Improvement on Service Part Supply Chain with Centralized Management and Global Optimization

by
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B. Eng. Electrical Engineering
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Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Mechanical Engineering

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ABSTRACT

This project was performed under the supervision of the global supply chain department of InFocus Corp. The company is having high service costs in the Asia Pacific region and desperate to lower the cost in the reverse supply chain and to improve the service level to its customers.

In this thesis report, InFocus' current reverse supply chain networks in different business regions were reviewed and detailed analysis was performed for the Asia Pacific region. The results of the analysis showed that the service part supply chain in the Asia Pacific was inefficient and costly due to redundant echelon, insufficient information sharing and lack of centralized management. A shorter and more centralized supply chain was proposed. A comparison was made and various key performance indicators were used to judge the effectiveness of the improvements. The analysis showed that the proposed supply chain has lower costs, lesser safety stock, and higher service levels. Transportation was also shown to be more flexible and cost effective through the proposed replenishment policies. Strategic 3PL partnership and vendor managed inventory (VMI) were also discussed in the later part of the report. Future work can be devoted in these areas to explore the potential of further improvement in the reverse supply chain.

Thesis supervisor: Dr. Stanley B. Gershwin
Title: Senior Research Scientist of Mechanical Engineering

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First all, I would like to express my appreciation to my thesis advisors and supervisors at MIT and NTU, Dr. Stanley B. Gershwin, Professor Stephen C. Graves, Professor Appa Iyer Sivakumar and Professor Rohit Bhatnagar for their help and guidance throughout the theme project duration. Special thanks go to Dr. Gershwin and Professor Graves, who had spent a lot of time to read my project updates, attending conference call to listen to my problems and provide valuable and timely feedbacks.

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1. Introduction

1.1 Company Profile

InFocus System Inc. was founded in 1986 and its global headquarter is located in Wilsonville, Oregon. Its principal business is to develop, manufacture and market digital projectors, technologies and services. A digital projector is an electro-optical machine which converts digital data from a computer or video source to a bright image which is then projected on a distant wall or screen using a lens system [1]. Digital projectors are widely used in the meeting rooms, auditoriums, theaters, offices and homes.

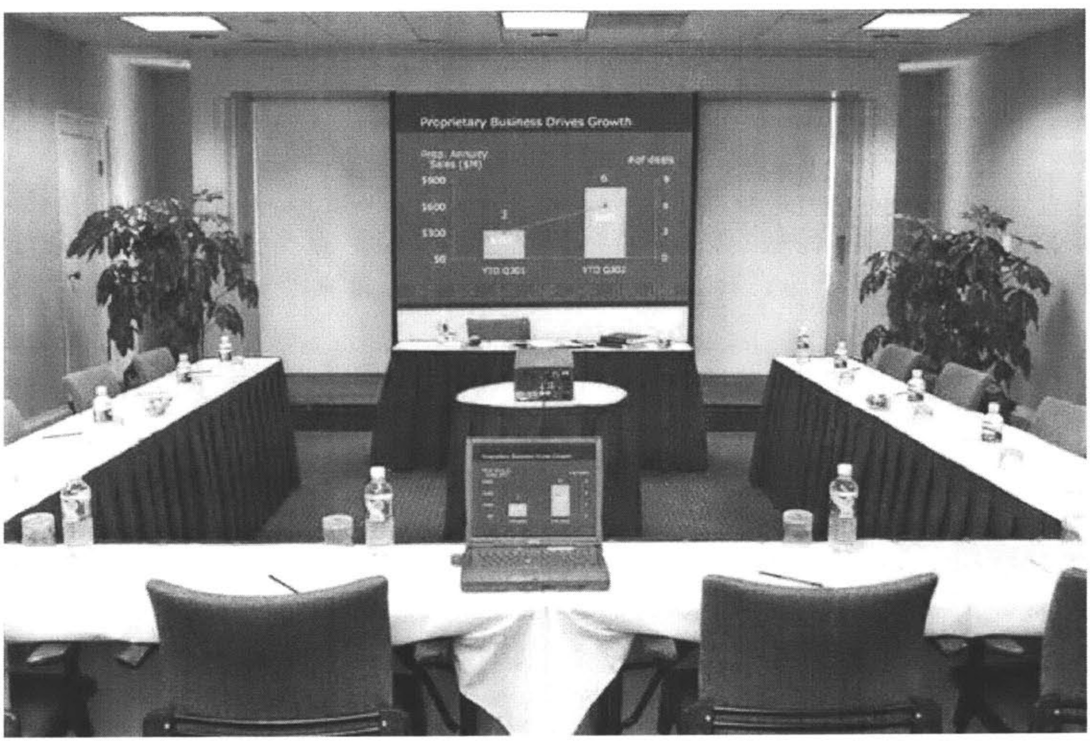


Figure 1: A typical digital projector in a meeting room

InFocus has a strong research and development team and it always maintains its leading position on the projector technology innovation. In the past, InFocus had the exclusive rights to the passive-matrix technology and was a leader in the thin-film transistor (TFT) technology. InFocus was also the pioneer in the industry who integrated networking and wireless solutions into the projectors. [2] InFocus projectors have won numerous awards due to their superior quality and performance.

In June 2000, InFocus merged with Proxima, a Norwegian company who was a leader in high-end projectors. The merger gave InFocus wider range of products and two more well-known brands: Proxima and ASK. In Europe, ASK and InFocus are leading brands. In Asia, InFocus is the strongest brand, except in China where ASK leads. In the U.S. InFocus and Proxima dominate the market. Additionally, each brand offers a different set of attributes that users and resellers appreciate. Proxima excels in the higher end and large-venue projector market; InFocus is the clear leader with light and portable projectors; ASK is particularly strong in LCD technology. [2]

1.2 The Challenge

Despite InFocus being strong in technology and having a well established sales network, it has started to suffer a consistent decrease in revenues and profits since 2002 due to the increase in competition, especially cost-driven competition. Big companies like 3M, Dell, Canon and Panasonic, are all investing heavily in the projector business. Too much competition is killing the profit margins. The competing manufacturers were able to drive the price down to a very low level due to their low manufacturing cost and diverse product range. InFocus' gross profit margin in the projector business shrunk from 26% in 2001 to 7% in 2005. It has been suffering negative profits since the year 2002 up to date, except for year 2004 [3]. Given the fierce competition, InFocus is facing the great challenge of increasing product profit margins and cutting operating costs. It has outsourced its manufacturing sector to more cost effective Asian countries, first to Malaysia and then to China. In September 2005, InFocus announced a comprehensive restructuring plan with the goal of simplifying the business and returning the company to profitability. Part of its restructuring plans consisted of carrying out key actions aimed at improving the reverse supply chain efficiency. The objective of these set of actions is to improve gross margins from 16% to 18% and to reduce the operating expenses to a level that will allow InFocus to achieve breakeven or better results in the most seasonally challenged quarters. [4]

1.3 Theme project scope and problem statement

This theme project was carried out with the support of InFocus' global supply chain department.

Project Scope

To review current reverse supply chain and find the most economic solution for projector repair in Asia Pacific region.

This report focuses on the service part supply chain, which is the major subset of reverse supply chain.

Project Problem Statement

Current projector repair cost in Asia Pacific region is high and has adverse effects on InFocus' profitability.

2. Review of current situation

2.1 Service part supply chain comparison by region

InFocus has three market regions: North America (mainly US), Europe and the Asia Pacific. The Asia Pacific is a relatively new market and only accounts for around 10% of sales. However this newest region has a very un-proportionate spending on its total service cost. The cost difference is contributed by various factors. Apart from the higher projector failure rate in Asia Pacific region, the unit repair cost structures are also very different among regions as will be shown later.

Figure 2 depicts the general supply chain for service parts. The dotted box on the right represents the supply chain for the Asia Pacific region and the dotted box on the left stands for the supply chain for both Europe and the US.

