ANALYSIS OF STRATEGIC OPTIONS FOR THE MAINTENANCE PARTS LOGISTICS SYSTEM OF THE INTERNATIONAL BUSINESS MACHINES CORPORATION

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March 15, 1982

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*This document is the final report of the private consulting study commissioned by the Service Research Function of the Field Engineering Division of IBM to the named authors, all of the Wharton School of the University of Pennsylvania. Considerable assistance was provided for this study by Mr. Hau Lee of the Wharton School and by Mssrs. Robert Hood, Amitabh Dutt, David Perlmutter, and Randy Ledbetter of the Service Research Function, Raleigh Office. The authors are solely responsible for the methods and recommendations of this study.

STRATEGIC OPTIONS FOR IBM SPARE PARTS DISTRIBUTION SYSTEM

EXECUTIVE SUMMARY

In December, 1981, the Service Research Function (SRF) of the Field Engineering Division (FED) of IBM commissioned the authors of this report as consultants to review existing inventory and distribution procedures for IBM's maintenance parts logistics system, with special emphasis on the Inventory and Distribution Function of FED, and to provide their recommendations for an idealized design of this system to meet IBM's strategic needs for the future. In following discussions with Mssrs. Harvey Herscowitch and Larry Lau of SRF, it was agreed that this analysis should not only develop general strategic options for such an idealized system, but should also delineate methods and procedures for accomplishing the most important next steps in moving towards the proposed system. This report is the result of this analysis. A brief summary of the report follows.

In Section 1, we discuss the problem environment of spare parts inventory and distribution in IBM, and we link this to competitive strategy issues in marketing, product development, and manufacturing. We then describe the main area of concern in this study, the structure and operation of the logistics system for maintenance parts.

In Section 2, we provide an overview of the key decisions and trade-offs in multi-echelon inventory systems for spare parts and we discuss the general state of existing theory and practice in dealing with these.

We describe key areas of concern in IBM's current logistics operations in Section 3. In summary form, these areas of concern are the following:

1. Definition and measurement of service levels;
2. Levels of current and projected inventories;
3. Parts Inventory Management System (PIMS);
4. Recommended Spare Parts (RSP);
5. Controllability and accountability of operations;
6. Location and size of stocking points;
7. The echelon inventory control structure;
8. Transportation costs and modes;
9. Outside location stock pooling (Vanning).

The above areas of concern lead us to define three generic problem areas in structuring an idealized system:

1. Performance Evaluation: Determine measures of performance (for example in terms of cost categories, service levels, etc.) to be used for evaluating design options.

2. Logistics Structure: Develop methods for determining the location, size and operation of facilities (field distribution centers, parts stations, outside locations) and linking transportation modes.

3. Stocking Policies: Determine forecasting methods for parts usage and for stocking and ordering policies for prepositioning and for resupply of parts at each echelon of the logistics structure.

Clearly, the above three problems are linked since optimal logistics structure will depend on how desired service level is defined and what stocking policies are used. Similarly, the nature of optimal stocking policies depends on the location and size of distribution facilities and on the costs and speed of delivery of associated transportation modes. A joint analysis of these three areas is therefore required and this is pursued in Section 4, where we specify the structure of a hierarchically structured model for an idealized distribution planning and control system.

In Sections 5 and 6, we use representative data for several parts classes and a problem scenario based on an aggregated model of the national system to indicate the nature of optimal stocking and transshipment policies for IBM's current environment. These policies lead to the estimation of stocking costs associated with various multi-echelon structural design options. The issue of an optimal system structure is then considered in a manner which trades off facility costs and individual part stocking costs. In Section 6 we extend our analysis for a sample of parts classes by considering the impact on optimal stocking policy of constraints on system response time. These results provide the basis for our recommendations and for our specification of follow-on studies in key areas of interest, which we describe in Section 7. In summary form, our conclusions are as follows:

Recommendations

1. Performance measurement systems should be reviewed and revised to allow management diagnosis and control of costs and service levels at each echelon in the logistics system;

2. A classification scheme for maintenance parts needs to be devised which will be useful for structuring optimal stocking policies and performance reports;

3. Present forecasting algorithms should be reviewed and updated to reflect state-of-the-art techniques, especially for very low usage items;

4. Stocking algorithms determined or affected by PIMS and RSP must be carefully reviewed and revised in light of the structure of optimal stocking algorithms elucidated below;

5. The present logistics structure, in terms of number of echelons and location of facilities, is likely not a major problem, but the structure of present transportation modes linking these facilities as well as policies related to which modes are used need careful review and revision;

6. The models developed during the course of this project should be further refined and documented, both in general terms and in providing specific benchmarks for optimal stocking policies and logistics structure.

Areas for Implementation Studies

1. A theoretical and follow-up empirical analysis of demand processes will provide needed information of better forecasting procedures;

2. Given the magnitude of transportation costs in the present system, it is important to perform a transportation systems analysis, concerning both costs and modes, to determine the structure and efficiency of present modal usage patterns;

3. A revised performance measurement system, tracking service levels and various cost and inventory categories, should be implemented on a trial basis to determine design standards for a full-scale implementation of a management control and decision support system for logistics operations;

4. Using the inputs of the demand forecasting, transportation cost, and performance measure studies, the results of the present study should be refined and extended to derive generic, part-specific optimal stocking policies and to predict service and cost improvements resulting from their implementation;

5. Based on the results of the above implementation studies, a pilot study for selected parts and machine types should be undertaken to empirically validate the predicted performance of derived optimal stocking policies;

6. Finally, there are many interesting areas for implementation study in the logistics structure area; we outline just a few of these relating to vanning options, advance diagnostics, and size and location changes of certain major, regional stocking facilities.

