A decision-making model for reverse logistics in the computer industry

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Abstract
Purpose – This paper seeks to present a decision-making model for manufacturers to maximize their profits in reverse logistics operations.

Design/methodology/approach – A system dynamic model has been developed to complement with prior models and is validated using data collected from a computer company manufacturer handling returns with volumes transacted over a period of two years.

Findings – The results from the model indicate that part replacements from suppliers are more profitable than refurbished computer parts. In addition, transportation delay and supplier delay in processing returns have a significant impact on the viability of reverse logistics regardless of return volumes.

Research limitations/implications – The current model is not designed for third-party logistics (3PL) offering reverse logistics services. However, this can be accomplished by resetting some of the parameters in the model. The other limitations are exchange rate fluctuation and product depreciation which are not incorporated in the model. This is important in Asia where each country has its own currency which fluctuates with time.

Practical implications – This dynamic model will assist decision-makers to test new policies related to reverse logistics, for example, liberal versus conservative return policy from supplier, shipment consolidation (longer delays) versus direct shipment, batch (longer delays) versus JIT remanufacturing, pricing of new parts versus re-condition parts, as well as to examine its long-term viability.

Originality/value – Using system dynamics to understand the profitability of reverse logistics for both replacement parts to suppliers and refurbished parts to manufacturers.

Keywords Reverse scheduling, Supply chain management, Decision-making, Electronics industry, Modelling

Paper type Research paper

Introduction
The growing concern for the environment, coupled with rapid increase in the introduction and use of new technology in the marketplace, has led to increased interest and focus in reverse logistics. According to Blumberg (2005), the compounded annual growth rate (CAGR) for repair service markets (part of reverse logistics operation) in the high-tech industry is about 9.6 per cent in the USA. The market potential based on Blumberg’s analysis suggests that there is an expected significant growth for repair services in this segment for the USA and Asia Pacific. In addition, Rogers and Tibben-Lembke (2001) confirm that reverse logistics accounts for 4 per cent...
of the total logistics costs. Thus, the study of reverse logistics in the computer industry is important to the Asia Pacific region including Singapore. According to the Economic Development Board (EDB) of Singapore this sector is one of the country’s largest within its manufacturing industry (EDB, 2002).

Reverse logistics can be defined as:

The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal (Rogers and Tibben-Lembke, 1999).

The model developed in this paper incorporates a systemic approach to analyze reverse logistics processes. Instead of analyzing reuse, remanufacturing, recycling separately, this model incorporates all these options to make a holistic judgement. Based on existing models, analyses of reverse logistics systems yield different decisions than when analyzed as a combined system with this new model.

The model is validated using data drawn from a computer manufacturer with an international exposure. Figure 1 shows the decision-making model proposed for reverse logistics that adopts a more systemic and dynamic approach in reaching a final decision.

Decision-making in reverse logistics operations involves the type of recovery to perform for returns, the location to perform recovery, the mode of transportation to move the returns to the recovery location and storage, and the pricing for recovered parts. These factors pose four key research questions on how they will affect reverse logistics operations:

1. Under what conditions should one consider employing reverse logistics (Kopicki et al., 1993)?
2. Which type of reverse logistics treatment should be given for each item or for each group of items (Tan et al., 2003)?
3. Where is the ideal location to perform the repair or scrap, and whether it should be performed locally or centrally (Fleischmann et al., 1997)?
4. What is the optimal pricing for the repaired or re-manufactured parts to match against replacement with new parts (Guide and Wassenhove, 2000)? This is to ensure that these parts are equally demanded and form a part of service part logistics.

These questions can be targeted individually, but studying how specific factors interact with one another provides a greater scope for understanding the overall reverse logistics system and constitutes the main thrust of this paper. Most models in

![Figure 1. Decision making model for reverse logistics](image-url)
the literature employ mixed integer programming for a single period computation while we use a system dynamics model to explore the behaviour for reverse logistics over multiple periods and how each variable interacts with other variables over time.

In order to verify the model developed, a computer company Xeptron agreed to provide data for the simulation. Xeptron is a large computer company based in the USA with presence in the USA, Europe and Asia. The company makes PCs, mini-computers, printers and computer accessories. A study was commissioned by Xeptron to evaluate the viability of reverse logistics operations in 14 countries in Asia (Tan et al., 2003). Data are gathered over a period of 18 months, from August 1999 to February 2001, pertaining to processes in the forward distribution of new spare parts from the company’s US headquarters to the reverse logistics operations of defective spare parts back to its US central stocking pool. The study also examined the on-going ERP implementation issues in the company and their impact on the reverse logistics operations which is not discussed in this paper.