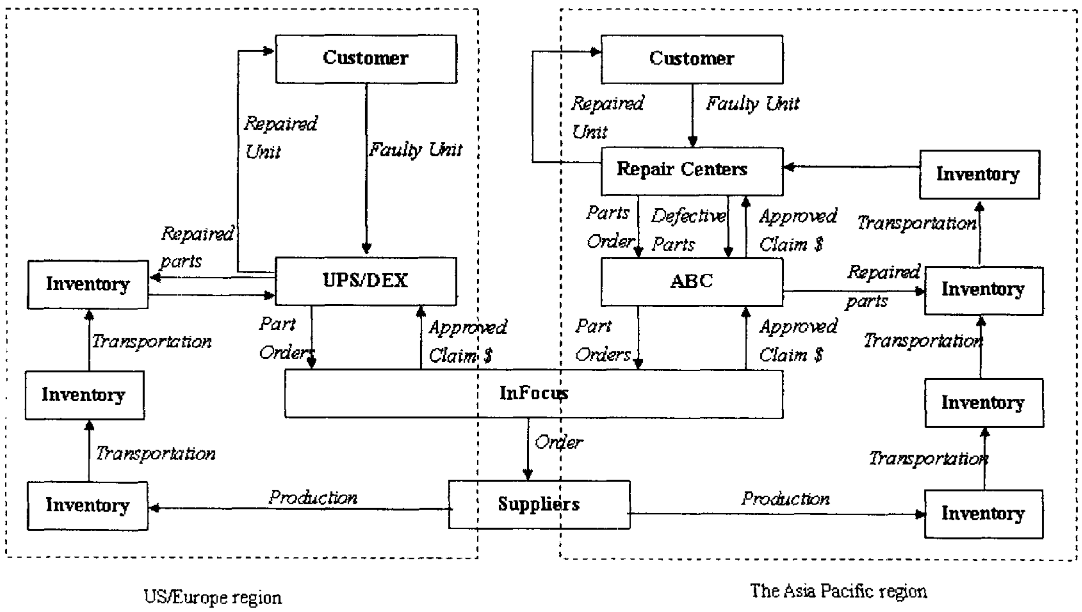


Figure 2: Service part supply chain comparison among regions

Terminology:

Customer – projector end users

Repair Centers – contracted repair service providers who are independent from InFocus. These repair centers also repair other kinds of products or other brands of projectors. InFocus will reimburse these repair centers if the repair is within the warranty period. For out-of-warranty repair, the repair center can negotiate the price with customers and charge them directly.

ABC – a third party contractor paid to manage the entire service network in Asia Pacific region for InFocus. ABC is a company that mainly provides reverse logistic management and electronic device repair services. Note that the actual company name is not used for confidentiality concern.

InFocus hires ABC to do the following jobs:

(a) To validate in-warranty claim

The validation process includes verification of the projector's warranty documents, physical examination of the replaced parts (repair centers need to ship the defective parts to ABC) to ensure that the damage is covered under the warranty terms and the claimed material costs match the parts replaced.

(b) To reimburse the repair centers for approved in-warranty repairs

ABC pays the repair centers on approval of the claims. It then invoices InFocus periodically after consolidation of the repair centers' claim.

(c) To purchase the service parts from InFocus and manage the service parts supply chain. They also have to ensure that the repair centers have sufficient service parts to meet the specific turn around time (TAT).

(d) Provide technical training and support to the repair centers.

UPS – UPS is an established shipping and logistic company. It provides repair and logistics services to InFocus in US and Europe.

Dex - similar to UPS, Dex is also an established shipping and logistics company. It is another third party contractor involved in repairing InFocus' projectors in Europe region.

Compared to the Asia Pacific region, North America and Europe enjoy the presence of two well established logistic companies, UPS (for North America and Europe) and Dex (for Europe only). UPS and Dex integrate their advanced distribution network with their repair services, which provides InFocus with a very cost effective reverse supply chain. However, in the Asia Pacific region the repair centers in the service network are independent from one another and scattered in different countries – many of the countries do not have free trade agreements. The multi-country network in the Asia Pacific region makes the supply chain much more complicated and costly since the various countries have different service industry regulations and import taxes/duties.

2.2 Current service part supply chain in Asia Pacific

2.2.1 Overview of service network operation

As shown in Figure 2, the RMA (Returned Merchandise Authorization) flow and service part supply flow are summarized below.

RMA Flow:

- Customer brings the faulty projectors to the nearby repair center
- Repair center raises RMA record, performs the repair and returns the repaired projector to the customer
- Repair center raises the repair imbursement request to ABC
- ABC validates the claim and reimburses the repair center
- ABC consolidates approved imbursements from individual repair centers and submits the claims to InFocus
- InFocus validates the claims and reimburses ABC

The service parts are supplied under a "buy-sell" agreement among InFocus, ABC and the repair centers. Under this agreement, each party has to manage its own service parts inventory and has the total ownership of the parts in their respective warehouses.

Service Parts Logistic Flow:

- The repair centers, as the first stage in the service parts supply chain, observe customer demand, forecast the future demand using historical data. According to the demand forecast, they purchase service parts from ABC and keep the on-site inventory.
- Similarly, ABC purchases service parts from InFocus and keeps its own inventory,

according to the forecast of the orders from the repair centers.

- InFocus purchases service parts from the suppliers and keep its own inventory, according to the forecast of the orders from ABC.

2.2.2 Market distribution

Figure 3 gives the geographic distribution of the repair job volume in Asia Pacific by countries. The top five countries are China, Australia & New Zealand, Hong Kong and Korea, and they make up 70% of the total repair volume.

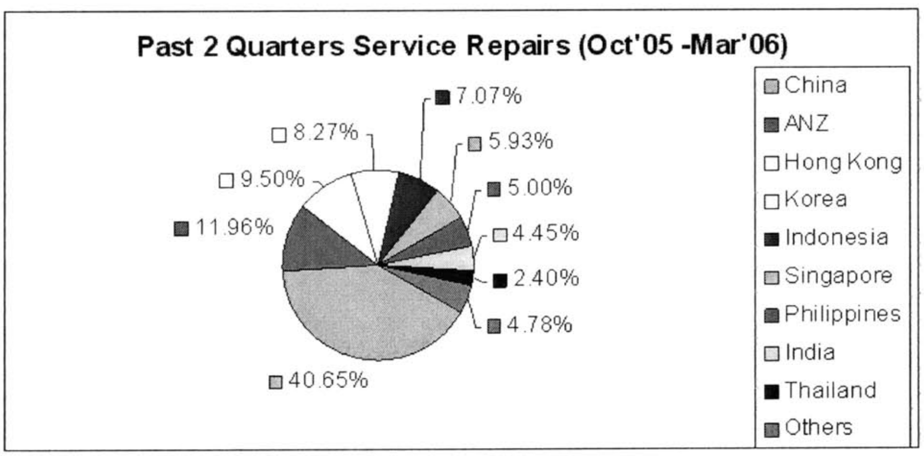


Figure 3: Service volume distribution by country in Asia Pacific region

2.2.3 Unit service cost breakdown

The unit repair cost is the direct cost InFocus has to pay for every in-warranty repair carried out by the repair center. For the Asia Pacific region, the unit repair cost consists of various items and Equation 1 gives the breakdown. Note that the numbers in the parentheses indicate weight of each item, in terms of percentage of total unit repair cost. The numbers are calculated from the past one year's repair records in the Asia Pacific region.

Unit_Repair_cost = Labor Cost (11.9%) + Material Cost (52.2%) + 10%*Material Cost (5.2%) + 4%*Material Cost (2.1%) + Import Tax/Duty (5.2%) + ABC Overhead (23.4%) (eqn 1)

Explanation of the contributing items of unit repair cost:

Labor Cost – the fee InFocus pays to the repair centers for the activities that they carry out for a single in-warranty repair.

Although the repair centers are required to have certified and trained personnel to repair the faulty projectors, the actual repair is relatively simple since InFocus projectors are highly modularized. Repairs mainly consist of the replacement of faulty modules. The past one year data showed that the labor cost per repair was relatively consistent with little variation. The labor charges are the sole source of revenue for many of the repair centers that repair InFocus projectors.

Material – the service parts used for the repair. The cost of material is dependent on the parts that failed and were replaced.

10%*Material – the financial burden compensation paid to ABC since ABC has to pay the repair center first before they are reimbursed by InFocus.

4%*Material – the inventory excess and obsolescence risk compensation paid to ABC as it holds the service part inventory.

Import Tax/Duty – many countries in Asia Pacific do not have a free trade agreement among one another. The importation of service parts in these countries will incur 5% to 25% import tax and duty. An average of 10% import tax/duty is assumed in equation 1.

ABC Overhead – the overhead fee (per repair) paid to ABC for managing service parts inventory, validation of repair centers' claim and provision of technical support. Table 1 itemizes the monthly overhead expenses that ABC charges InFcous for managing the service network.