1. PROBLEM ENVIRONMENT AND GOALS OF THE STUDY

The information processing industry has experienced several decades of sustained, profitable growth. Together with the excitement and challenges of high technology, this growth and profit record have attracted to the industry some of the best business and technical talent in the world. The result has been intense competition, rapid technological advance, and a proliferation of end products and services. From IBM's perspective as industry leader, these trends have important implications for all aspects of business operations and not least of which for the maintenance parts logistics system (hereafter: MPLS) supporting the servicing and repair of products in the field. It is the idealized structure and operation of this logistics system which is the primary focus of this report.

Growth in industry sales and scope of product offerings has led naturally to increases in the number of spare parts in the MPLS. To economize on training costs for customer engineers and to simplify diagnostic procedures, spare parts for information processing technology have also become more modular and more expensive. These trends are quite evident in IBM. Current IBM projections* indicate that by 1985 the number of installed points will top 2 billion, with accompanying annual usage of spare parts nearly $450 million at cost.

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*As per discussion (12/30/81) with Mr. Cliff Rice, Director of Inventory and Distribution Function, Field Engineering Division, IBM, Mechanicsburg.

These figures represent a more than doubling of corresponding 1980 figures. Associated with them are projections of substantial growth in the value of inventory necessary to respond with appropriate speed to customers' requests for service. Given current and projected opportunity costs of money, a major question which arises in this regard is how large this maintenance parts inventory needs to be and where it should be located to provide a given level of service.

To understand better the complex nature of the question just posed, we illustrate in Figure 1 below the relationship between maintenance parts logistics policy and other key areas of business strategy. The basic flow in Figure 1 is as follows. Consumer demand and sales revenue are determined through the interaction of consumers' perceptions and needs as these relate to product quality, product attributes and price. A key aspect of product quality is the reliability and maintainability of installed machines. These product characteristics give rise to demands for spare parts for usage and diagnostic purposes. Such demands may be met either by third-party maintenance agreements or through IBM's own MPLS. How well this latter system operates is then a function of two major performance measures: the cost of running the system and the service level it provides. The profit impact of MPLS must be traced through the effects of MPLS policies on the sum of revenues generated by sales of original equipment and of spare parts minus the costs of manufacturing and logistics systems. The interactions among the various areas represented in Figure 1, especially those relating service level to market demand, are highly complex. For this reason, it is useful to consider the design problem for the MPLS as consisting of two

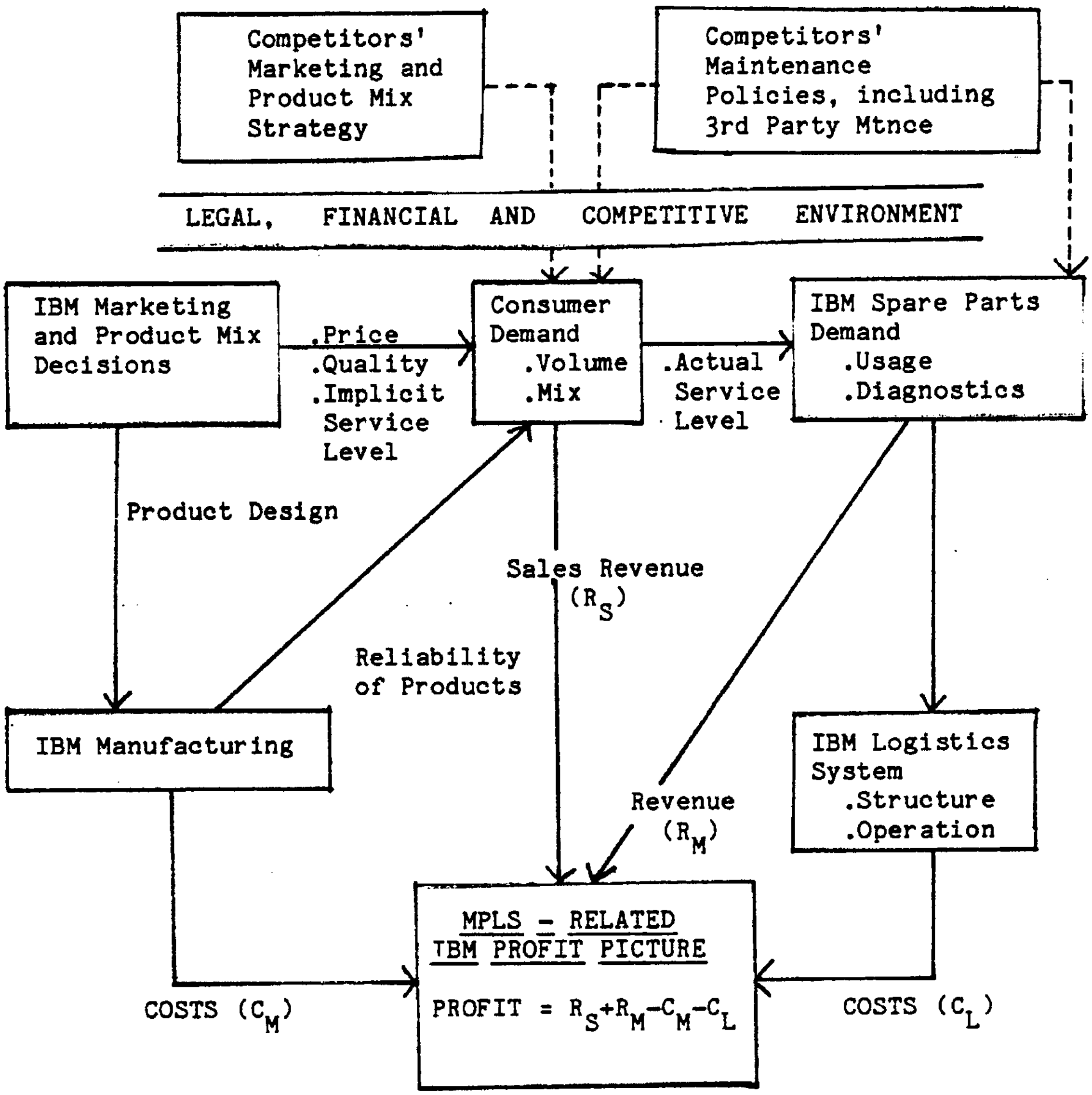

Figure 1: The Nature of Maintenance Parts Logistics Systems

sub-problems:

1. Determining the appropriate level of service (as measured by part availability levels, response time, etc.) for various customer groups and product lines.

