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A Study of Benefits of Information Sharing between Production Systems and Service Centers

N. Viswanadham

Vijay Desai

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N. Viswanadham, Vijay Desai

The Logistics Institute – Asia Pacific, National University of Singapore
10 Kent Ridge Crescent, Singapore 119260
tlinv@nus.edu.sg; tlivd@nus.edu.sg

ABSTRACT

Integrated Manufacturing and Service Networks (IMSNs) are an assemblage of companies formed with the primary goal of delivering value in terms of both goods and services to the customer through out the product life cycle - from cradle to the grave. Manufacturing-service integration will lead to information sharing between design, manufacturing and sales units of the manufacturer and the service centres. While the integration between design and manufacturing is very well studied, the subject of collaboration between manufacturing units and service centre received practically no attention.

In this paper, we present two models each with increasing complexity to elucidate the benefits of integration and alert against problems like bullwhip effect percolating from supply chains into IMSN. The first one is a conceptual model that captures the relationship between manufacturing and service networks and makes a case for coordination between the two entities. The second model, IMSN with single product, evidences the benefits of collaboration in a more realistic setting.

In all the above models, we make use of cause effect diagrams and system dynamic models to study the benefits of integration. We study the effect of reactive (feedback) and also the proactive (feedforward) use of information for service centre resource management.

KeyWords: Manufacturing, Service, Bullwhip effect, Service Center Design.

1. INTRODUCTION

Integrated Manufacturing and Service Networks (IMSNs) are an assemblage of companies formed with the primary goal of delivering value in terms of both goods and services to the customer through out the product life cycle - from cradle to the grave. The product life cycle could be divided into design, manufacturing and service phases. During the design phase, collaborative teams design products taking into account the manufacturability, logistics requirements, ease in assembly, ease in fault diagnosis and the serviceability. The manufacturing phase involves procurement, manufacturing, distribution and sales. The service phase comprises of activities like preventive maintenance, testing and fault diagnosis, repair services, call centres and emergency services.

There is lot of interaction between the production phase and service phase, which has not been given attention. For example, a company which considers service phase in design and manufacturing phase can introduce onboard diagnostics for monitoring machine health and proactive maintenance to provide failure free performance. *It is estimated that reactive maintenance costs over six times more as compared to proactive maintenance and leads to increased customer satisfaction.* Expert system software combined with strategically located sensors and transducers (e.g., pressure, temperature, vibration, viscosity, wear debris, and moisture) will provide comprehensive machine health monitoring and as a result making the whole process more efficient.

Every product sold is a potential source of revenue through sales of spare parts and after-sale services such as repair, maintenance and the upgrades. Consumers are demanding better service and OEMs are realizing the importance of providing good service. A recent GM study reported that $9 billion in *after-sale revenue* yielded $2 billion in profits. On the other hand, for producing $2 billion profit from product sales GM will have to sell cars worth $150 billion. In the sale of products and gaining customer loyalty, after sales service has become a significant factor. Decisions made during design and manufacturing phases affects the performance and cost of service phase. On the other hand, providing good service will boost the product sales. Feedback from service to design will help produce more reliable products. It is thus important to consider the maintenance, fault diagnosis, reparability and serviceability aspects in addition to manufacturability at the design stage.

With OEMs taking a more proactive role in service, they will have a better idea of customers needs. For example, most auto makers have relatively few opportunities to interact with car owners; most of the "touches" they do experience are indirect (through independent dealerships) and occur in less-than-happy circumstances (for example, when repairs are needed or a vehicle recall is required). Getting involved in service would provide first-hand information of the problems that arise in service and a quick feedback all the way to the design/manufacturing phase for possible pre-emption.

In this paper, we study the benefits of manufacturing-service integration. More specifically, we want to quantify the benefits of information sharing between design, manufacturing and sales units of the OEM and the service centres. The vehicle for our study is the system dynamic models. We develop a cause effect diagram for conceptual model and single product model.