Table 1: ABC overhead cost breakdown

Item	Charge %
Manpower for InFocus Service Network Management	26%
Manpower for InFocus Logistics Management	20%
Manpower for InFormation System Support	3%
Equipment for InFormation System	3%
Equipment for Facilities (Maintenance)	2%
Hotline Call Center	7%
Insurance for inventory	4%
Spare Part Hub Running Cost	9%
Warehouse Floor Space	13%
Telecommunication/IT Expense	5%
Training and Travel	9%
Total	**100%**

3. Identification of Problem

From the current service network review and the repair cost breakdown, various problems that need to be solved have been identified. Their solution will lead to the improvement of the service part supply chain efficiency and the reduction of cost.

3.1 Poorly distributed repair centers

Currently, there are 46 repair centers located in 15 countries in the Asia Pacific region. All these repair centers are independent of InFocus, i.e., InFocus does not own any of the repair centers. ABC manages the service part supply chain and validation of the in-warranty repair claim from the repair centers. From past repair records, it was noticed that some of repair centers have very low volume of repairs due to the InFocus sales shrinkage or redundant repair center setup in the same area (Figure 4). The low volume gives these repair centers little incentive to provide satisfactory service levels to InFocus.

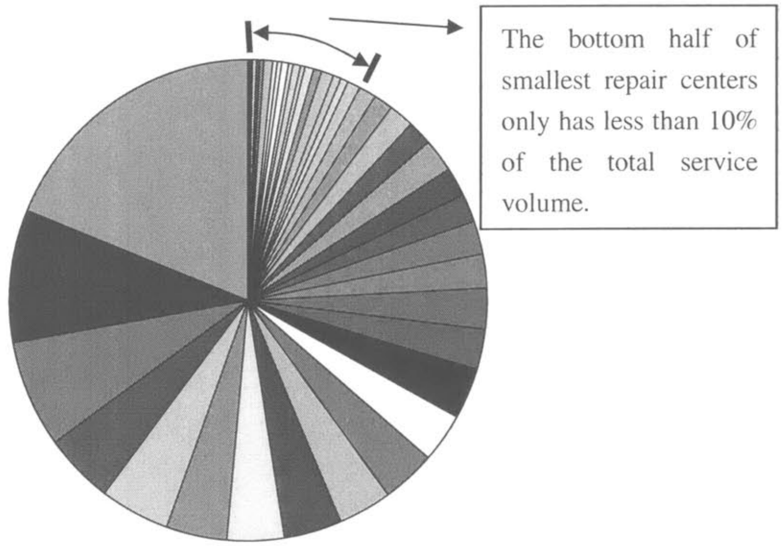


Figure 4: Service volume distribution by repair center in Asia Pacific region

3.2 Redundant echelon in the supply chain

From the comparison of the service part supply chain network between different regions, it was noticed that the Asia Pacific region had an additional echelon, ABC, in the supply chain. There are significant costs incurred due to ABC' need to manage and hold service part inventory. These costs include the inventory holding risk cost, logistic management manpower cost and warehouse cost.

ABC holding inventory does not add significant value to InFocus since InFocus has to manage and hold inventory to satisfy ABC's order anyway. This redundant echelon in the supply chain may cause inefficiency and longer lead time.

3.3 Bullwhip effect

Because of the long supply chain and independent buy-sell scheme with insufficient information sharing, bullwhip effect may arise where the demand fluctuation is magnified as we move up the supply chain. Current service parts buy-sell model requires every stage to have total ownership of the service parts in their own inventory (Figure 5). Repair centers are required to stock enough so that the service parts are available when the customer sends the projector for repair; ABC will base their planned inventory levels that they order from InFocus on the ordering quantity from repair centers; likewise, InFocus uses ABC's ordering information to determine how much to order from its suppliers. This decentralized demand information in the supply chain aggravates the demand variation, as shown in Figure 6. Detailed analysis and calculation of bullwhip effect will be shown shortly.

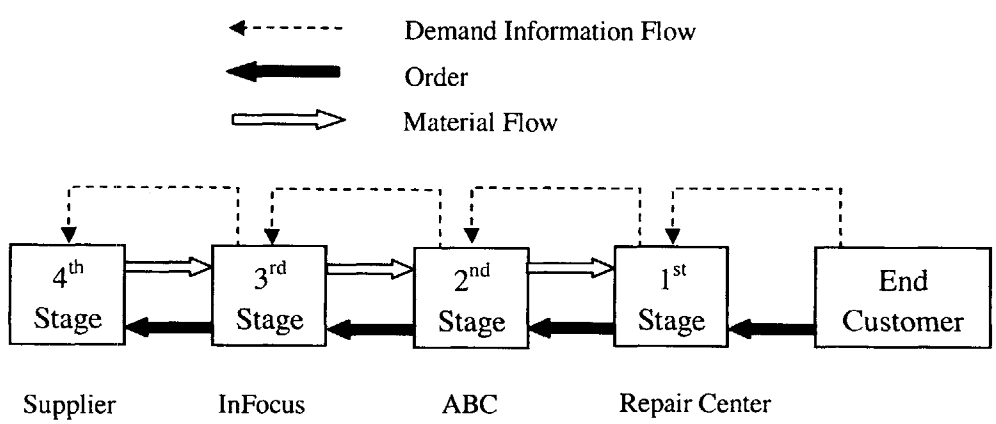


Figure 5: InFocus service parts supply chain

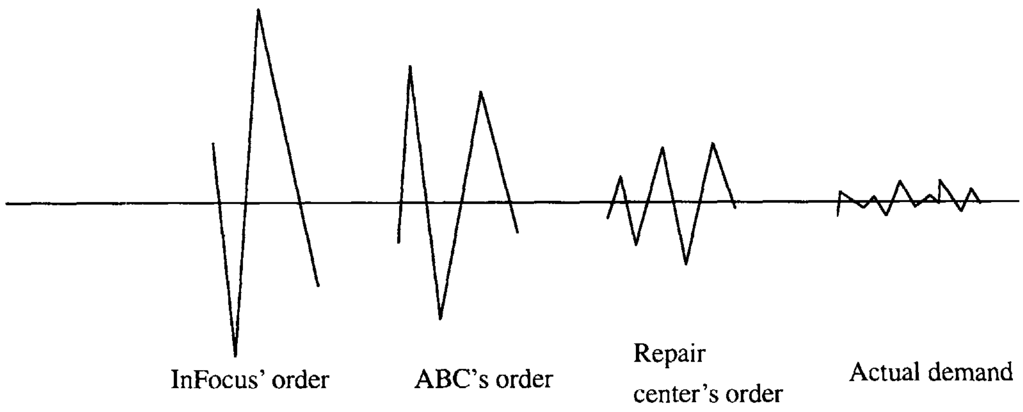


Figure 6: Graphic illustration of bullwhip effect

3.4 Lack of centralized management and system-wide cooperation

In the entire service part supply chain, the suppliers, InFocus, ABC and the repair centers are independent entities. The procurement of the service parts happens between the suppliers and InFocus; InFocus then sells the parts to ABC; ABC sells the parts to the repair centers. Under current buy-sell scheme, the price of the service parts is controlled by the different selling parties, i.e., the same parts were sold to InFocus, ABC and repair centers at different prices.

Repair centers are the first stage in the service part supply chain and have first-hand experience of the actual customer demand. However, this information is not well shared and utilized at its upper stages (ABC, InFocus and suppliers) for their inventories planning, which was solely based on the historical depletion rate of their stock.

For the service industry, the product sales and failure rate information is important to in determining the service part demand forecast. However, this information is controlled at InFocus and not used in improving the demand forecast.

In short, the absence of a centralized management results in lack of system-wide cooperation among different parties in the supply chain.