2. For a given level of service, determine the most efficient structure and mode of operation of the MPLS which meets the given service level constraint.

Ideally, one would like to jointly optimize the design of the MPLS across both of the above sub-problems. In this report, however, we will be primarily concerned with only the second of the above problems. Our reasons for this restriction are simple: first, the problems associated with tracing the organizational and revenue consequences of changing the service level required are highly complicated and would require a very extensive study; second, making tradeoffs between revenue-side effects (changes in sales revenue due to changes in service levels) and cost-side effects (changes in costs of running the MPLS to meet various service level constraints) require an accurate assessment of the costs of an <u>efficiently designed</u> MPLS as a first step.

Thus, our primary focus will be to understand the cost consequences for an efficiently designed MPLS of given levels of service required. After insuring the implementation validity of these results and fine-tuning the MPLS to achieve flexible response, the profit and market-share consequences of alternative service level requirements can be assessed and an effective competitive strategy based on these can be developed.

The basic solutions available for effecting an efficient design of the MPLS are of three types:

1. Change the logistics structure (i.e., the location and size of stocking points) or the stocking policies for individual parts. Methods for analyzing these design options include traditional approaches to modeling inventory systems.*

2. Change the technology of operating logistics facilities. This includes such issues as changes in warehousing technology, changes in communication structure and changes in transportation modes.

3. Change organizational design and accounting procedures. Here the key issues are to properly measure performance of the MPLS and to provide appropriate signals to managers whose decisions affect MPLS so that such decisions are taken in light of their global impact.

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*See Section 2 below for a more detailed discussion of existing approaches to logistics system design.

From here on, our concern will be to determine how best to use the above three broad solution categories in the IBM MPLS context. To do so, we shall first identify the tradeoffs in the efficient operation of any multi-echelon MPLS. We then discuss areas of current concern in the operation of the Inventory and Distribution Function of FED, and we develop from these a set of strategic design options, which are essentially concrete specifications of the solution options 1-3 above. Thereafter, we evaluate these options via a newly developed mathematical model appropriate to IBM's MPLS, and we delineate recommendations for follow-on study and systematic changes in the current system based on this analysis.

2. EXISTING THEORY AND APPROACHES

The fundamental tradeoff in any inventory/logistics system is between cost and service. In the particular environment of spare parts support for computers and peripherals this tradeoff is of special importance due to the high visibility of the service component associated with the products sold to customers. Our analysis of IBM's system and other computer hardware vendors' systems identified the following specific inventory related costs and measures of service:

1. Cost Categories
    - Inventory holding costs
    - Normal transportation costs
    - Emergency (expedite) transportation costs
    - Facility operating costs
    - Part salvage cost
2. Service Measures
    - Parts availability level (PAL)
    - Parts delivery time (response time)
    - Customer machine down time

Inventory holding costs reflect both the opportunity cost of capital and the direct operating costs associated with storage and handling. The level of total holding cost is determined by three factors: 1) the dollar value (at cost) of each part, 2) the holding cost rate as an interest rate, and 3) the average number of parts stored in the inventory. Transportation costs depend upon the mode (normal vs expedite) as well as distribution and shipment control procedures due to their impact on average shipment size, sourcing and choice of carrier. In most inventory related studies the complexities of detailed transportation cost computation are subsumed into a set of average (per unit or per shipment) transportation costs which may be specific to part class (value, weight, size, etc.) and mode. The emergency (expedite) cost will also include those costs associated with special handling, faster delivery modes and suboptimal shipment quantities and/or routes. Other shortage induced costs associated with customer machine down time, ill will and customer engineer delay time are typically not easily estimated and consequently minimal service level constraints or inflated expedite costs are used to capture these costs. Facility operating costs refer to both the fixed and variable costs associated with the annual operation of distribution centers, parts stations and other stocking facilities. These costs will depend in particular on the size of the facility, its personnel complement and the technology in place for picking, filling and shipping orders. Finally, salvage costs refer to the net of procurement cost minus salvage value of a part at the time of its obsolescence. This cost is usually accounted for by either inflating the holding cost or by solving a dynamic (multi-period) tradeoff problem.

As noted above, it is possible to consider the dollar cost implications associated with the occurrence of shortage in inventory systems. Due to the unreliability of estimates of such costs, most firms adopt the service level concept instead. Under this approach various measures of service are defined and corporate wide objectives (reflecting competitive and strategic factors) are set on the minimal level to be attained. Non shortage related costs can then be computed for different levels of service. The most common measure of service is parts availability (PAL) which is defined to be the fraction of units shipped from a stocking location divided by the total number of units demanded from that location. Another important measure in a high technology, repair system is response time, which is defined to be the total waiting time for delivery of a part once it is requested by a customer engineer at a customer location. The fundamental measure of customer service in computer and peripheral support is, of course, the total amount of time a customer's machine is down and/or operating at less than desired performance. This concept of service recognizes that parts are an intermediate good in the production of Field Engineering's end product -- i.e., customer machine performance. Issues of parts criticality, machine cost, customer importance, and "hard" vs "soft" machine failures have in fact led to the uniform treatment of all parts through PAL or response time criteria in the IBM system. The possibility of using alternative parts classification schemes to obtain a more representative measure of service will be discussed below.