It is known that manufacturing systems are discrete event dynamical systems and so are service networks. Together, they form large discrete event networks. But events in manufacturing system occur at much faster rate than in service networks. The production rates are generally much faster than failure rates. For example, an automobile is manufactured in days but it may not go for servicing for months. Also, while designing IMSN one should be cautious about bullwhip effect in the integrated system which could lead to service system exhibiting oscillatory behavior in its resources: repair crews, spare parts, etc. Our study here using system dynamic models demonstrates the benefits of:

1. Use of service centre feedback in product design to improve both the serviceability as well as reliability.
2. Use of marketing and sales information in reducing bull whip effect in service centre resources.
3. Use of service level or service quality feedback to improve the sales.

In this sense, our study here is a significant contribution to the literature on design – manufacturing - service networks.

2. LITERATURE SURVEY

In scanning the literature on IMSN, one has to search from various angles. From the consumer's angle, there are lots of white papers and reports from Accenture and Mckinsey on the benefits of selling solutions rather than products [3, 6, 9, 10]. It is now established through various surveys that profit margins in service are much higher than in product sales. For certain types of industrial equipment such as heavy machines, aircraft engines, etc service is integral part of product sales proposition. Pricing of services, products and product services bundles is an important issue.

From the economic point of view there have been studies on the importance of manufacturing in service economy [7, 8]. There are two other viewpoints, which are important in practice and implementation, the product life cycle and the business process integration viewpoints. The supply chain limits itself to the point of sale of product, which needs to be overcome by integrating the service phase: physically, informationally and organizationally.

As is known, the product goes through the design, production, customer use, service and finally disassembly, reuse and disposal. Most attention in Product Lifecycle (PLC) is given to the direct chain of events i.e. from the design to the customer but the service and recycling are not integrated into other phases of PLC. In service literature, preventive maintenance [12], the repairman problem [12], spare parts management [1, 11] have received lot of attention. Queueing theory, discrete-event simulation and mathematical optimization techniques are widely used to study these problems. Cohen et al [4] build a product life-cycle model to study a set of strategic choices facing the manufacturer of durable good as he designs the joint product/service bundle. They adopt a competitive (as opposed to single-firm optimization) framework, where there is competition for the provision of after-sales service between the manufacturer and an independent service operator. The product price and service quality/price are characterized by equilibrium to a sequential game. Cohen et al. [5] report on a benchmarking study of 14 companies in electronics, computing and communication industries. They observe that after-sales service revenues constitute 30% of product sales revenues. Optimization of field service operations has received attention in the business literature [2].

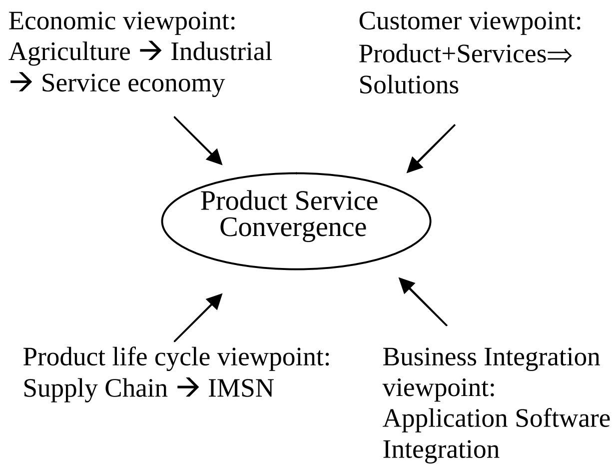

Figure 1: Perspectives on Product Service Convergence

Our attention here is on showing the benefits of sharing information between OEMs and the service providers in terms of improvement in service levels and better service capacity planning.

3. MODEL DESCRIPTION

We consider manufacturing–service network for a complex product with one manufacturing company and several geographically distributed service centres as shown in figure 2.