3.5 Unrealized outsourcing benefits

Outsourcing the service operation to ABC was supposed to be more cost effective and efficient on the service part supply chain by leveraging on the company's inventory management expertise, economies of scale for procurement and transportation. However, in current service part supply chain, ABC' role is merely a middle man between InFocus and repair centers. The Above mentioned benefits are not realized in current system:

- ABC' inventory policy is simply to stock up 1.5 months worth of inventory for the ordering period of one month, based on past three month demand data from repair centers. [5] Repair centers are managing their inventory based on their experience and cost. From actual field data, both repair centers and ABC often face shortages in service parts. Whenever this happens, ABC will raise "urgent request" to InFocus on an ad-hoc basis and repair turn around time is often sacrificed. The ad-hoc orders also worsen the accuracy of the demand forecast at InFocus.
- On service parts procurement, InFocus is buying from its own suppliers. ABC has no leverage with its limited business scale.
- The transportation costs incurred by ABC for InFocus business are reimbursed by receipts monthly, i.e. as long as ABC presents the receipt of transportation of InFocus materials, InFocus has to reimburse ABC. There is no agreement or motivation for ABC to save on transportation costs for InFocus through coordination of goods shipment with its other business.

In summary, none of advantages that outsourcing should bring are realized in current supply chain.

3.6 Insufficient supplier management

The cooperation between InFocus and its suppliers is insufficient. For example, the supplier lead time and minimum ordering quantity are crucial parameters when managing the service part ordering and safety stock holding. However, it was found that this information is not well maintained at InFocus. Even if there is such a lead time requirement, no contractual enforcement is in place to ensure the on-time delivery, which increases the inventory planning uncertainties.

4. Service part supply chain improvement proposal

To address the problems identified in section 3.1-3.4, the following improvements are proposed.

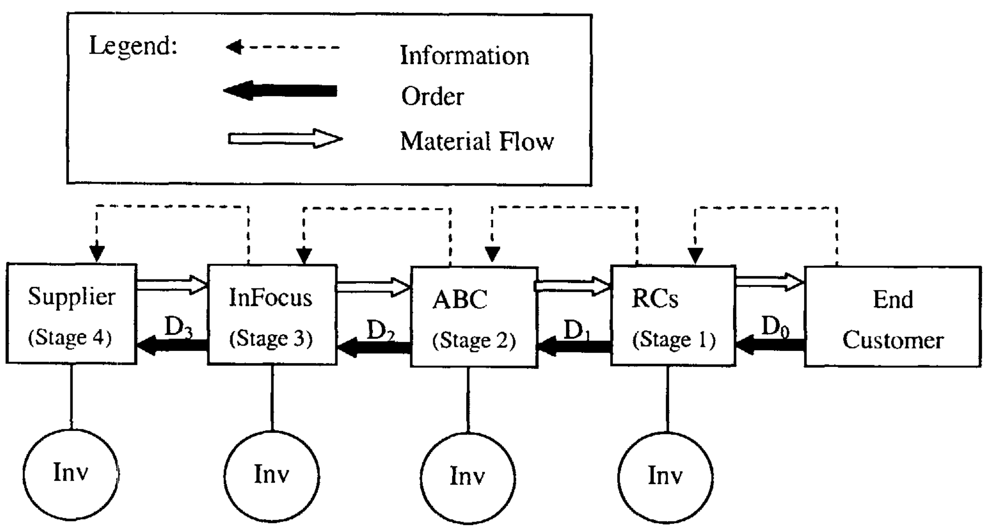
4.1 Reduce number of repair centres

It is proposed to deactivate those less active repair centers and consolidate the volume to the key repair centers. It will greatly simplify the entire service network and create more demand risk pooling effect, ensuring that the remaining repair centers will experience economies of scale and lower overhead costs per repair. As repair center costs go down, InFocus could have a higher bargaining power on the labor charges. InFocus also can enjoy the cost savings on the service part shipment to less repair centers.

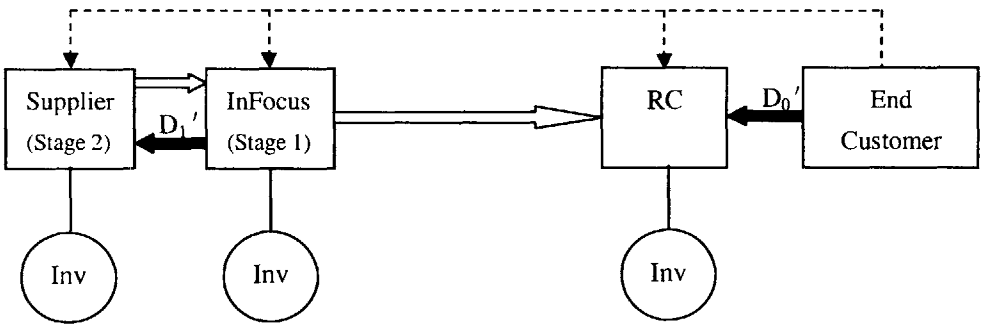
The main drawback of the exclusion of some existing repair centers is that it may cause some inconvenience to a small number of customers who will have to ship the faulty projector to a repair center that is farther away. However the advantages far outweigh the disadvantages as the, customers will probably experience a shorter turn around time and better service quality with the bigger repair centers.

4.2 Shorten the supply chain with centralized management

Figure 7 (a) shows the current service part supply chain. In comparison, a simplified and shorter supply chain with a centralized management is shown in (b). Unlike the current supply chain with four stages, where each stage in the supply chain manages the service parts independently under the buy-sell scheme, the proposed supply chain employs a consignment scheme between InFocus and the repair centers to enhance cooperation and reduce the system level cost. Once the service parts are purchased from the suppliers, InFocus will have the total ownership of the parts until they are consumed in repairs. By proactively monitoring the demand and the inventory level at each repair center, InFocus will be responsible for triggering the replenishment of the necessary service parts whenever a shortage is detected. InFocus effectively becomes the first stage and the total number of stages in the supply chain is reduced to two. Although repair centers still hold some of the inventory physically, the planning and ownership belongs to InFocus. Therefore in Figure 7 (b), the proposed supply chain shows no inventory at repair centers. This proposal assumed that InFocus is the central management of the supply chain. Outsourcing the management role to a third party company is possible if it has better expertise and more leverage than InFocus does. Third Party Logistics (3PL) and Vender Managed Inventory (VMI) will be discussed in the section that covers future improvements.



(a) Current service part supply chain



(b) Proposed service part supply chain with ship-per-need model

Figure 7: Current and proposed service part supply chain for Asia Pacific

5. Feasibility study of proposed supply chain

5.1 Benefits

5.1.1 Immediate per unit repair cost reduction

Table 1 is the cost breakdown of ABC's overhead. Estimation is shown below on how much InFocus would be able to save if ABC were to be eliminated from the service parts supply chain.

The savings come from:

(a) 4%*Material

(b) ABC overhead

- Manpower for Logistic Management
- Insurance on inventory
- Inventory HUB running cost
- Warehouse Floor Space

The total savings worked out from above items are 13% of total unit repair cost shown in equation 1.

5.1.2 Better control

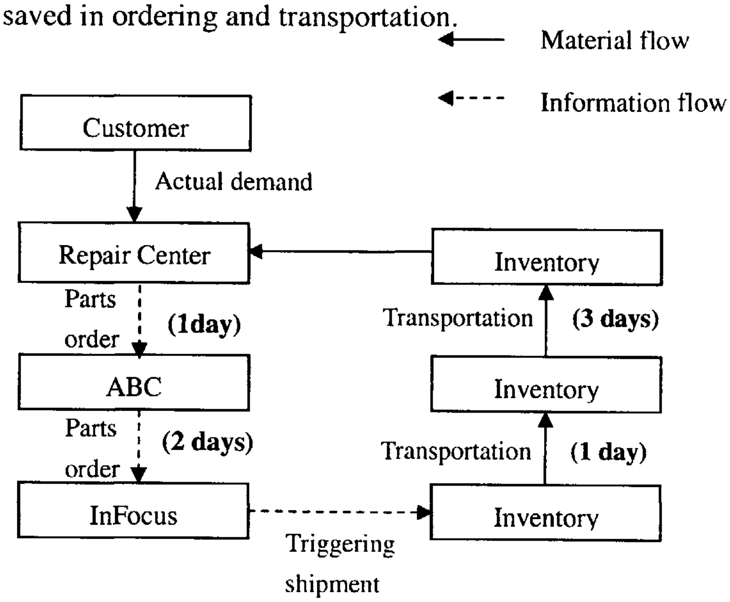
By managing the service network in-house, InFocus can integrate the demand information with its projector sales and failure rate data (which is very confidential and sensitive to InFocus) to generate a more accurate forecast. The suppliers can also benefit from the sharing of demand forecasting information, which would further reduce the system level cost.

Besides the supply chain benefits, InFocus will also have a clearer and more timely feedback on its projector quality and market response from direct interaction with the repair centers, who deal directly with the projector users.