In order to explore the service/inventory cost tradeoff in an efficient and effective manner, it is necessary to use an appropriate analytical model of the inventory system in question. Such models can capture the impact of system configuration (size, location of the various warehouses, distribution centers and parts stations) and the inventory stocking policies which control the flows and levels of parts at each stocking location. In this section we will briefly review the state of knowledge with respect to both theory and practice as it relates to the parts logistics problem.

At the level of single echelon/single location inventory systems, there is an extensive literature dealing with the fundamental question of how much inventory to stock in an environment of demand uncertainty in a fashion which optimizes the cost/service tradeoff. While there are many variations on this theme (single vs multi-period, production vs distribution inventories, product obsolescence, and perishability), the essential result is that one increases the level of inventory until the expected marginal holding cost is equal to the expected marginal shortage cost. Design issues, other than capacity, are not relevant since we are dealing with a single stocking location. Algorithms for computing optimal stocking levels and detailed, implementable management systems are readily available.

In the case of multi-echelon systems, the state of our knowledge and the sophistication of implemented systems is much less developed. Indeed, it is fair to say that at an analytical level only two special classes of multi-echelon systems are well understood, 1) the serial or chain system, and 2) two echelon logistics systems for repairable items, which are to be found in military environments.

Indeed, given the complexity of analyzing and controlling multi-echelon systems, it is important to understand their special advantages over simpler logistics structures. The particular aspects of multi-echelon systems which may lead to an overall reduction of inventory costs and the improvement of service levels include: 1) the possibility of trading off transportation costs (both normal and expedite modes) with echelon holding costs; 2) the potential for variance reduction through the pooling of random demands occurring in multi-echelon systems serving many customers; and 3) the flexibility to select and maintain pre-positioned inventory parts banks at strategically located stocking points to reduce response time and increase parts availability.

It is clear that management policies for multi-echelon structures allow for consideration of alternative system structures as well as for the specifics of stocking control rules. The issue of system structure includes questions of the number of echelons, the location of facilities at each echelon, the capacity and technology (equipment) for each facility and the assignment of lower-echelon facilities to higher echelon centers (e.g., outside locations to parts stations, parts stations to branch offices, parts stations to distribution centers, distribution centers to central warehouse(s)). Stocking policy design parameters usually focus on min/max inventory levels, order points, expedite sourcing procedures and lot quantities. It is important to note that these stocking controls are set on a part number specific basis. Finally, we also note that the issue of performance evaluation is of concern in multi-echelon systems since many decision makers can now impact on the costs and service levels achieved in the system.

If one now considers the particular case of those inventory systems associated with the support of maintenance parts, there are some additional challenges. The service mission of a repair structure is usually given the highest priority in competitive, technologically complex markets. Indeed, the weight given to inventory related costs in such systems is often perceived to be zero. Yet, as noted previously, the rapid increase of parts costs and the escalation of interest rates has given rise to the need to re-evaluate the basic inventory/service tradeoff for parts logistics systems. The lack of sufficiently rich and accessible multi-echelon models, coupled with the possibility that users of the inventory may not be directly accountable for its cost has made such re-evaluation difficult. On the analytic side it is important to note that demand for spare parts is triggered by failures in the field. Given the extremely high levels of individual parts reliability, the wide variation of machine loading and usage patterns and the complex interaction effect of parts used together in a system, it is clear that the stochastic demand processes for the majority of these parts are characterized by 1) extremely low expected usage rates, and 2) extremely large variance levels. An additional complicating factor stems from the long term trend towards modularization of machine design. This has led to the use of "parts as tools" to diagnose machine failures. As a result of this change in usage patterns, many parts are issued to the field and not consumed. Rather, after a variable length of time, they are returned to the closest stocking location (outside or parts station).

From this overview of the state of knowledge for the design and control of multi-echelon parts logistics systems, we may conclude that three key areas of concern require analytic and evaluative input. They are: 1) Inventory Stocking Policy, 2) Logistic Systems Structure, and 3) Accountability Measurement and Control. To be concrete, we first discuss these areas of concern in the context of IBM's current MPLS.

3. CURRENT AREAS OF CONCERN IN IBM

Before proceeding it will be useful to define a classification scheme for maintenance parts. This will enable us to present evidence concerning inventory levels and demand patterns in this section. It will also be the basis of our representative data analysis in Sections 5 and 6. The classification scheme we will use is the cost-demand parts classification proposed in the IBM "Cincinnati Project," April, 1981, which now serves as a provisional basis for many file/report formats in IBM. Table 1 below illustrates the classification scheme in question. On the left are labelled per unit costs of parts; across the top are labelled total disbursements. Thus, a part which costs $1200 and has 5 demands per year will be in cost class 8 and demand class 6, or simply class 86 for short.