The manufacturer designs the product, produces it and sells the same to a pool of customers. The product could be automobiles, agriculture equipment like tractors, medical equipment, aircraft engines, ink jet printers, etc.

The common feature is they are all durable products that require after sales support for preventive maintenance, spare parts and also breakdown servicing. Three kinds of maintenance and repair services are possible: self service performed by the customer with on-line help, preventive maintenance where the product performance is monitored by in built diagnostics or by periodic checks, and break down service generally conducted by the service centre. The breakdown service could be either major or minor and the repair time depends on the type of failure. The repair centre has generally the following physical resources: repair crew, disassembly tools, diagnostic equipment, and spare parts. The customer interface of the repair centre is through a call centre or help desk. The informational resources include the data base containing equipment history, types of problems reported for this equipment as well as similar ones installed elsewhere, the knowledge from the crew reports, etc. The data base also may contain information on the spare parts, and can access the CAD designs and the manufacturing data if needed. The resources of the service centre determine the service levels such as the delivery time and the quality of service etc. The service quality as well as the service centre profitability is monitored for possible improvement. The service centre capacity consists of the physical and human resources and this can be changed by hiring or firing the repair men. In this study we assume that the repair centre capacity can be increased with a delay of three months and decreased as and when necessary. Transferring the regional sales information to service centre would help them increase the service capacity in timely manner.

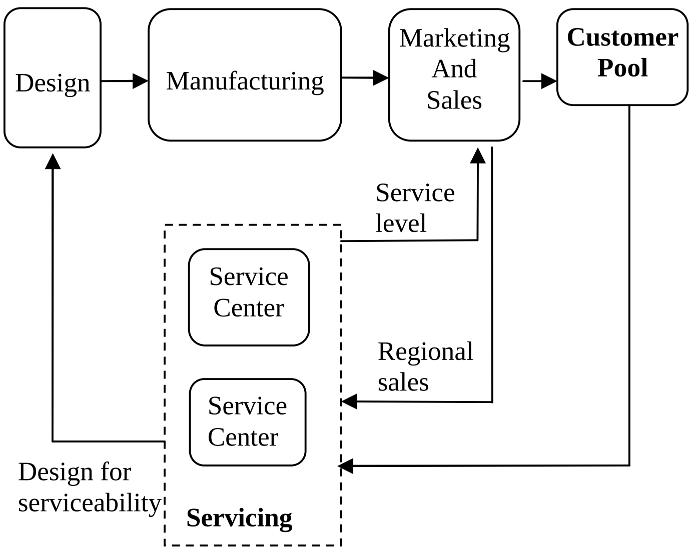

Figure 2: A typical manufacturing-service network

It is known from the literature that after sales service quality influences the product sales particularly from the past customers. We incorporate this in to our system dynamic model by making the service quality as a variable influencing the product sales. Also, the service centre and product design interaction can lead to design of high reliability products, products with fault diagnostic features, modular products with ease in serviceability etc. We use a utility function to show the positive influence of the service levels on product design which will result in more product sales.

Information exchange between design, service centre and marketing and sales will lead to improvement in the performance of system by bringing coordination. Service centre resource planning will be enhanced by information about regional sales. Similarly, service levels provided by repair centre will improve the sales forecasts of marketing department. We will present three models to demonstrate this.

4. CONCEPTUAL MODEL

We first present a simple model to show benefits of manufacturing, marketing and service centre collaboration. The model demonstrates that sharing information between manufacturing and service phases can have a huge impact on the performance of the system. The simple manufacturer-service network with elements: production, population, sales, service level, repairs, etc. is considered here for illustration. The cause-effect diagram for this is shown in figure 3.

