0	20
19			0	20	0	15	0	0	20	0	20
20			0	80	0	15	0	0	20	0	20
21			0	80	0	15	0	0	20	0	20
22				50	0	15	0	0	20	0	20
23				50	0	15	0	0	0	20	0
24				30	0	15	0	0	0	20	0
25				30	0	15	0	0	0	20	0
26				30	0	15	0	0	0	20	0
27					0	15	0	0	0	20	0
28					0	15	0	0	0	40	0
29					0	35	0	0	0	40	0
30					0	35	0	0	0	40	0
31						35	0	0	0	40	0
32						35	0	20	0	20	0
33						35	0	20	0	20	0
34						35	0	10	0	20	0
35							0	10	0	20	0
36							0	10	0	30	0
37							0	10	0	30	0
38							0	20	0	30	0
39							0	20	0	30	0
40								30	0	30	0
41								30	0	20	0
42								20	0	20	0
43								20	0	20	0
44									0	20	0
45									0	20	0

Grouped Uncertain MPS: Product 10.

per	11	15	19	24	28	32	37	41	45	49	53
2	200	200	200	100							
3	200	200	200	100							
4	200	200	200	100							
5	200	200	200	100							
6	200	200	200	100							
7	200	200	200	100							
8	200	200	200	100							
9	200	200	200	100							
10	200	200	200	100							
11	200	200	200	100							
12		100	165	100							
13		145	165	200							
14		145	165	200							
15		145	150	200	100						
16			150	300	100						
17			150	300	50						
18			150	300	50						
19			150	300	100	100					
20				300	100	100					
21				300	100	100					
22				300	100	100					
23				300	100	100					
24				300	100	100	0				
25					100	100	0				
26					100	260	0				
27					100	260	50				
28					100	260	50	20			
29						260	50	20			
30						260	30	20			
31						260	30	20			
32						260	30	20	125		
33							30	20	125		
34							30	20	125		
35							30	15	125		
36							30	15	100		
37							30	15	100	100	
38								15	100	100	
39								15	100	100	
40								15	120	100	
41								15	120	100	100
42									120	100	100
43									120	100	100

Grouped Uncertain MPS: Product 12.

per	14	18	22	27	31	35	40	44	48	52	56
5	50	50	0	75	75						
6	50	50	0	75	75						
7	50	50	0	75	75						
8	50	50	0	75	75						
9	50	50	0	75	75						
10	50	50	0	75	75						
11	50	50	0	75	75						
12	50	50	0	75	75						
13	50	50	0	75	75						
14	50	50	0	75	75	50					
15		50	0	75	75	50					
16		50	0	75	75	50					
17		50	0	75	75	50					
18		50	50	75	100	100	0				
19			50	75	100	100	40				
20			50	75	100	100	40				
21			50	100	100	100	40				
22			50	100	100	100	40	0			
23				100	100	100	40	20			
24				100	150	50	40	20			
25				100	150	50	40	20			
26				100	150	50	40	20			
27				100	150	50	20	10	0		
28					150	50	20	10	0		
29					150	50	20	10	0		
30					150	50	20	10	0		
31					150	50	10	10	0	75	
32						50	10	10	0	75	
33						50	10	20	75	75	
34						50	10	20	75	75	
35						50	20	20	75	175	75
36							20	20	75	175	75
37							20	20	75	175	75
38							20	20	75	175	75
39							20	20	50	100	25
40							20	20	50	100	25
41								20	50	100	25
42								20	50	100	25
43								20	50	100	25
44								20	75	100	25
45									75	100	25
46									75	100	25

Grouped Uncertain MPS: Product 16.

per	14	18	22	27	31	35	40	44	48	52	56
5	200	200	100								
6	200	200	100								
7	200	200	100								
8	200	200	100								
9	200	200	100								
10	200	200	100								
11	200	200	100								
12	200	200	100								
13	200	200	100								
14	200	200	100	100							
15		200	100	150							
16		100	100	150							
17		100	100	150							
18		100	100	150	100						
19			100	150	100						
20			100	0	250						
21			100	0	250						
22			100	0	250	150					
23				0	250	150					
24				0	180	150					
25				0	180	150					
26				0	180	150					
27				0	180	150					
28					180	200					
29					180	200					
30					180	200					
31					180	230					
32						230					
33						230					
34						230					
35						230					
36											
37											
38											
39											
40											
41											
42											
43											
44											
45											
46											