Several comments are in order. First, the definitions of these parts classes in terms of cost and usage need not be precisely those of Table 1. Next, one can imagine other information (e.g., return rate, transportation costs) serving as a basis for a more refined parts classification scheme. We return to this point in Section 7. Finally, and most importantly, the definition of demand classes <u>could be</u> location specific (i.e., defined on the basis of demand for a given location). But what is the purpose of a parts classification scheme which classifies a given part into several classes depending on location? We believe this confuses the issue of parts classification and we strongly recommend a unified basis for any such classification scheme. The most obvious way of doing this is to use total national

Table 1

CLASSIFICATION OF PARTS
BY
COST - DEMAND

FROM IBM "CINCINNATI REPORT"

		ZERO DEMANDS YEARS				DEMANDS/YEAR							
		<1	>3	>2	>1	=1	>1	>3	>10	>30	>100	COST	
	=0	00	01	02	03	04	05	06	07	08	09	0X	ZERO
	>0	10	11	12	13	14	15	16	17	18	19	1X	LOW
	>1	20	21	22	23	24	25	26	27	28	29	2X	
	>3	30	31	32	33	34	35	36	37	38	39	3X	
UNIT	>10	40	41	42	43	44	45	46	47	48	49	4X	MEDIUM
COST	>30	50	51	52	53	54	55	56	57	58	59	5X	
	>100	60	61	62	63	64	65	66	67	68	69	6X	
	>300	70	71	72	73	74	75	76	77	78	79	7X	HIGH
	>1000	80	81	82	83	84	85	86	87	88	89	8X	
	>3000	90	91	92	93	94	95	96	97	98	99	9X	
	DEMAND	X0	X1	X2	X3	X4	X5	X6	X7	X8	X9	XX	
		NEW	OLD			SLOW		MEDIUM		FAST			
		NON MOVING						MOVING					

demand for a part as a basis for its demand class. This is the procedure we will use below. We provide in Table 2 below a picture of basic national disbursement patterns corresponding to the classification scheme of Table 1. Note that some of the demand classes of Table 1 have been redefined in Table 2, so that only 8 demand classes appear there.

We can now proceed to a discussion of perceived problem areas in IBM's current MPLS. Through an analysis of IBM internal documents and discussions with key I & D people,* several areas of concern were identified with respect to IBM's present MPLS. We discuss these under the three generic areas of concern delineated in the previous section.

3.1. Inventory Stocking Policies

We list in Figure 2 the major issues raised concerning current MPLS stocking policies and procedures. We briefly discuss each of these below.

Service Level: Understandable performance measurements at various levels of the MPLS are lacking. What is routinely available are aggregate PALs, but these do not appear to be broken down by parts classification or other useful management control categories. Thus, if PAL for a given installation (say, a parts station) declines in a given month, it may be quite difficult for the installation manager to

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*Principally with Mssrs. Cliff Rice and Jack Sather of IDF, Mechanicsburg, and with Mssrs. Robert Hood and Larry Lau of SRF, Raleigh.

Issue	Problems	Solutions
a. Service Level	.Lack of integrated measurement structure	.Design Performance Measurement structure
b. Inventory Level	.Too High (?) .Effects of Returns and diagnostic use .No tradeoff with service level (a.)	.Review inventory planning system .Develop part-specific stocking policies
c. PIMS	.Algorithms for forecasting and reorder policies .Single-echelon philosophy of PIMS	.Experimental research on demand forecasting .Redesign algorithms
d. RSP	.Process for setting .Level of RSP-related inventory .Accountability	.Relate RSP to optimal stocking policies .Research on dynamics of RSP
e. Span of Control	.Accounting structure and incentives .Use of expedite orders	.Design performance measurement structure .Evaluate (over-) use of expedite rules

Figure 2: Areas of Concern with Inventory Stocking Policies

determine which parts or part classes are responsible and what the reasons for this are. As a further point, it is not clear that PAL itself is the only useful measure of service performance. For example, measures related to customer down-time or to response time would clearly be of interest. Such measures are not as difficult to obtain as might be imagined, since they may be approximated through weighted sums of the PALs at various levels of the MPLS, with the weights being the average expedited travel times from the level in question to a typical outside location.

Possible Solutions: What is needed here is a hierarchically structured performance measurement system, which will provide not only aggregate performance measurements (e.g., PAL and response time) for a given installation, but will also allow further exploration and inquiry by installation managers to determine the source and nature of service problems.

Inventory Level: There is a general sense among knowledgeable parties that inventory levels in the MPLS are too high, that is, that the same service level achieved by the present system could be achieved with less inventory (and no greater expediting costs). Determining whether this is so and the reasons for it, if so, is a very complicated matter, since it requires comparing current system operation to some achievable, efficient benchmark. We provide a structure and supporting models for determining such benchmarks in Section 4 below. For the moment, let us consider how inventory is distributed in the present system.

In Tables 3a-3b we present the inventory levels by part class in the entire MPLS and in the Detroit Region as of January, 1982. It is useful to take an aggregate view of these Tables. By summing various entries in Tables 3a-3b, we obtain Table 4a, which presents the distribution of total inventory value in the four aggregate cost-demand classes indicated. It is interesting to compare this with Table 4b, which shows similar figures for the Detroit region.[*]

		Demand/week	
		D≤.6	D>.6
Cost	1-5	2.52%	0.77%
Class	6-10	48.75%	47.96%

a. National

		Demand/week	
		D≤.6	D>.6
Cost	1-5	3.17%	3.45%
Class	6-10	48.89%	44.48%

b. Detroit Region

Table 4: Percentage of Inventory Value by Cost & Demand Class

The differences between the National and Detroit regional data are not large. In both regions, about 49% of the inventory is concentrated in the lower demand, higher cost classes which are more difficult to forecast and control. There is slightly more inventory in high cost parts at the national level than at the Detroit FDC.

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[*] Total inventory value in the Detroit FDC and its four parts stations was $6.7 million for the period in question. Detroit was selected as a typical FDC and region.