Reverse logistics modelling literature
Most research efforts have focused on ways to minimize losses associated with reverse logistics operations. This traditional view assumes that the company concerned seeks to create new markets for used products, but reluctantly accepts product returns to avoid incurring additional costs. Few studies are aimed at valuing the potential economic benefits of reverse logistics (Guide and Wassenhove, 2000). Despite the potential profitability of reverse logistics, there are no integrated decision models to advise decision-makers about the economic viability of various reverse logistics options.

Most reverse logistics models are published in the operations research (OR) literature. Researchers have tried different mathematical modelling and solution approaches such as heuristics or modifications on existing algorithms to manage models with return flows (Fleischmann et al., 1997; Spengler et al., 1997; Realff et al., 1999; Fleischmann, 2000; Shih, 2001; Toktay et al., 2000).

From an economic perspective, there are few relevant research findings available. Klausner and Hendrickson (2000) present a mathematical model that might be used for estimating the buy-back price while Guide et al. (2001) present a mathematical model to determine the optimal acquisition price for products from the field as well as the selling price of these products. In the area of inventory costing, van der Laan (2003) investigates whether average costing for two-source systems with joint manufacturing and remanufacturing give optimal results based on a deterministic model.

Sterman (2000) presented a dynamic model to simulate the reverse logistics for automobiles. This model deals with the recycling of automobiles over a period of time and its economic impacts generated. Georgiadis and Vlachos (2004) develop a simulation model using systems dynamics to evaluate the effect of environmental issues on long-term decision-making in the collection and remanufacturing activities and on product demand. The model includes major inventories of new, used and recovered products as well as the flows among them.

The first observation to be made is that each method is suited to a set of different situations and problems. No single technique is able to provide a panacea for solving all problems encountered. OR tools have their place at a tactical level in the design of supply chains. They constitute the only analytical approach that is able to solve batch
sizing and job sequencing problems. Yet they are unable to throw much light on the
dynamic behaviour of the supply chain as a whole. Qualitative phenomena such as
demand amplification can only be investigated and hence tackled by methods based on
the dynamics of the system.

A second observation is the implications of strategic design on supply chain
performance can only be discovered by using simulations based on the dynamics of
the system. The OR optimization techniques examined provide some insights into
how system parameters influence the solution. However, it must be conceded that
little actual sensitivity analyses have been carried out to examine any of these
methods.

A third observation is that most of the models treat all returns in a similar way,
especially those cases in the electronics (Waste Electrical and Electronic Equipment
weee_index.htm) and computer sectors, but this is not realistic assumption. The
model in this paper will treat different type of parts (make part or buy part) differently
for reverse logistics. Furthermore, most models in the literature consider return
volumes, return quality, tariffs and other factors as constants. In order to be more
realistic, the dynamic model captures fluctuations in a design and analysis of
experiments with selected low and high values for some of the factors.

Therefore, system dynamics techniques will therefore be an appropriate tool to gain
insights into the dynamics of reverse logistics network and how rules and constraints
interplay based on several variables through simulation. This is because in most
reverse logistics networks there will be “leads and lags”. In other words, there may be
delays in the response to an input or a change in the network.

Delays in reacting to variations in market demand for different aspects of supply
chain performance have long been studied. The seminal works here are those of
Forrester (1958, 1961), who investigates the effect of changes in market demand on a
four-level supply chain. Forrester incorporates delays in both the physical structure of
his supply chain as in the managers’ decisions and policies governing inventory
adjustment. His model later came to be known as the “Beer Game” (Sterman, 1989), in
which these policies and delays generate well-known supply chain dynamics such as
the bull-whip effect (Lee et al., 1997a, b; Fransoo and Wouters, 2000).

Research methodology
The approach in this case was to develop a system dynamic model as a method to
analyse the profitability of reverse logistics. The steps involved are adapted from
Sterman’s (2000) modelling process:

1. define the dynamic problem to be solved and its scope;
2. identify the variables involved and their relationship;
3. draw the causal loop diagram;
4. select a software suitable to model the system;
5. construct the stock and flow diagram;
6. simulate the model;
7. verify the model using a case study; and
8. validate the model.
In order to develop a system dynamics model to study the dynamics of reverse logistics network, it requires identifying the key decision points in the system. These decision points form part of the models that may be developed and tested in relative isolation. Once each of the key decision points is close to accurately capturing the real-world decision processes, the next main task will then be to capture the feedback between the various decision points or sub-systems. This process is iterative in nature since there is no template upon which to base the model structure. This process evolves over time as more information becomes available which is fed as critical decision points into the system (Sterman, 2000).