Grouped Uncertain MPS: Product 18

TYPE per	13	17	21	26	30	34	39	43	47	51	55
4	4	3	2	5	6	6	0	0			
5	4	3	2	5	6	6	0	0			
6	4	3	2	5	6	6	0	0			
7	4	3	2	5	6	6	0	0			
8	4	3	2	5	6	6	0	0			
9	4	3	2	5	6	6	0	0			
10	4	3	2	5	6	6	0	0			
11	4	3	2	5	6	6	0	0			
12	4	3	2	5	6	6	0	0			
13	4	3	2	5	6	6	0	0			
14		3	2	5	6	6	0	0			
15		3	2	0	8	9	0	0			
16		3	2	0	8	9	0	0	5	6	5
17		3	2	0	8	9	0	0	5	6	5
18			2	0	8	9	5	0	5	6	5
19			2	0	8	9	5	0	5	6	5
20			2	0	8	9	5	0	5	6	5
21			2	0	8	9	5	0	5	6	5
22				4	8	9	5	0	5	6	5
23				4	5	9	4	0	5	6	5
24				4	5	9	4	0	3	6	0
25				4	5	9	4	5	3	6	0
26				4	5	9	4	5	3	6	0
27					5	9	4	5	3	6	0
28					5	9	4	5	3	6	0
29					5	9	4	5	3	6	0
30					5	9	4	5	3	6	0
31						9	4	5	3	6	0
32						9	4	5	3	6	5
33						9	4	5	3	6	5
34						9	4	5	3	6	5
35							4	5	3	6	5
36							4	5	3	6	5
37							4	5	3	1	5
38							4	5	3	1	5
39							4	5	3	1	5
40								5	3	1	5
41								5	3	1	5
42								5	3	1	5
43								5	3	1	5
44									3	1	5
45									3	1	5

Grouped Uncertain MPS: Product 37.

per	14	18	22	27	31	35	40	44	48	52	56
5	60	0	0								
6	60	0	0								
7	60	0	0								
8	60	0	0								
9	60	0	0								
10	60	0	0								
11	60	0	0								
12	60	0	0								
13	60	0	0								
14	60	0	0	0							
15		0	0	0							
16		0	0	0							
17		0	0	0							
18		0	0	0	60						
19			0	0	60						
20			0	0	60						
21			0	0	60						
22			0	0	60	20					
23				0	60	20					
24				0	60	10					
25				0	50	10					
26				0	50	10	10				
27				0	50	10	10				
28					50	10	10				
29					50	10	10				
30					50	20	10				
31					50	20	10	60			
32						20	10	60			
33						20	10	60			
34						20	10	60			
35						20	10	60	20		
36							15	40	10		
37							15	40	10		
38							15	40	10		
39							15	40	10		
40							15	40	10	20	
41								70	10	20	
42								70	10	20	
43								70	10	20	
44								70	10	20	
45									10	20	20
46									10	20	20

Grouped Uncertain MPS: Product 41.

per	13	17	21	26	30	34	39	43	47	51	55
4	20	16	16								
5	20	16	16								
6	20	16	16								
7	20	16	16								
8	20	16	16								
9	20	16	16								
10	20	16	16								
11	20	16	16								
12	20	16	16								
13	20	16	16	4							
14		16	16	4							
15		16	16	4							
16		16	16	4							
17		16	16	4	0						
18			16	4	0						
19			16	4	0						
20			16	4	0						
21			16	4	0	0					
22				4	0	0					
23				0	0	0					
24				0	0	0					
25				0	0	0					
26				0	0	0	1				
27					0	0	1				
28					0	0	1				
29					0	0	1				
30					0	0	1	1			
31						0	1	1			
32						0	1	1			
33						0	1	1			
34						0	1	1	0		
35							1	1	0		
36							1	1	0		
37							1	1	0		
38							1	1	0		
39							1	1	0		
40								1	0		
41								1	0		
42								1	0		
43								1	0		
44								1	0		
45								1	0		

Grouped Uncertain MPS: Product 47.

per	12	16	20	25	29	33	38	42	46	50	54
3	2	2	2	2	0	0					
4	2	2	2	2	0	0					
5	2	2	2	2	0	0					
6	2	2	2	2	0	0					
7	2	2	2	2	0	0					
8	2	2	2	2	0	0					
9	2	2	2	2	0	0					
10	2	2	2	2	0	0					
11	2	2	2	2	0	0					
12	2	2	2	2	0	0	0				
13		2	2	2	0	0	0				
14		2	2	3	0	0	0				
15		2	2	3	0	0	0				
16		2	2	3	0	2	0	0			
17			2	3	0	0	0	0			
18			2	3	0	0	0	0			
19			2	3	0	0	0	0			
20			2	3	0	0	0	0	4		
21				3	0	0	0	0	4		
22				2	0	2	2	0	4		
23				2	0	2	2	0	4		
24				2	0	2	2	0	4		
25				2	0	2	2	0	4	3	
26					0	2	2	0	4	3	
27					0	2	2	0	4	3	
28					0	2	2	0	4	3	
29					0	2	2	0	4	3	2
30						2	2	0	4	3	2
31						2	2	0	2	3	2
32						2	2	0	2	3	2
33						2	2	0	2	3	2
34							2	0	2	3	2
35							1	0	3	3	4
36							1	0	3	3	4
37							1	0	3	3	4
38							1	0	3	3	4
39								0	4	4	5
40								0	4	4	5
41								0	4	4	5
42								0	4	4	5
43									4	4	5
44									4	4	5