This may be due to PIMS buffer stock policies for high-demand items* and to the fact that higher cost classes tend to be more centrally located by PIMS (i.e., typically at MDC). These higher concentrations of high-cost parts at the MDC then lead to higher concentrations of such parts nationally than regionally.**

Further analysis of Detroit regional data indicated substantial "excess inventory" as defined by PIMS, especially for high-cost, low-demand parts. We do not pursue this matter further here since the definition of "excess inventory" in PIMS is itself suspect. Indeed, what these tables point to is the very great need for rational benchmarks for part-specific stocking policies to provide guidelines on what an effective and efficient distribution of inventory by level and part class should be.

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*That is, the higher concentration of inventory value nationally in higher cost classes may be due to the PIMS policy of setting a 3-month buffer stock (for every part) in the Mechanicsburg reorder cycle. For October, 1981, we estimated that this policy resulted in more than 50% of the total on-hand inventory at Mechanicsburg being delivery lead-time buffer inventory. This high buffer inventory is naturally most apparent in the high-demand parts, leading to higher inventories of high-cost high-demand parts at the MDC than at FDCs. Thus, the differences in the lower right-hand corners of Tables 3a-3b.

**Note that the distribution of ending 1981 inventory, at cost, by echelon level was: MDC = 38%, FDCs = 26%, PSs = 12%, and OLs = 24%. Thus, the distribution of inventory value across part classes at MDC significantly affects national averages.

STATISTICAL ANALYSIS SYSTEM 8:02 TUESDAY, FEBRUARY 16, 1982 1

INVENTORY STATUS - YEAR ENDING 01/82
$ INVESTED, QUANTITY & NUMBER OF PARTS STOCKED

COST CLASS		NATIONAL AVERAGE DEMAND CLASSES								TOTALS
		0	1	2	3	4	5	6	7	
		D<0	D=0	0<D<=.1	.1<D<=.2	.2<D<=.6	.6<D<=2	2<D<=6	6<D	
1	$ INVESTED	0	0	0	0	0	0	0	0	0
	# STOCKED	48	2768	11	0	0	0	0	0	2827
	PNQTY	6	24985	50	14	6	3	1	5	25070
2	$ INVESTED	0.967	0.271	0.356	0.192	0.272	0.254	0.488	0.847	3.647
	# STOCKED	2345	512	894	289	779	536	1742	1019	8116
	PNQTY	227	37249	8161	2600	3814	3163	1868	2273	59355
3	$ INVESTED	17.068	10.898	2.051	1.135	2.297	1.871	1.269	7.262	43.851
	# STOCKED	7429	5613	1078	424	943	797	839	3026	20149
	PNQTY	258	17404	4465	1197	1767	1372	747	785	27995
4	$ INVESTED	941.142	75.074	146.323	80.814	158.639	176.958	128.638	98.476	1806.064
	# STOCKED	137153	11517	21531	12143	22979	24704	17785	13683	261495
	PNQTY	1801	21463	5785	1838	2482	1783	911	841	36904
5	$ INVESTED	6180.284	293.143	551.44	328.22	682.503	816.353	860.182	798.837	10510.96
	# STOCKED	316426	15097	29232	17592	36497	41654	38544	35782	530824
	PNQTY	3339	18972	4816	1264	1771	1232	590	393	32377
6	$ INVESTED	36713.89	1541.094	3624.116	2565.257	5652.77	8384.441	8131.958	19987.19	86600.72
	# STOCKED	625915	26615	63942	43999	97586	140850	144547	350153	1493607
	PNQTY	5000	18601	3760	956	1222	897	499	422	31357
7	$ INVESTED	47580.96	2168.489	5556.483	4022.408	9063.188	13477.25	14629.64	19711.42	116209.8
	# STOCKED	313205	13562	34272	25946	55431	84476	90123	119634	736649
	PNQTY	2759	10312	2049	532	693	524	338	183	17390
8	$ INVESTED	8429.468	1232.942	3443.563	1832.078	6791.867	13467.56	14236.47	24965.87	74399.81
	# STOCKED	18568	2602	6467	3863	13051	26690	27884	54632	153757
	PNQTY	956	3885	716	162	252	209	131	82	6393
9	$ INVESTED	1092.04	671.146	1764.166	1375.967	5058.975	16918.75	12238.26	8958.787	48078.1
	# STOCKED	763	494	1168	891	3275	8990	7568	5360	28509
	PNQTY	68	742	165	48	64	59	34	16	1196
10	$ INVESTED	2014.663	1197.9	6684.431	14612.75	8666.719	1490.074	2563.719	1235.155	38465.41
	# STOCKED	310	87	434	858	1309	389	787	215	4389
	PNQTY	42	256	45	19	17	4	4	1	388
TOTALS	$ INVESTED	102970.5	7190.957	21772.93	24818.82	36077.23	54733.51	52790.62	75763.85	376118.4
	# STOCKED	1422162	78867	159029	106005	231850	329086	329819	583504	3240322
	PNQTY	14456	153869	30012	8630	12088	9246	5123	5001	238425