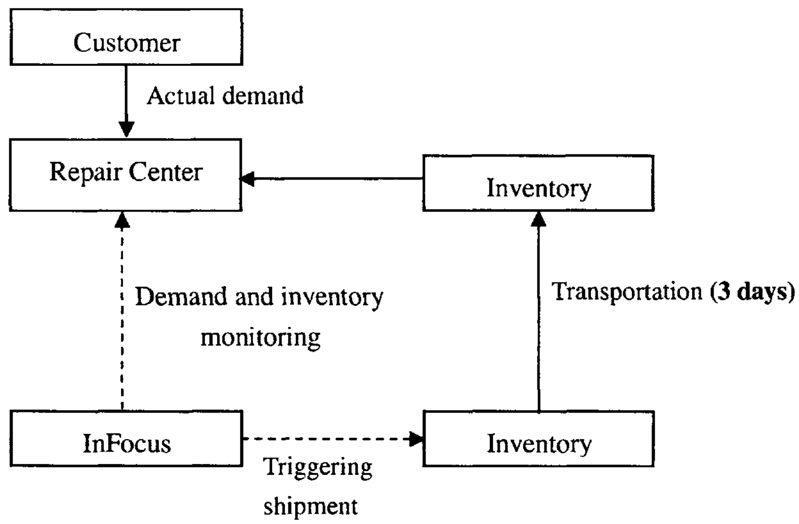
5.1.3 Shorter lead time on service part

As shown in Figure 8 (a), in the situation where a repair center orders service parts from ABC when ABC has no inventory, current supply chain takes at least seven days (three day order processing time and four day transportation time) to receive the parts.

In comparison, the proposed supply chain in Figure 8 (b) only takes 3 days to obtain the parts due to time saved in ordering and transportation.



(a) Current supply chain with lead time of 7 days



(b) Proposed supply chain with lead time of 3 days

Figure 8 Lead time comparison between current and proposed supply chain

It is noticed that above cycle time is only realizable if InFocus always holds enough inventory. If InFocus has a shortage in the service parts, it is would be most likely too late to purchase the required parts from the supplier due to the long lead time and minimum ordering quantity requirement. In this situation, InFocus has to replace a new projector to the customer. Since the shortage at InFocus will result in a very costly solution, the service part stock out level at InFocus has to be low.

5.1.4 Demand risk pooling

Refer to Figure 9 and consider there are three repair centers in the network. InFocus enjoys demand risk pooling by consolidating the demands from all repair centers, treating the three repair centers as a whole. Since the service parts can be stored in repair centers' warehouse, to maintain the demand risk pooling, transshipment must be allowed among repair centers. As InFocus has the ownership of the parts, transshipment would be possible among repair centers. Although the repair centers will incur additional administrative and handling cost, they are not exposed to any risk of inventory ownership, as compared to the previous buy-sell model.

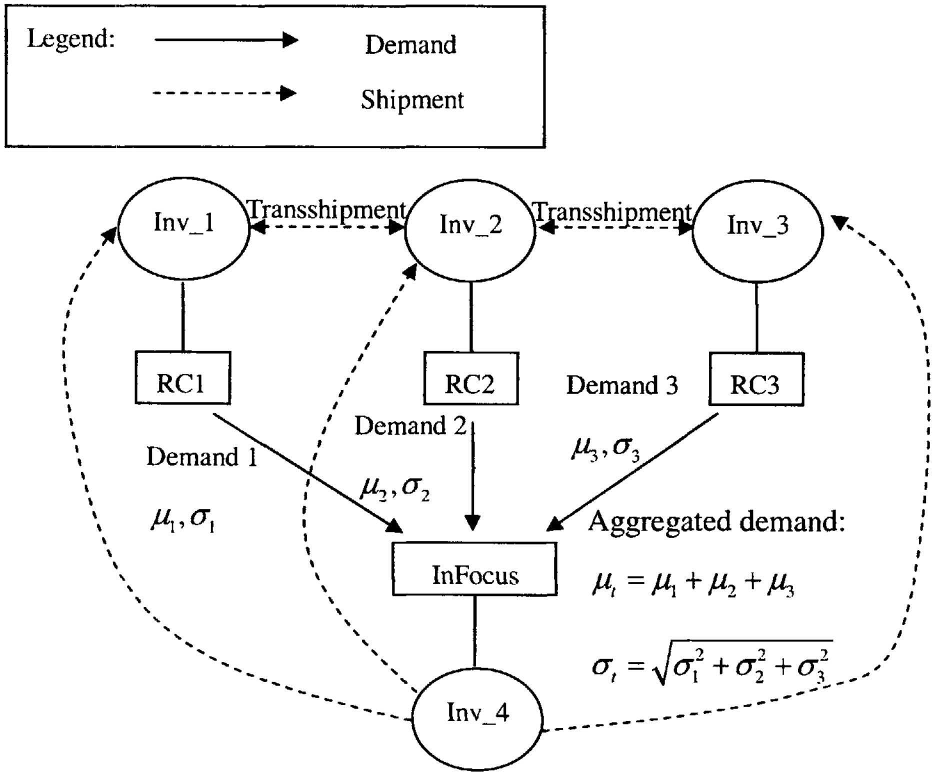


Figure 9: Proposed supply chain with demand risk pooling

5.1.5 Optimized transportation cost

More flexible transportation

If we assume the repair center needs one day for diagnosis (to decide which service parts to use) and one day to repair and return the repaired unit to customers after receiving the required service part, the turn around time of the projector repair will be nine days if the repair center places orders to InFocus through ABC in current supply chain. Given the ideal turn around time to be less than seven days, the repair centers have to hold service parts inventory.

In the proposed supply chain, the reduction in lead time makes it possible to ship the parts when they are needed (5 day TAT), which we will refer as "ship-per-need" (SPN) in this report. In comparison, if we ship the parts to the repair center before the demand comes based on the demand forecast, it is called "ship-to-stock" (STS).

Cost Tradeoff

Ship-per-need and ship-to-stock together will enable more flexible ways for the service part inventory storage, i.e., a service part can be stored at either InFocus' warehouse or at the repair center's site. Both ways will ensure an in-time access to the service parts that a repair job requires. However, there exists a tradeoff in the transportation cost: in ship-per-need mode, InFocus ship the repair centers service parts after the repair demand arrives, therefore no transshipment of parts can occur among repair centers. However, the ordering and shipping activity will become much more frequent, which will result in more fixed order cost. On the other hand, if we were to ship the parts in bulk and store all inventory at the repair centers (ship-to-stock), the per unit transportation cost will drop but potential transshipment cost will incur. In summary, the tradeoff between ship-per-need and ship-to-stock is listed in Table 2.

Table 2: Transportation cost tradeoff between SPN and STS

Transportation cost	ship-per-need	ship-to-stock
Fixed cost	higher	lower
Transshipment cost	nil	higher

The tradeoff might provide an opportunity to achieve minimum transportation cost by finding the optimum point where both ship-to-stock and ship-per-need are used.

Service parts replenishment policy

Figure 10 depicts the proposed inventory replenishment process with a detailed explanation given below:

(a) InFocus orders from the supplier according to the aggregated demands from all the repair centers. As shown in Figure 9, assuming a 99.7% service level (safety stock factor z=3), the total stock InFocus will receive from its supplier is:

$$\begin{aligned} \text{Stock\_total} &= \mu_t + z \cdot \sigma_t \\ &= (\mu_1+\mu_2+\mu_3)+3\sqrt{\sigma_1^2+\sigma_2^2+\sigma_3^2} \end{aligned} \qquad \text{(eqn 2)}$$

(b) Certain percentage of total stock is shipped in ship-to-stock mode to individual repair center as on-site stock while the remaining stock at InFocus will be used for ship-per-need later.

(c) The repair centers consume the on-site stock until exhaustion.

(d) InFocus ships service parts to the repair centers that have zero on-site stock on ship-per-need basis. As shown previously, ship-per-need transportation mode can still meet the specified turn around time in the proposed supply chain.

(e) After InFocus has exhausted the stock in its warehouse, transshipment will be triggered among repair centers.