Grouped Uncertain MPS: Product 56.

per	12	16	20	25	29	33	38	42	46	50	54
3	60	0	0								
4	60	0	0								
5	60	0	0								
6	60	0	0								
7	60	0	0								
8	60	0	0								
9	60	0	0								
10	60	0	0								
11	60	0	0								
12	60	0	0	0							
13		0	0	0							
14		0	0	0							
15		0	0	0							
16		0	0	0	60						
17			0	0	60						
18			0	0	60						
19			0	0	60						
20			0	0	60	20					
21				0	60	20					
22				0	60	20					
23				0	60	20					
24				0	60	20	10				
25				0	30	30	15				
26					30	30	15				
27					30	30	15				
28					30	30	15				
29					30	30	15	10			
30						30	10	10			
31						30	10	10			
32						30	10	10			
33						30	10	10	5		
34							10	5	5		
35							20	5	5		
36							20	5	5		
37							20	5	5		
38							20	5	5	10	
39								5	5	10	
40								5	10	10	
41								5	10	10	
42								5	10	10	10
43									10	10	10
44									10	10	10

Grouped Uncertain MPS: Product 67.

per	14	18	22	27	31	35	40	44	48	52	56
5	0	0	6	6							
6	0	0	6	6							
7	0	0	6	6							
8	0	0	6	6							
9	0	0	6	6							
10	0	0	6	6							
11	0	0	6	6							
12	0	0	6	6							
13	0	0	6	6							
14	0	0	6	6	6						
15		0	6	6	6						
16		0	6	6	6						
17		0	6	6	6						
18		0	6	6	6	6					
19			6	6	6	6					
20			0	6	0	0					
21			0	6	0	0					
22			0	6	0	0	0				
23				6	3	3	4				
24				6	3	3	4				
25				6	3	3	4				
26				6	3	3	4	3			
27				6	3	3	4	3			
28					3	3	4	3			
29					3	3	4	3			
30					3	8	4	4			
31					3	8	5	5	6		
32						8	5	5	6		
33						8	5	5	6		
34						8	5	5	6		
35						8	5	5	6	6	
36							5	5	6	6	
37							6	3	6	6	
38							6	3	6	6	
39							6	3	6	6	
40							6	3	6	6	6
41								6	6	0	6
42								6	6	0	6
43								6	6	0	6
44								6	6	0	6
45									6	0	6
46									6	0	6

Grouped Uncertain MPS: Product 68.

per	12	16	20	25	29	33	38	42	46	50	54
3	5	0	36	0							
4	5	0	36	0							
5	5	0	36	0							
6	5	0	36	0							
7	5	0	36	0							
8	5	0	36	0							
9	5	0	36	0							
10	5	0	36	0							
11	5	0	36	0							
12	5	0	36	0	0						
13		4	48	0	18						
14		9	48	0	18						
15		9	48	0	18						
16		9	48	0	18	7					
17			48	0	18	7					
18			48	0	18	7					
19			48	0	18	7					
20			48	0	18	7	0				
21				2	16	7	7				
22				2	16	7	7				
23				2	16	7	7				
24				2	17	7	8				
25				2	17	6	8	3			
26					17	6	8	3			
27					17	6	8	3			
28					17	6	8	3			
29					17	6	8	3	1		
30						5	5	3	2		
31						5	5	3	2		
32						5	5	3	2		
33						5	5	7	2	7	
34							5	7	0	7	
35							7	7	0	7	
36							7	7	0	7	
37							7	7	0	7	
38							7	7	0	7	3
39								6	3	7	7
40								6	3	7	7
41								6	3	7	7
42								6	3	7	7
43									3	7	7
44									3	7	7

Grouped Uncertain MPS: Product 70.