PART QUANTITIES ON HAND AT MDC FDCS AND OLS
$ INVESTED IS MEASURED IN THOUSANDS

Table 3a

STOCKED QUANTITY AND DOLLARS INVESTED 7:32 TUESDAY, FEBRUARY 16, 1982 3

DETROIT REGION INVENTORY STATUS - YEAR ENDING 01/82
$ INVESTED, QUANTITY & NUMBER OF PARTS STOCKED

		NATIONAL AVERAGE DEMAND CLASSES								
COST CLASS		0	1	2	3	4	5	6	7	TOTALS
		D<0	D=0	0<D<=.1	.1<D<=.2	.2<D<=.6	.6<D<=2	2<D<=6	6<D	
1	$ INVESTED	0	0	0	0	0	0	0	0	0
	# STOCKED	0	71	0	0	0	0	0	0	71
	PNQTY	6	24985	50	14	6	3	1	5	25070
2	$ INVESTED	0.055	0.73	1.249	0.785	1.802	2.824	3.025	21.044	31.514
	# STOCKED	186	3055	5209	3028	8452	14426	13622	117177	165155
	PNQTY	227	37249	8161	2600	3814	3163	1868	2273	59355
3	$ INVESTED	0.287	1.623	2.775	1.557	3.676	5.313	5.915	23.888	45.034
	# STOCKED	122	890	1529	827	2013	2913	3369	12984	24647
	PNQTY	258	17404	4465	1197	1767	1372	747	785	27995
4	$ INVESTED	16.627	5.061	10.69	6.676	14.802	19.065	19.224	51.889	144.034
	# STOCKED	2392	891	1850	1160	2582	3249	3426	9719	25269
	PNQTY	1801	21463	5785	1838	2482	1783	911	841	36904
5	$ INVESTED	123.366	15.533	24.533	16.306	34.327	45.69	44.828	64.3	368.883
	# STOCKED	6248	832	1367	875	1965	2490	2277	3710	19764
	PNQTY	3339	18972	4816	1264	1771	1232	590	393	32377
6	$ INVESTED	782.431	40.056	85.433	62.226	127.47	187.192	176.138	397.76	1858.706
	# STOCKED	13238	701	1522	1066	2236	3131	3189	6894	31977
	PNQTY	5000	18601	3760	956	1222	897	499	422	31357
7	$ INVESTED	1058.237	48.173	145.484	107.344	207.609	309.685	345.48	430.003	2652.015
	# STOCKED	6915	292	891	670	1252	1956	2051	2589	16616
	PNQTY	2759	10312	2049	532	693	524	338	183	17390
8	$ INVESTED	100.734	33.348	89.859	56.427	160.525	372.311	352.362	455.253	1620.819
	# STOCKED	224	63	166	106	307	715	659	975	3215
	PNQTY	956	3885	716	162	252	209	131	82	6393
9	$ INVESTED	13.433	17.169	51.927	48.814	114.352	370.214	282.014	169.241	1067.164
	# STOCKED	7	14	36	35	78	200	174	103	647
	PNQTY	68	742	165	48	64	59	34	16	1196
10	$ INVESTED	103.668	18.861	153.592	471.638	251.674	41.353	45.65	22.98	1109.416
	# STOCKED	17	1	10	26	34	11	13	4	116
	PNQTY	42	256	45	19	17	4	4	1	388
TOTALS	$ INVESTED	2198.838	180.554	565.542	771.773	916.237	1353.647	1274.636	1636.358	8897.585
	# STOCKED	29349	6810	12580	7793	18919	29091	28780	154155	287477
	PNQTY	14456	153869	30012	8630	12088	9246	5123	5001	238425

PART QUANTITIES ON HAND AT DETROIT FDC PS & OLS
$ INVESTED IS MEASURED IN THOUSANDS

Table 3b

Possible Solutions: First, an unambiguous parts classification scheme needs to be agreed upon. Then, based on this scheme, part-class-specific forecasting and stocking algorithms need to be developed, with special emphasis on low-demand, high-cost parts.

PIMS: The Parts Inventory Management System (PIMS) really has two functions: to coordinate inventory-related data collection and to provide algorithms for forecasting stocking, and reorder policies for parts. Concerning the first function, PIMS seems to be state-of-the-art. Its problems are related to the second. The procedures embodied in PIMS seem to be based on a single-echelon philosophy, which neglects many of the fundamental tradeoffs in multi-echelon inventory systems described in Section 2. Moreover, the forecasting algorithms in PIMS are not class specific. This is clearly a problem, since low-demand items are likely to have quite different demand distributions (and therefore different forecasting methods appropriate to them) than high-demand items. It should be mentioned that very good theory and operating systems exist for high-demand items, while the contrary is the case for low-demand items. Our own thoughts on forecasting procedures for low-demand items are contained in Section 7.

Possible Solutions: What is needed is a pilot study to test various methods for improving demand forecasting and associated ordering policies, even within the current PIMS context. What is needed beyond this is a complete redesign of the stocking, ordering and transshipment algorithms within PIMS to account for the multi-echelon nature of the MPLS in IBM. The idealized structure of such algorithms is presented in the next section.

Recommended Spare Parts (RSP): The problems with RSP are several. First, the process for setting these initially seems quite ad hoc, at least relative to the guidelines we present below for optimal stocking policies. Moreover, the levels of RSP-related inventory in the system are not readily obtainable from current data files. For example, in our study of the Detroit FDC and its parts stations, unrealistically low values of RSP-related inventory were obtained from current data files. Even if these point estimates were correct, however, the effects of RSP are dynamic and long-lasting, and a much more detailed study of how they reverberate through the system, given current stocking algorithms, would be required before drawing conclusions.

Possible Solutions: What is required is a more detailed study of both the stock and flow effects of RSP levels for various demand classes. One would expect for high-demand classes that initial errors in estimating RSP levels would be quickly corrected by the (high-demand) stock control logic of the current PIMS. However, for low-demand classes, which appear to be trouble spots for excess inventory, one would expect initial errors in estimating RSP levels to have longer-lasting effects. Again, a key element in understanding whether RSP degrades system performance is the determination of optimal stocking policies for various parts classes. By comparing actual RSP stock levels against optimal stocking policies, one would obtain a very clear picture of those parts classes where current RSP policy is substantially in error. Finally, concerning accountability, tracing the inventory costs and service level consequences of various RSP levels could lead to more effective use of the inventory investment. In particular, passing these RSP consequences through to responsible product planners (e.g., through direct product pricing) would be a reasonable step after the effects of RSP have been better understood.