Goods are produced at a constant rate and sales take place according to the utility function. Excess goods produced are inventoried and sold goods enter the population. Whenever a product fails, they come for repairs and service centre makes use of service capacity to perform the repairs. As the population of sold goods increases, more number of products comes for repair and the service capacity needs to be synchronized with population growth to maintain quality of service. Loop 1 in figure 3 shows that as the population increases, there will be more number of products for repair. This would in turn lead to lower service levels and lower the product sales. The service level can be maintained by controlling service capacity in appropriate manner. We explore two mechanisms for controlling service centre capacity in order to maintain the required service level:

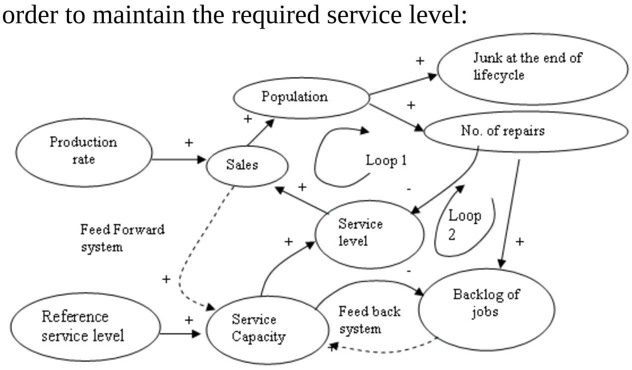

Figure 3: Cause-Effect diagram for Conceptual Model

1. **Feedback system**: Loop 2 is the feedback loop that reduces the backlog of jobs. Whenever jobs get accumulated for repair, the service capacity procurement process is initiated. The new capacity arrives after a fixed

lead time from the time an order is placed. This is the reactive, feedback system and most service centres would typically operate in this fashion when they have no information about product sales. The equation used by the feedback system for capacity requisition is:

Capacity ordered on any day = (Rate of arrival of new jobs)*1.1 + (Backlog of jobs) / 5 – Existing Capacity – Capacity in the process of procurement

Everyday the service centre is checked for overcapacity and excess capacity is removed according to the following equation:

Amount of capacity freed = Current Capacity - 1.2*(Job arrival rate) - Backlog

2. **Feedforward system**: Sales information can be used to forecast the growth in population and calculate the incremental service capacity required to support the added population. Taking into account the lead-time in procurement of capacity we can ensure timely increase in service capacity. Information visibility that comes with IMSN allows us to have feedforward control to add the service capacity.

We have assumed the lead time to be 120 days and every 120 days we forecast the population growth. The required extra capacity is the population growth multiplied by the failure rate.

Capacity ordered every 120 days = Population growth in 120 days * Failure rate

Overcapacity is removed according to the following equation:

Amount of capacity freed = Current Capacity - 1.2*(Job arrival rate) – Backlog – Capacity to support expected population growth

The dotted arrows in figure 3 indicate the feedback and feedforward mechanisms in the cause-effect diagram. We use the cause-effect diagram in figure 3 and Ithink software to simulate the system dynamic model. We assume the following values:

1. A production rate of 1000 units/day is assumed.
2. Car life = 10yrs or 3650 days
3. The service level is the only factor that influences the sales. Product Sales = (Mean_Service_level - 0.7)*10000/3.
4. Mean number of failure per day = 0.01*Population
5. Acquisition of service capacity takes 120 days because of the delays involved in hiring and training.
6. We assume the product life-cycle to be 10 years long.
7. For performing one repair job, one unit of capacity is engaged for a day.
8. Service level for a particular day is the ratio of number of repairs completed in that day to total number of jobs to be completed (including the backlog jobs). Since the number of repairs completed is at most equal to the capacity, Service level = Min (Capacity/Total number of failures, 1).

Under the above assumptions, the ideal service centre capacity = mean number of failures = 0.01*Population
We simulate both feedback and feedforward strategies outlined above.

Feedback system (system 1) responds to accumulation of jobs by increasing the service centre capacity. Since there is a delay in acquiring service capacity and making it operational, in the interim period, the service level declines and jobs accumulate. To clear this up quickly, excess capacity needs to be hired. Thus the reactive feedback system creates a bull whip effect: a sudden increase in product sales will after a lag create a need for excess service capacity. Because of the set up times involved in increasing the service centre capacity, the service levels decline bringing down the sales. This is clear from figure 4. The kind of fluctuations in the service capacity shown in the figure can be prevented by collaboration between the manufacturing and the service centre.