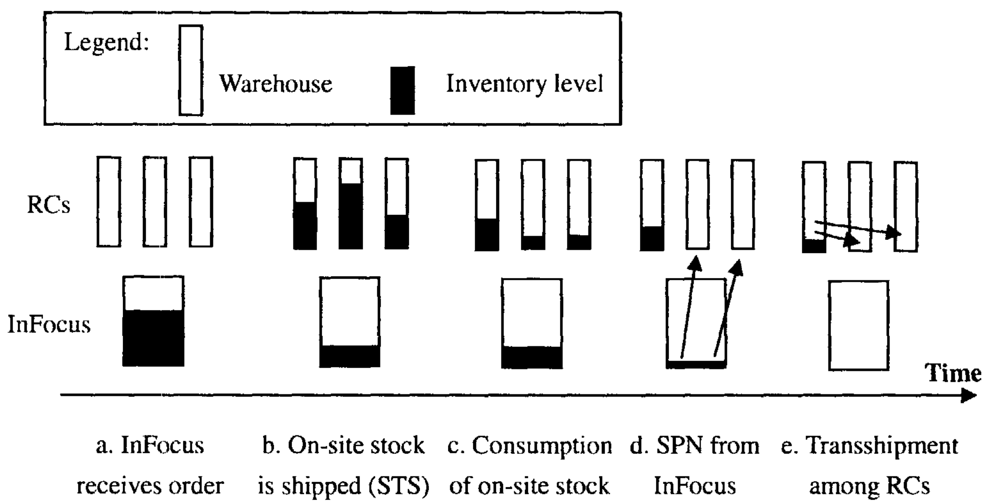


Figure 10: Service part replenishment process

Simulation and optimization

For the wide range of service parts InFocus has, which method (ship-per-need or ship-to-stock) will be better for a given part? Or is a hybrid way is more cost effective? The analysis below uses simulation to determine the optimum shipping strategy to use for a given part.

Crystal Ball ™ was employed to simulate the stochastic demand at individual repair centers. The optimization objective is to minimize the total transportation cost by assigning the optimum percentage of total parts to ship-to-stock and ship-per-need respectively. Appendix 1 gives the detailed simulation setup and a sample calculation for a projector service part on determining the optimum inventory to keep at repair centers and at InFocus. Apparently the proposed service part replenishment policy not only keeps the benefit of demand risk pooling but also minimizes the transportation cost.

In comparison, the current supply chain and replenishment policy cannot achieve above benefits due to:

- Buy-sell scheme prohibits the transshipment among repair centers.
- The lead time between repair center and InFocus is too long to meet the required turn around time.

5.1.6 Lesser safety stock

As shown in Figure 7, compared to the current supply chain, the proposed supply chain is shorter and the aggregated demand information from the repair centers is shared between InFocus and the supplier. These differences minimize the bullwhip effect in the proposed supply chain and result in a much lower safety stock level.

In Appendix 2, the bullwhip effects and safety stock levels are compared between the current supply chain and the proposed supply chain for the same system service level. Proposed supply chain would reduce the system safety stock by half for the given part.

5.1.7 Higher customer service level

In theory, the current supply chain can achieve system service level of 95% as shown in Figure 11 (a), provided every stage stocks enough to ensure 98.7% service level. However, this requires very high inventory stock-up at the all stages due to the bullwhip effect and lack of risk pooling.

Under the buy-sell agreement, both repair centers and ABC are very reluctant due to the high inventory holding costs. ABC is only holding 1.5 month worth of inventory for its one month ordering cycle, despite the different demand characteristics of different parts; the repair centers stock even less inventory, hoping that ABC will always provide them service part when the repair jobs arrive. At times, the turn around time of the repair might be sacrificed due to shortage of the service parts. Although InFocus has requirement that ABC and service centers should stock enough to meet the specific turn around time, some uncertainty exists where the responsibility of the part shortage is not clear and the enforcement is difficult. Therefore, the theoretical 95% service level was never realized in current service part supply chain as shown in Figure 11 (b).

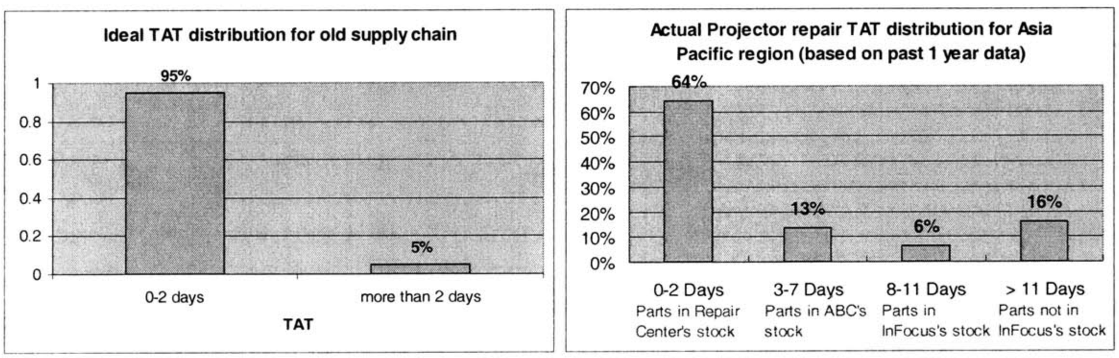


Figure 11: Projector repair TAT distribution for current supply chain

(a) Ideal TAT (b) Actual TAT

In the proposed supply chain, we can push the 6% repairs with TATs of 8-11 days to below seven days with four days lead time reduction. It is also noticed the 16% of TATs greater than 11 days are due to part unavailability at InFocus, which cannot be solved by the proposed supply chain alone. However, the proposed supply chain and the replenishment policy will better position InFocus and its suppliers to improve the service level at least cost.

5.1.8 Happier repair centers

The centralized management by InFocus not only removes the inventory planning work load from repair centers, but also eliminates the inventory planning uncertainties resulting from lack of inventory management expertise at many repair centers. The consignment scheme also frees the repair centers from inventory holding risk. All these benefits repair centers enjoy will help InFocus to implement the new supply chain concepts and develop a better partnership with the repair centers.

5.2 Work to be done

To implement the proposed service part supply chain system, InFocus has to invest in an information system and establish good partnership with the repair centers and suppliers. The service level at InFocus has to be maintained high to satisfy the demands at the repair centers with required TAT.

5.2.1 Investment in information system

Centralized supply chain management and shorter lead time require advance information system to monitor the inventory at all sites in real time. Specifically, the real-time visibility of the inventory at individual repair center is crucial to implementation of the ship-per-need method. The inventory system has to be integrated with the RMA system to trigger the immediate shipment when a shortage at a repair center is detected.

5.2.2 Repair center management and partnership

An advanced information system can only function with accurate and timely data inputs. The repair centers need to log the service part usage and repair jobs on hand in the information system in time to allow InFocus to monitor the service part availability and plan the shipment accordingly. This might require some of repair centers to make investment on the computers and internet subscriptions.

For transshipment, repair centers having excess parts must be promptly ship the part to the service center that needs it.

In conclusion, InFocus has to establish a cooperative partnership with the repair centers to ensure the proposed supply chain operates smoothly.

5.2.3 Supplier management and partnership

As pointed out previously, current supplier management at InFocus has to be improved to ensure InFocus has sufficient and in-time service part replenishment. The share and use of information to improve the system efficiency must also be based on a good partnership.

5.2.4 Service level improvement at InFocus

As pointed out in section 5.1.7, the proposed supply chain works only if InFocus has a very high service level. Various causes leading to the current low service level at InFocus have been identified and possible solutions are discussed:

- Inaccurate forecasting method

Current demand forecast for the spare parts is purely based on the historical depletion rate of the inventory. However, the actual data has shown an unbalanced inventory: on one hand, some parts have excesses in the warehouse and are probably obsolete; on the other hand, many other parts have back orders, which result in unacceptable TATs or financial penalties. A comparison between the forecast and actual demand reveals that current forecasting method is not accurate enough. [6] A much better prediction can be developed with consideration of the projector sales volume at different regions. For example, if a type of projector sells well in certain region, we should expect higher volume of repairs after some time. Therefore we should stock more spare parts in that region.

Engineering study also need to be done to identify the failure rate of different projector parts to help improve the forecast accuracy even further.