Span of Control: The general issue of accountability for inventories and for other cost categories, especially for expediting costs, is very important. A common complaint heard from I & D managers was that while they were being judged and evaluated on the performance of the MPLS, in terms of inventory and service levels, control of a part of the system is in the hands of branch office managers and customer engineers.

Possible Solutions: For certain key areas, such as inventory levels, service levels, and transportation costs, detailed accounting information must be made available to allow management evaluation and control of the most important causal elements affecting system cost and service level. Such a system should make it possible to quickly perform comparative analyses across FDCs and parts stations of inventory levels, service levels, expediting costs, and other key performance indicators. Organizational reporting and control procedures can then be evaluated in light of trouble spots which such a performance evaluation system will allow.

3.2. Logistics System Design Options: The second generic category of problems concerns the structure of the logistics system itself. The general questions of interest here are the location and size of stocking points and the nature of communications and transportation modes linking these together. Figure 3 lists the issues which we have identified in this area. We will now discuss each of these individually.

Location and Size of Stocking Points: Logistics facilities cost money to operate and they also tend to attract inventory (see below). Thus, their location and size is an important matter. The key tradeoffs associated with this question are those between fixed costs of additional facilities and the pooling and response time benefits which such facilities bring. The current problem in this area is simply that appropriate analytical tools are lacking for resolving this tradeoff in an efficient manner.

Possible Solutions: At a naive level, a review of the costs and benefits of each existing parts station and FDC would establish the comparative performance of individual stocking installations relative to one another. An initial step in this direction is taken in Section 5, where we evaluate the fixed and variable costs of FDCs. At a more sophisticated level, a logistics planning model is required to optimally trade off facility costs and locations versus the per part inventory costs and service levels. Some progress on this point is reported in Sections 4, 5, and 6.

Issues	Problems	Solutions
a. Location and size of stocking point	.Stocking points attract excess inventory	.Develop models to tradeoff inventory costs of parts versus facility costs .Link logistics structure to stocking policies
b. Echelon inventory control	.Many parts stocked at 3 or more levels .Parts pushed forward via RSP are not repositioned satisfactorily	.Revise part-specific stocking algorithms
c. Transportation Costs	.Transportation Costs represent a large fraction of total operating costs .Relationship to holding costs and service levels is poorly understood	.Use optimal stocking model to tradeoff transportation costs with holding and shortage costs
d. Outside location stock pooling ("Vanning")	.Parts assigned to outside locations are relatively inaccesible to demands at other sites .IDF does not influence stocking policies at this level	.Use inventory and outside location models to tradeoff cost savings of pooling versus fixed cost for implementing vanning

Figure 3: Areas of Concern with Current Logistics Structure

Echelon Inventory Control: Many parts are stocked at three or more levels. Our exploration of optimal stocking policies below indicates that this is not likely to be optimal. In a related vein, it appears that parts pushed forward by RSP are not re-positioned in a satisfactory manner after demand patterns become more clearly defined. Finally, the usual multi-echelon inventory practice (quite evident in IBM) is to stock a part at all higher levels in the echelon structure once it is decided (e.g., by RSP) to stock the part at a given level. As we point out in our analysis and results, this practice is also likely to be non-optimal.

Possible Solutions: It is necessary to revise current part-specific stocking algorithms in PIMS to achieve efficient utilization of MPLS multi-echelon structure. Models directed towards this end are discussed in Sections 4 and 5 below.

Transportation Cost: These costs represent a large fraction of total operating costs, yet their relationships to holding costs and service levels is poorly understood and not explicitly considered in current stocking policies. It also appears that shipments of parts may not be optimally routed. More direct shipping routes (e.g., from manufacturing to FDCs directly) should be considered in lieu of the present practice of shipping nearly everything over Mechanicsburg.

Possible Solutions: An optimal stocking model is required (see Section 4) to evaluate the tradeoff between transportation costs and holding and shortage costs. Empirically, a detailed review of costs and frequencies of use of various transportation modes needs to be undertaken to determine when, where, and for what parts classes each transportation mode is used. The possibility of money-saving modal substitutions, including the development of new transportation modes, may be thereby identified.

Outside Location Stock Pooling (Vanning): Inventory at outside locations has typically accounted for from 20-25% of total MPLS inventory. Reducing this is clearly a high priority task. One way of doing so would be to pool outside location stock, especially high cost parts, using mobile stocking points (i.e., vans).

Possible Solutions: To evaluate "vanning," one needs to understand the annual fixed costs of operating such a van and compare these against the savings in holding plus emergency shipment costs which such stock pooling would occasion. For this, an appropriate model needs to be developed to identify these savings. We discuss such a model in the next section.

3.3. Accountability and Performance Measurement

Many of the above areas of concern highlight the importance of accountability and performance measurement in determining areas for improving current operations and in assessing whether such improvements have been effected by the proposed solution methods. Clearly, a key area for improvement is the design of a useful, management oriented decision support system to enable top management as well as installation managers to assess performance and determine trouble spots in their area of MPLS responsibility.

Such a system would provide a current database with detailed performance information (e.g., cost, inventory levels, response time, PALs) by location and parts class. The mentioned decision support system would then allow flexible and fast inquiries to be directed to this database at various levels of detail (e.g., by region, across FDCs, nationally, across demand or cost classes). The goal of such a system would be to support both long-range planning and short-run trouble-shooting.

In concluding our analysis of current areas of concern in IBM's MPLS, it should be noted that the development of benchmarks for efficient operation is the most common apparent solution. We now turn our attention to this task and describe the structure of an idealized, model-based approach to optimal stocking policies and to optimal structural design of the logistics system.