Figure 5 compares the two systems: 1) System with only feedback. 2) System with both feed forward and feedback. The feed-forward system is able to maintain very high service levels while the feedback system shows fluctuations. This is because feed-forward system accurately predicts the required capacity and adds it taking into account the lead time.

On the other hand, feedback system shows considerable variation in the service level, which in turn effects the population growth. The graph in figure 4 illustrates the significant benefits. We observe that because of the high service level, the population in system 2 has more sales than system 1, which is reflected in the populations of the corresponding systems.

An IMSN based on a feedback mechanism responds to the accumulation of jobs by increasing the service center capacity. However since there is an inherent delay in acquiring and deploying service capacity, the impact of service capacity addition is not immediate. Consequentially the service levels continue to decline and jobs continue to accumulate in the interim period. Hence, to rapidly clear the backlog of jobs and to bring the service up to the desired levels, sometimes more capacity than required needs to be added. Thus the reactive feedback system results in a bull whip effect: *a sudden increase in product sales after a lag creates a need for excess service capacity.* Because of the leadtimes involved in service capacity addition, the service centres are unable to maintain their service levels and accordingly the sales decline as shown in Figure 4. The fluctuations in service capacity observed in the system (as shown in Figure 4) can be prevented by promoting collaboration between the manufacturing, sales and the service operations of the IMSN.

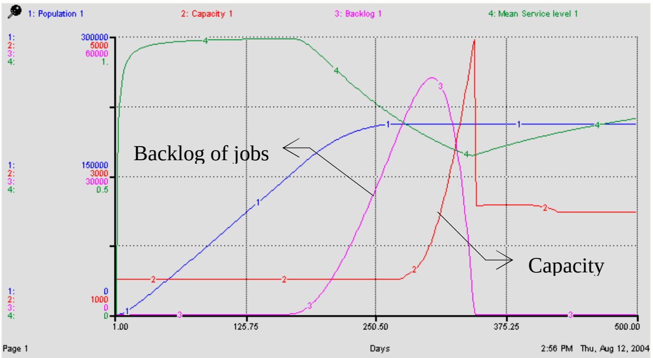

Figure 4: Buildup in service capacity to clear accumulated jobs

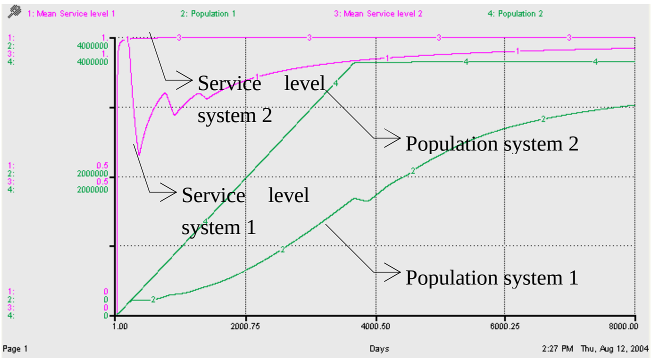

Figure 5: System with Feed-forward and Feedback maintain higher service level than system with only feedback

5. MODELING IMSNS WITH A SINGLE PRODUCT

The basic model presented in Section 4 is simplistic in its assumption that the consumer's decision to buy a product is based primarily on the quality of the service. However, in reality the purchase decision is influenced by multiple factors such as the price and quality of both the product and the service and the quality and length of the warranty period. In this section we attempt to incorporate these features into a more realistic model of an IMSN that manufactures and services a single product.

For our analysis we assume that the utility of a product to a consumer is a linear function of product price and quality, service price and quality and the length of the warranty period.

Utility = -Product price + 1000*Product quality - Service price +1000*Service level + Free service contract.