- Loose control of inventory replenishment operation

Currently InFocus is using an ERP system for the spare parts inventory management. The system uses the historical data to calculate the important parameters used to forecast the safety levels. For example, the lead time used to calculate the safety stock level is derived from historical data by subtracting the date of PO (Purchase Order) from the date of DO (Delivery Order). However, this lead time could be skewed as the planner purposely expedited or delayed a DO due to unexpected surge or slowdown on the part demand after the PO had been made. The skewed lead time causes the safety stock to be calculated wrongly for the next planning cycle. To make things worse, InFocus does not have a good contractual enforcement with its suppliers to ensure a timely delivery of orders. It is suggested that the data with uncertain human interference should not be used in the inventory planning and better control on the suppliers is needed.

6. Future Improvement

6.1 3PL

Currently, more and more companies are outsourcing their service part supply chain management to third party companies who have more expertise and leverage in the industry. Instead of in-house management, the proposed supply chain can be managed by capable 3PL (third party logistics) companies if they are able to provide more leverage. For example, they may have the information system InFocus lacks to monitor the repair centre inventory and repair jobs; they may also have many other similar customers so that higher economies of scale on the procurement and transportation can be achieved.

6.2 VMI

In the proposed supply chain, even if we eliminate the extra layer between InFocus and the repair centers, the service parts are still required to be shipped from supplier to InFocus and from InFocus to individual repair centers. The system-wide supply chain can be even more efficient if the suppliers (vendors) can manage the production and supply chain by themselves, and replenish the repair centers directly. The suppliers own the parts until they are used at the repair centers. This is called Vendor Managed Inventory (VMI).

With the demand and sales information provided by repair centers and InFocus, suppliers can minimize the bullwhip effect and better schedule their production to improve production capacity utilization, shorten lead time and reduce the system level safety stock; it is also noticed that some suppliers are actually located very near centers. The direct shipment from supplier to repair centers will shorten the transportation distance and lead time significantly. InFocus can be freed from the service parts supply chain management and the expense of inventory holding. However, the supplier normally will incur addition cost and risk like added logistic manpower, information system and the inventory ownership risk. The benefits and cost associated with VMI have to be shared fairly between both parties and enforced by contracts.

Although the impact will be great if implemented successfully, VMI requires more effort to establish and maintain. The VMI is only feasible for high value and high demand parts. Moreover, confidentiality and trust between different parties are crucial to the success of VMI since the vendor probably has customers who are InFocus' competitors.

7. Recommendation and Conclusion

The recommendations summarized from the proposal are listed below:

- Reduce number of repair centers
- Shorten the service part supply chain and centralize the service parts management

- Manage repair centers' inventory replenishment according to cost optimization
- Explore the feasibility of outsourcing whole service part supply chain to 3PL to enjoy additional leverages
- Explore possible VMI for high demand, high value parts to further improve the service level and cost

In conclusion, this report has studied InFocus' service part supply chain and proposed ways to improve its efficiency and reduce the cost. The proposed supply chain with lesser number of echelons and centralized management demonstrate better performance on the lead time, safety stock, service level and transportation cost. Strategic 3PL partnership and vendor managed inventory (VMI) were also discussed and future work can be devoted in these areas to further improve the service part supply chain.

Appendix 1 Crystal Ball ™ simulation for optimum inventory replenishment

Simulation Setup

Table 3 gives an overview on the simulation setup. The detailed explanation on the individual terms in the table will be provided shortly. Note that the numbers in the stochastic demand cells are from one of the possible trial runs.

Table 3 Crystal Ball simulation setup for proposed inventory replenishment

Parameters	Safety factor	3		
	Total stock	30		
	Fixed per shipment cost	100		
	Unit shipment cost	10		
	Repair Center Index	**1**	**2**	**3**
	Demand mean	1.33	4.83	4.33
	Demand stdev	1.37	5.27	3.56
Assumption	Stochastic demand	6	15	8
Decision variables	STS percentage	0.1	0.36	0.32
	SPN percentage (total)		0.22	
Constrains	- sum of STS percentage for all repair centers <= 1			
	- individual STS percentage for each repair center is in the range of [0,1]			
Intermediate results	STS stock surplus	-3	-4.2	1.6
	SPN stock surplus (total)		-0.6	
	STS cost	130	208	196
	SPN cost	726		
	Transshipment cost (total)		66	
Forecast	Total cost		1326	

Safety factor – it is the factor z determining the safety stock level in equation 2. It is set as 3 with 99.7% service level in this example.

Total Stock – the aggregate service parts ordered according to equation 2.

Fixed per shipment cost – the fixed administrative and handling fee associated with one shipment.

Unit shipment cost – the variable transportation cost per unit. Therefore, for one shipment, the transportation cost is equal to:

Transportation_cost = Fixed_per_shipment_cost + N*Unit_shipment_cost (eqn 3)

Where N is the quantity of parts shipped.

Stochastic demand – the stochastic demand data are generated by Crystal Ball with specified mean, standard deviation and the distribution function. Normal distribution is used in this simulation. The demand at repair center i is noted as demand_i.

STS percentage – the percentage of total stock shipped in a single shipment to a particular repair center as on-site stock at the beginning of the replenishment cycle.

SPN percentage - the percentage of total stock remained in InFocus' warehouse after the on-site stock is shipped to the repair centers.

$$\text{SPN\_percentage} = 1 - \sum_{i=1}^{k} \text{STS\_percentage}_i \qquad \text{(eqn 4)}$$

Where k is the total number of repair centers

STS_surplus – the number of on-site service parts leftover at repair center i after all demands in the replenishment cycle are satisfied.

$$\text{STS\_surplus}_i = \text{STS\_percentage}_i \times \text{Stock\_total} - \text{demand}_i \qquad \text{(eqn 5)}$$

A negative STS_surplus means a STS_shortage, which will require parts shipped from InFocus (ship-per-need) or other repair centers (transshipment) to satisfy the demand.

$$\text{STS\_surplus}_i = -\text{STS\_shortage}_i \qquad \text{(eqn 6)}$$

SPN_surplus – the number of remaining service part at InFocus after satisfying all repair centers' demand on ship-per-need basis.

If $\sum_{i=1}^{k} \text{STS\_surplus}_i < 0$

$$\begin{aligned}\text{SPN\_surplus} = {} & \text{SPN\_percentage} \times \text{Stock\_total} \\ & - \sum_{i=1}^{k} \text{STS\_shortage}_i\end{aligned} \qquad \text{(eqn7)}$$

If $\sum_{i=1}^{k} STS\_surplus_i \geq 0$

$$SPN\_surplus = SPN\_percentage \times Stock\_total \qquad \text{(eqn 8)}$$

Negative SPN_surplus means a SPN_shortage, which require parts transshipped from other repair centers.

$$SPN\_surplus = -SPN\_shortage \qquad \text{(eqn 9)}$$

STS cost – The transportation cost when shipping the service parts in batch to repair center i at the beginning of the replenishment cycle.

$$\begin{aligned} STS\_cost_i &= Fixed\_per\_shipment\_cost \\ &+ STS\_Percentage_i * Total\_stock * Unit\_shipment\_cost \end{aligned} \qquad \text{(eqn 10)}$$

SPN cost – the total transportation cost when shipping the service parts on ship-per-need basis. The service parts were assumed to be shipped one by one under ship-per-need mode.

Let $SPN\_qty = SPN\_percentage * Total\_stock$ (eqn 11)

if $SPN\_qty < \sum_{i=1}^{k} STS\_shortage_i$,

$$SPN\_cost = (Fixed\_per\_shipment\_cost + Unit\_shipment\_cost) * \sum_{i=1}^{k} STS\_shortage_i \qquad \text{(eqn 12)}$$

if $SPN\_qty > \sum_{i=1}^{k} STS\_shortage_i$,

$$SPN\_cost = (Fixed\_per\_shipment\_cost + Unit\_shipment\_cost) * (SPN\_qty - \sum_{i=1}^{k} STS\_shortage_i) \qquad \text{(eqn 13)}$$

Transshipment cost – transshipment only happens when the stock at InFocus cannot satisfy all STS shortages. It is assumed that only one service part is shipped per transshipment.

Let Tansshipment_qty be the number of service parts transshipped.

$$\text{if SPN\_qty} < \sum_{i=1}^{k} \text{STS\_shortage}_i, \quad \text{Transshipment\_qty} = \sum_{i=1}^{k} \text{STS\_shortage}_i - \text{SPN\_qty} \qquad \text{(eqn 14)}$$

$$\text{if SPN\_qty} \geq \sum_{i=1}^{k} \text{STS\_shortage}_i, \quad \text{Transshipment\_qty} = 0 \qquad \text{(eqn 15)}$$

Optimization Results

The optimization was carried out under following constrains:

- STS percentage at each repair centers must be in the range of (0,1)
- The sum of STS percentages for all repair centers has to be not greater than 1

The objective is to determine the optimum STS percentages for every repair centers – how many service parts are to be shipped by batch at the beginning of review cycle to achieve minimum total transportation cost.