The whole process is divided into two phases: the first phase is the qualitative analysis of the system. During this phase, a causal loop diagram is built which is then transformed into a flow diagram. The second phase is the quantitative analysis of the system. During this phase, the flow diagram is translated to a simulation program using Vensim software (Vensim, Vensim software is a commercial software for developing, analyzing, and simulating dynamics models, available at: www.vensim.com) which is then verified and validated using a case study:

**Defining the dynamic problem to be solved and its scope (qualitative analysis)**
Decision-making in reverse logistics operations involves a variety of logistical and management factors. The key factors to examine in this model are namely:

How to determine the type of reverse logistics treatment for each groups of returns; where to perform the treatment; how to transport the returns for treatment and storage; and how to price parts after treatment. Qualitative analysis is performed on these factors to understand their interaction and behaviour in the overall reverse logistics system.

**Identifying the variables and their relationship among them**
The model structure in Figure 2 shows the overall model construct by examining the profitability of reverse logistics from four elements, namely: cost of reverse logistics incurred, types of returns flowing back to manufacturer, types of servicing required based on the quality of returns, and revenues generated from reverse logistics.

Costs of reverse logistics can be broken down into two components:

1. Unit costs include:
   - Transport cost – cost incurred in local transport for each product return from customer to the manufacturer.
   - Customs duty – cost incurred in clearing each product return at the customs.
   - Acquisition cost – cost incurred to acquire each product return.
   - Handling cost – cost incurred to track and document each product return.

2. Variable costs depending on the quality of returns:
   - Repair cost – cost incurred to repair each product return before it is sold.
   - Reuse costs – cost incurred to repackage each product return before it is sold.
   - Scrap cost – cost incurred to scrap each product return.

3. Variable costs depending on the time of storage:
   - Storage cost – cost incurred to store each product return.
   - Freight cost – cost incurred to ship the product returns via air or sea.
Most costs are linear except for freight and storage costs which pose challenges for the model. The storage cost is determined by the amount of space allocated for storage per month (in term of pallet size). Thus, storage cost of each unit is based on the monthly storage cost for the space divided by the average number of units stored during the period. In the case of freight cost, there is a minimum charge if the total weight falls below the minimum weight (usually at 45 kg for air freight cargoes). Shipments with weight above the minimum weight will be charged based on per unit basis.

Types of returns. The first group is the make parts that can be repackaged, repaired or scrapped. These are parts designed and made by the manufacturer where the technology know-how is kept within the organization. For example, the motherboard or the main circuit board belongs to this group of parts. The second group of returns is the purchase parts that can be exchanged with suppliers or for credit and scrap. These are parts purchased by the manufacturer where the supplier can make the parts at a lower cost or the manufacturer does not have the expertise to make them.

Type of servicing. The quality of returns is critical in determining the proportion of parts meant for repair, reuse, exchange, credit or scrap and thus impacting on the profitability of reverse logistics. Higher quality returns result in simple repackaging or repair while lower quality returns result in scrap. The quality of returns will be simulated in the model assuming three conditions, namely, best quality condition, average quality condition and worst quality condition where:
Revenues from reverse logistics. The resale price of refurbished parts constitutes an important input to determine the demand for returns and hence its profitability. The resale price of these parts cannot be higher than the price of new parts; otherwise everyone will purchase new parts. The customers for these refurbished parts represents the consumers themselves or it could be the secondary markets such as dealers, resellers, OEMs, and so on.

Drawing the causal loop diagram
Figure 3 shows the causal-loop diagram for reverse logistics network in the computer industry. The arrows represent the relations between each variable. The arrows show the direction of the effect while the signs (+) and (−) at the end of the arrows show the sign of the effect. When the sign is (+), the variables change in the same direction and this is known as a reinforcing loop when all the signs in the loop are (+) or it has even number of sign (−). Otherwise, when the sign is (−), the variables change in the opposite direction and this is known as balancing loop if it has odd number of sign (−).

There are four reinforcing loops and five balancing loops in this model. They are as follows:

R1. An increase in demand for resale parts or products will trigger an increase in the demand for used PCs, servers or component parts. This will lead to an increase in selling price (loop R1) to acquire more PCs, servers or parts from the customers.

R2. Increasing the acquisition cost or trade-in cost for used PCs, servers or component parts will lead to an increase in the supply of these products or parts for repair, reuse or exchange with supplier (loop R2). In addition, computer companies are more willing to give higher trade-in value for computers with more recent technologies than those with older technologies.