per	13	17	21	26	30	34	39	43	47	51	55
4	0	0	14								
5	0	0	14								
6	0	0	14								
7	0	0	14								
8	0	0	14								
9	0	0	14	0							
10	0	0	14	0							
11	0	0	14	0							
12	0	0	14	0							
13	0	0	14	0	0						
14		0	14	0	0						
15		0	14	0	0						
16		0	14	0	0						
17		0	15	0	15	0					
18			15	15	0	15					
19			15	15	0	15					
20			15	15	0	15					
21			15	15	0	15	0				
22				0	15	15	0				
23				0	15	15	0				
24				0	15	15	0				
25				0	15	15	0				
26				0	15	10	10	10			
27					15	10	10	10			
28					15	10	10	10			
29					15	10	10	10			
30					15	10	10	10	10		
31						15	15	15	10		
32						15	15	15	10		
33						15	15	15	10		
34						15	15	15	10	15	
35							10	12	8	10	
36							10	12	8	10	
37							10	10	8	10	
38							10	10	8	10	
39							10	10	8	10	15
40								15	8	10	10
41								15	15	10	10
42								15	15	10	10
43								15	15	10	10
44									15	10	10
45									15	10	10

Grouped Uncertain MPS: Product 201.

per	11	15	19	24	28	32	37	41	45	49	53
2	10	0									
3	10	0									
4	10	0									
5	10	0									
6	10	0									
7	10	0									
8	10	0									
9	10	0									
10	10	0									
11	10	0	0								
12		0	0								
13		0	0								
14		0	0								
15		0	0	220							
16			10	220							
17			10	220							
18			10	220							
19			10	220	220						
20				220	220						
21				220	220						
22				220	350						
23				220	350						
24				220	350	200					
25					350	200					
26					220	200					
27					220	400					
28					220	400	0				
29						400	0				
30						350	0				
31						350	0				
32						350	0	150			
33							0	150			
34							0	150			
35							0	150			
36							0	200			
37							0	200	150		
38								200	150		
39								300	150		
40								300	150		
41								300	150	300	
42									150	300	
43									150	300	

Grouped Uncertain MPS: Product 202.

per	11	15	19	24	28	32	37	41	45	49	53
2	10	0									
3	10	0									
4	10	0									
5	10	0									
6	10	0									
7	10	0									
8	10	0									
9	10	0									
10	10	0									
11	10	0	0								
12		0	0								
13		0	0								
14		0	0								
15		0	0	220							
16			10	220							
17			10	220							
18			10	220							
19			10	220	220						
20				220	220						
21				220	220						
22				220	220						
23				220	220						
24				220	220	400					
25					220	400					
26					220	400					
27					220	400					
28					220	400	0				
29						350	0				
30						350	0				
31						350	0				
32						350	0	200			
33							0	200			
34							0	200			
35							0	150			
36							0	150			
37							0	150	0		
38								150	0		
39								300	0		
40								300	0		
41								300	0	300	
42									0	300	
43									0	300	

Grouped Uncertain MPS: Product 225.

per	14	18	22	27	31	35	40	44	48	52	56
5	0	0									
6	0	0									
7	0	0									
8	0	0									
9	0	0									
10	0	0									
11	0	0									
12	0	0									
13	0	0									
14	0	0	0								
15		0	0								
16		0	0								
17		0	0								
18		0	0	0							
19			0	0							
20			0	0							
21			0	0							
22			0	0	0						
23				0	0						
24				0	0						
25				0	0						
26				0	0						
27				0	50	50					
28					50	50					
29					50	50					
30					50	50					
31					50	50	50				
32						0	50				
33						0	50				
34						0	50				
35						0	50	50			
36							50	0			
37							50	0			
38							50	0			
39							50	0			
40							50	0	50		
41								0	50		
42								0	50		
43								0	50		
44								0	50	0	
45									50	0	
46									50	0	

Grouped Uncertain MPS: Product 226.

per	12	16	20	25	29	33	38	42	46	50	54
3	0	0									
4	0	0									
5	0	0									
6	0	0									
7	0	0									
8	0	0									
9	0	0									
10	0	0									
11	0	0									
12	0	0	0								
13		0	0								
14		0	0								
15		0	0								
16		0	0	0							
17			0	0							
18			0	0							
19			0	0							
20			0	0	0						
21				0	0						
22				0	0						
23				0	0						
24				0	0	550					
25				0	0	550					
26					0	550					
27					0	550					
28					0	550					
29					0	550	0				
30						550	550				
31						550	550				
32						550	550				
33						550	550	50			
34							550	50			
35							550	50			
36							550	50			
37							550	50			
38							550	150	0		
39								150	0		
40								150	0		
41								150	0		
42								150	0	150	
43									100	50	
44									100	50	

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