Product price and service price have a negative influence on the utility function since higher prices deter customers from buying the product. Similarly, free service contract periods, better product and service qualities, have a positive influence on the utility as perceived by customers. Furthermore, we also incorporate a reference utility function, similar to the utility described above, which defines a target utility level for the company to aspire towards. In reality this reference utility is equivalent to the utility of the products offered by the competitors. In this manner we are able to account for competitive pressures facing an IMSN. The reference utility level also provides a goal for the company to work towards, by improving the product and service value proposition. As can be expected, the better the product offered by the IMSN, relative to the competition, higher its sales. Hence, the number of sales that take place in a day is directly proportional to the difference between the reference utility (utility of competitive offerings) and utility of the product offered by the IMSN. If a product service bundle offers superior value the demand for the product will expectedly increase. However increased sales and growth in the product population will over time result in more service demands putting a strain on service levels and quality, requiring some kind of monitoring process to remedy the service deterioration. The influence diagram for an IMSN manufacturing and servicing a single product under the above operating assumptions is presented in Figure 9.

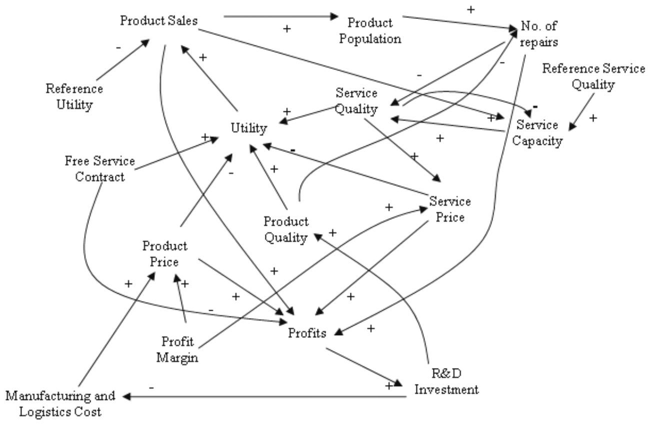

Figure 9: Influence diagram for IMSN with single product

The profits of the IMSN are derived from the sales of both products and services, less the cost of production, service provision and cost of providing free services during warranty. In addition, we assume that a fixed percentage of the profits are continually invested in R&D. These investments bear fruit at a later time in the form of improved product quality, reliability and reduced product prices, in turn stimulating further sales and profits. Concurrently, as the product quality improves, the reliability of the product increases and the number of failure events and consequentially repairs is reduced. In this manner, the concept of design for serviceability is included in our model of an IMSN. However for the sake of simplicity, we have assumed aggregated models for service centres, each of which are geographically distributed. One key differentiating factor in the extended model presented in this section, as compared to our earlier analysis, is the assumption that the product failure rate increases with the age of the product. With an increase in product sales over time the population grows at a higher rate, resulting in greater number of repair jobs. Also, as a product gets old it comes more often for repair. Hence, to predict the load on the service centre we need to *track both product sales and the age of the installed base.*

Additionally, we incorporate the feedforward and feedback mechanisms, explained in the earlier sections, for controlling the interaction between the manufacturing and service sectors and for ensuring that service levels are maintained at the required level. For example, in a feedback based system, if the service level drops below the reference service level, service capacity is added. On the other hand, in a feedforward system, the sales data is employed to forecast and plan for additional capacity requirement.

The above model was simulated in IThink to demonstrate that the feed-forward system is better than the feedback system in terms of its ability to improve service levels and the bottom-line for the IMSN. For the simulation study, it was assumed that the lead time for service capacity addition was 120 days and the initial capacity was set to be adequate to meet all demands occurring in the first 120 days of operations. Based on growth of the population and age of installed base a forecast is made for number of failures per day after 240 days and the required extra capacity is added as appropriate. From the influence diagram it may be noticed that the dynamics within this extended and realistic model are more intricate than the basic model presented in Section 4 (Figure 3), establishing the fact that it is harder to predict the behavior of realistic IMSN models. Our analysis was based on the following parameters and assumptions.