R3 and R4. In terms of scrap, an increase in the demand for returns will cause an increase in the price for scrap, which will trigger an increase in acquisition cost for scrap to make it more attractive for parts to be scrapped (loops R3 and R4). This is similar to the second-hand car industry where an increase in demand for scrap car will cause an increase in the price of scrap car to attract more car owners to scrap their cars.

B1, B2, B3 and B4. Better quality of returns will result in sending more returns for repair or reuse leading to an increase in the cost of repair or reuse (loops B2, B3 and B4) but will decrease the cost of scrap since the scrap quantities are decreased (loop B1). For example, printers sent for servicing are first diagnosed to determine whether they require simple repair or an overhaul. Those needing simple repair will be sent to a repair workshop while those with serious problem will be scrapped. Thus, if most of the returns are of higher quality involving simple repair or reuse, then the cost of repair or reuse will increase due to increased quantities but not the cost of scrap.

Similarly, more liberal return policy from suppliers will decrease the cost of exchanging with suppliers since suppliers would agree to credit the price of return
without having to exchange the parts for them. This will mean that the scrap cost will increase as these parts will need to be scrapped instead of returning to the suppliers, especially bulky monitors that will cost more money to transport them than to scrap them.

An increase in the demand for returns will cause an increase in the supply of scrap and an increase in the cost of scrap as in loop B1 while increasing the selling price of scrap will increase the profitability of scrap as in loop R3. So, the strength of reinforcing loops R3 and R4 to offset the strength of balancing loop B1 will ultimately determine the profitability of scrap.

In summary, increasing the cost of repair or reuse or exchange will reduce the profitability of reverse logistics as in loops B2, B3 and B4 while increasing the selling price will increase the profitability of reverse logistics as in loop R1. Thus, the strength of reinforcing loops R1 and R2 to offset the strength of balancing loops B2, B3, B4 and B5 will ultimately determine the profitability of reverse logistics.
Selecting the software suitable to model the system (quantitative analysis)
To simulate the competitive nature of the computer industry with numerous variables and constraints, Vensim software is used to expand the model to allow for multiple scenarios and countries/regions. The Vensim software has a feature to generate stochastic inputs and allows “what-if” scenarios. The results are displayed or printed. In this way, the decision-making structures can be presented in a graphical way to facilitate better understanding of the complex dynamics of the system behaviour.

Constructing the stock and flow diagram
The stock and flow diagram is shown in Figure 4. The diagram is constructed using variables categorised as levels represented by boxes, and flows represented by valves and constants. Valves are the rate of change in level variables and they represent those activities which fill in or drain the level variables. Constants are values that are used to compute the rate of change of level variables. For example, to compute the repair flow rate (valve), the average repair time (a constant) is used. Level variables represent accumulations in the system while flow variables are the rate of change in level variables and they represent those activities which fill in or drain the level variables. Delays are introduced into the model and these are the significant ones that have an impact to the material flow. Single-line arrows are information flows while double-line arrows are material flows in the model.

The model is built under the following general configurations:
• Time horizon: two years (sufficient to cover the product life cycle of computer).
• Time unit: week (inventory movement for returns are less frequent).
• Time step: one week (sufficient time to monitor and track the movement of returns).

The model employed 92 variables and can be grouped under level, flow and constant. The key variables in this model can be found in Appendix 1.

Simulating the model
The model is tested on three dimensions; return quantity, customs duty and quality of returns to determine its profitability as shown in Table I. The return quantity can be segmented into low volume (1-99 pieces), medium volume (100-999 pieces) and high volume (more than 1,000 pieces) as the freight charges differ significantly between low volume, medium volume and high volume since their charges are non-linear. Low volume return quantity will be charged a flat freight fee below the minimum weight (@ 45 kg) while high volume return quantity will get a bulk discount above a certain weight in this case. The quality of returns can be sub-divided into three groups, high quality (high serviceability), average quality (moderate serviceability) and low quality (poor serviceability). Similarly, the customs duty can be segmented into countries with low or no tariff (e.g. Singapore) and countries with high tariff (e.g. India or China). The reverse logistics profitability is calculated by subtracting the revenue earned through reselling the recovered parts from the total cost of reverse logistics.