For the given parts, the optimization results gave a minimum expected total cost of $580.58 with below decisions:

Table 4 Crystal Ball optimization results

Repair cent index	1	2	3
STS percentage	10%	36%	32%
SPN percentage	22%		

Appendix 2 Estimation of bullwhip effect

Many causes of the bullwhip effect have been identified by researchers. Notably Lee et al. had identified five main causes of bullwhip effect: the use of demand forecasting, supply shortages, lead time, batch ordering and price variations. [7] Simchi-Levi et al. proposed a method to quantify the impact of demand forecasting on the bullwhip effect, where the increase of the demand variation between two neighboring supply chain stages is expressed as a function of lead time and historical demand observations used for demand forecast. [8]

For example, consider any two neighboring stages in Figure 12 (a) for current service part supply chain. The demand variation faced by stage i is amplified when we move to the upper stage i+1.

If the demand information is not shared and each stage reacts based on the order received from the lower stage, the bullwhip effect can be calculated using equation 16.

Without information sharing: $$\frac{\mathrm{Var}(Q_k)}{\mathrm{Var}(D_1)} \geq 1+\frac{2\sum_{i=1}^{k} L_i}{p_k}+\frac{2\left(\sum_{i=1}^{k} L_i\right)^2}{{p_k}^2} \qquad \text{(eqn 16)}$$

Where

$\mathrm{Var}(Q_k)$ is variance of the orders placed by the kth stage of the supply chain

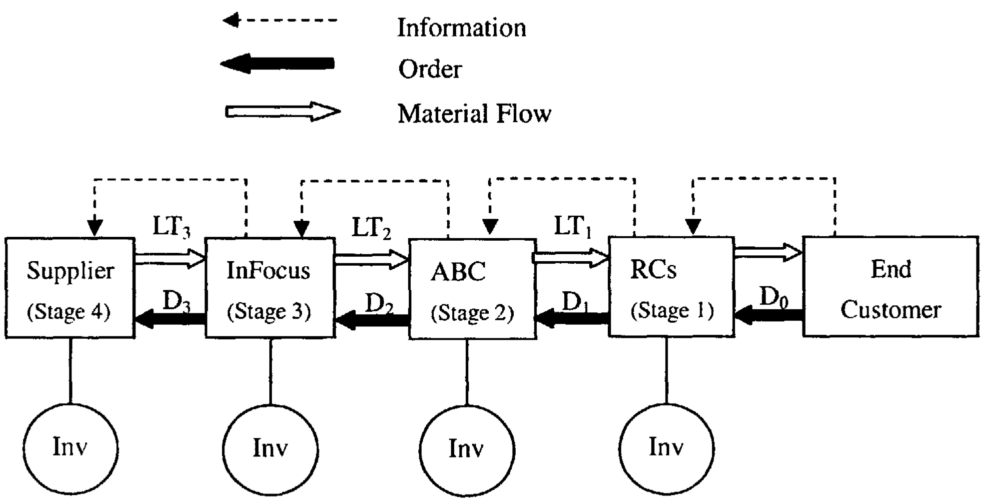
$\mathrm{Var}(D_1)$ is the customer demand at repair center

L_i is the normalized lead time of parts being shipped from stage i-1 to stage i, in terms of number/fraction of review period at stage i (due to review period is set to 1 in the equation derivation).

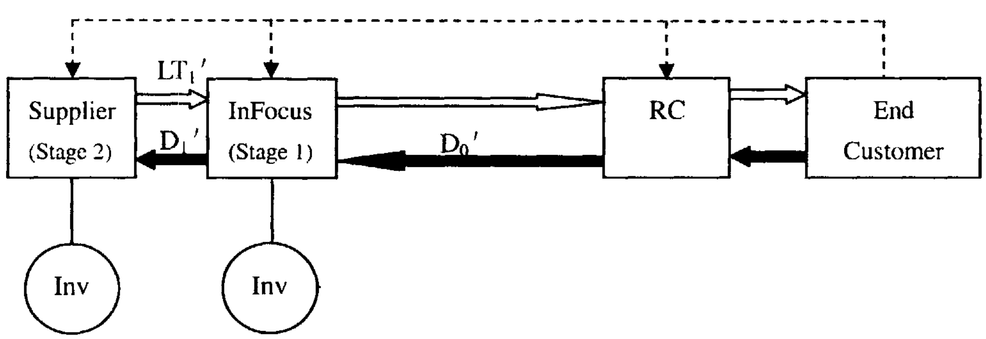
p_i is number of previous observations of demand used to forecast future demand at stage i

System wide information sharing cannot eliminate bullwhip effect, but it can greatly reduce it according to equation 17. [8]

With information sharing: $$\frac{\mathrm{Var}(Q_k)}{\mathrm{Var}(D_1)} \geq \prod_{i=1}^{k}\left[1+\frac{2L_i}{p_k}+\frac{2L_i^2}{p_k^2}\right]$$ (eqn 17)



(a) Current service part supply chain



(b) Proposed service part supply chain with ship-per-need model

Figure 12: Bullwhip effect driven by demand forecast

It is noticed from both equation 16 and 17 that bullwhip effect could be reduced with shorter lead time and more historical data used for the demand forecast. In reality, however, lead time is always limited by the geographical distance and transportation cost. And too old historical data may not be representative enough for current demand; therefore the number of previous observations that can be used is limited too.

Below calculation in Table 5 estimates the minimum bullwhip effect existing in current supply chain with decentralized information (Figure 12 (a)) and the proposed supply chain with centralized information (Figure 12 (b)). And corresponding total stock in the system is also calculated.

Table 5: Calculation of minimum bullwhip effect

	Current supply chain (a)			**Proposed supply chain (b)**
Stage Index	1	2	3	1
Review period (days), R	14	30	30	30
Lead time (days), LT	4	3	30	30
Normalized leadt time, L	0.29	0.1	1	1.00
No. of observations, p	6	6	6	6
Bullwhip effect, BE	1.05	1.07	1.25	1.18
Safety stock factor*, z	2.23			1.95
System safety stock**, ST	9.74			4.25

* use 95% system service level. For current 4-stage supply chain, each stage needs to have a service level of $\sqrt[4]{95\%}=98.7\%$ and corresponding safety stock factor z=2.23. For the proposed 2-stage supply chain, z=1.95

** System safety stock equals to the sum of individual stage safety stock.

let the customer demand stand deviation be $\sigma_0=1$.

For current supply chain:

$$\begin{aligned} ST_{sys} &= z\cdot\sigma_0 + z\cdot(BE_1\cdot\sigma_0) + z\cdot(BE_2\cdot\sigma_0) + z\cdot(BE_3\cdot\sigma_0) \\ &= z\cdot\sigma_0\cdot(1+BE_1+BE_2+BE_3) \\ &= 2.23\cdot 1\cdot(1+1.05+1.07+1.25) \\ &= 9.74 \end{aligned} \qquad \text{(eqn 18)}$$

For proposed supply chain:

$$
\begin{aligned}
ST'_{sys} &= z'\cdot\sigma_0 + z'\cdot(BE'_1\cdot\sigma_0) \\
&= z'\cdot\sigma_0\cdot(1+BE'_1) \\
&= 1.95\cdot 1\cdot(1+1.18) \\
&= 4.25
\end{aligned}
\qquad \text{(eqn 19)}
$$

Reference

[1] Definition by http://www.reference.com

[2] Interview with InFocus CEO, John Harker by CDW in 2002.

[3] InFocus Financial report 2001-2005

[4] InFocus Form 10K for year 2005

[5] Interview with ABC logistic manager

[6] Yang Ni, Thesis for MIT M. Eng, "Optimization of service parts planning".

[7] Lee H.L. and Padmanabhan V. 1997. "The bullwhip effect in supply chains". Sloan management review, No.38(Mar), 93-102.

[8] Simchi-Levi D., Kaminsky P., and Simchi-Levi E. "Designing and Managing the Supply Chain". McGraw-Hill Companies, Inc, 2nd edition. P101-106