1. One unit of service capacity costs 100 units of money per period.
2. The price charged for service dependent on the service level offered as dictated by the following relationship.
Service Price = Service capacity cost(1 + service level).*
3. Profit margin of 10% incorporated in the price of products
4. Product quality & Manufacturing cost improves non-linearly for incremental investments in R&D, meaning that the ROI for R& D investments is more than 100%.
5. The probability of a product failing increases over time.
6. The product becomes obsolete in 6 years, in a non-linear manner, as it rapidly becomes outdated in its first few days before being gradually replaced over time.

The service levels for IMSNs with only feed-back and with both feed-back and feedforward were simulated and compared as shown in Figure 10. Clearly an IMSN with feedforward and feedback mechanisms is able to provide consistent service levels, inspite of the dynamics involved in the system. It may be observed from Figure 11 that the service capacity growth in an IMSN with a feedforward system is more planned in comparison to an IMSN with just a feedback system. Since one unit of service capacity is needed to complete a single repair job in a day, the service capacity over time in a well synchronized manufacturing service network, such as one with a feedforward system, will trace the number of incoming repairs jobs. However, due to the long lead-times in service capacity acquisition the service capacity increases only in a stepwise manner. It may also be noticed that the excess service capacity added in an IMSN with only feedback is eventually eliminated as the backlog of service jobs is cleared. The models for IMSNs with both feedback and feedforward were simulated over the entire lifecycle of the product and their profits compared. The profits in an IMSN with both feedback and feedforward mechanisms are 50% higher than the profits for an IMSN with only feedback.

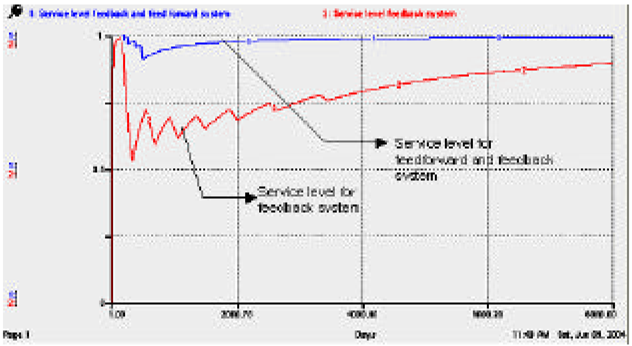

Figure 10: Comparison of service levels for an IMSN with
feedback and one with both feedforward and feedback.

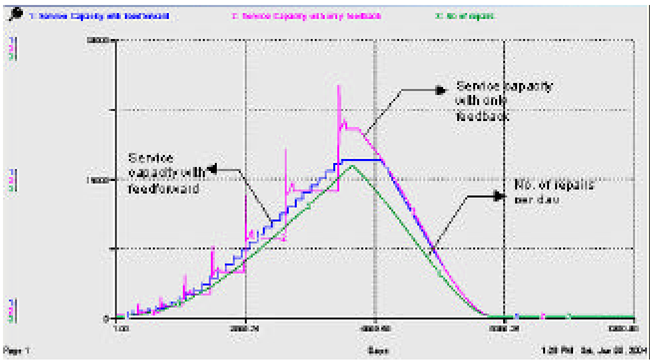

Figure 11: Comparison of service capacity for system with only feedback and system with feedback and feedforward

6. CONCLUSION

In this paper, we have studied the information sharing between manufacturing plant and service centres. While there are several studies in the form of business cases and white papers on benefits, ours is the first systematic study providing a framework for the analysis. In particular we study the beneficial effects of service centres feedback to design teams and sales and marketing departments. Feed forwarding the sales information to the service centres to reduce the bullwhip effect on the repair crews and spare parts.

In terms of the future, we develop multiple product models and determine optimal time for the new product introduction. We also hope to develop queueing network and Petri net models to further study and develop analytical models.

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