Verifying the model using a case study
Four assemblies are randomly chosen from the product family and their components’ return transactions to the US head office are collected over a period of 24 months for
Figure 4.
Dynamic model for reverse logistics network
<table>
<thead>
<tr>
<th>Return quantity (no. of pieces)</th>
<th>Return quality (based on their serviceability)</th>
<th>Market attractiveness of resale item</th>
<th>Impact due to delays in sorting, repair, reuse, transportation, sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low volume 1 &lt; volume &lt; 99</td>
<td>High quality average quality low quality</td>
<td>Profit margin for each scenario</td>
<td>Profit, margin for each scenario</td>
</tr>
<tr>
<td>Medium volume</td>
<td>High quality average quality low quality</td>
<td>Profit margin for each scenario</td>
<td>Profit margin for each scenario</td>
</tr>
<tr>
<td>100 &lt; volume &lt; 999</td>
<td>High quality average quality low quality</td>
<td>Profit margin for each scenario</td>
<td>Profit margin for each scenario</td>
</tr>
<tr>
<td>High volume volume &gt; 1,000</td>
<td>High quality average quality low quality</td>
<td>Profit margin for each scenario</td>
<td>Profit margin for each scenario</td>
</tr>
</tbody>
</table>

Table I. Experiment design for simulating the dynamic model for reverse logistics
this study – the average product life cycle of a computer is less than 24 months. There are two types of parts in the bill-of-material, make parts and purchase parts. The make parts are generally core parts (e.g. motherboard) that Xeptron will make internally using their most advanced technology and know-how. In the case of purchase parts, they are products easily available (e.g. disk drive) from the market where the price is very competitive. Thus, it is logical to split the data into make and purchase parts to understand their characteristics as the starting point.

At present, each of Xeptron’s overseas offices manages its own spare parts return process. This involves the handling of a large volume of spare parts, which are returned to the suppliers or to the USA for refurbishment, repair or disposal, as shown in Figure 5. Subsequently, a third-party logistics (3PL) provider picks up these parts for consolidation before shipping them to the USA. At the US headquarters, all the returned parts are sorted out prior to deciding on repair or disposal.

Good spare parts are then sent to the central stocking pool for reuse while defective ones are repaired or refurbished before being returned to the central stocking pool. One of the reasons for returning good spare parts is to facilitate stock rotation. This will replace slow-moving spare parts or those with little or no demand from each warehouse with newer parts so that they can support new Xeptron models. Defective parts are also returned to the suppliers for replacement or credit. This has helped Xeptron in reducing its cost of servicing customers without service level being compromised since it does not need to expand its warehouses and yet maintain a current inventory of parts closer to its customer base to support newer models.

Table II shows the percentage of spare parts in good condition originating from countries in the Asia-Pacific region that were shipped to the US headquarters over a six-month period.

Three countries, namely Japan, Australia, and South Korea, were more active in returning good spare parts to the US headquarters for credits as compared with other countries. Others recorded low return rates as a result of the low sales volumes in their respective markets. For example, Vietnam recorded a spare parts return of 0.3 per cent. India and China have relatively high sales volume but the return volume is

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**Figure 5.**
Xeptron existing part return process to the US head offices

Clear customs and process returns
Authorize parts’ return for overseas offices
Freight parts to US
Collect parts
Update parts status in system
By staff from Central Store
surprisingly small (at less than 1 per cent) against the region’s total returns. This can be attributed to Xeptron valuing all defectives at zero costs (book value) and the fact that India’s and China’s export customs charge high tariffs based on product cost. As such, returning the spares did not make economic sense. This resulted in having to store the defective spare parts in large warehouses or to undertake the repair or re-manufacturing locally. However, not all repairs can be done in these countries due to lack of the required skills and equipment that can only be found in the USA.

The estimated logistics cost in returning a spare part is about $100. This is the amount that 3PL providers, such as DHL and Air Express International, are charging Xeptron for most shipments from any part of Asia to the US repair centre. The shipment of very heavy items, which constitutes less than 10 per cent of total return volume, such as monitors weighing more than 10 kg, is an exception. The $100-charge per part includes freight, shipment consolidation, customs clearance, sorting, warehouse handling, systems updating, and spare parts administration. Xeptron wants to avoid returning spare parts in cases where the product cost is less than its reverse logistics cost. In its opinion, these low-cost parts should be scrapped at the country’s site, rather than sent back to the US headquarters. Therefore, the study was not concerned with the expensive spare parts, but dealt with the low-cost parts costing less than $100.

Since, the return volumes fluctuate over time and there were delays in shipping the returns for repair, using system dynamics modelling will allow one to understand the behaviour in a reverse logistics network better as well as providing a guide to management action to overcome these effects. Thus, the model must be capable of including the delay time factor to simulate Xeptron’s operations.

A spreadsheet is used for data entry while the simulation model generates the outputs and graphs for analysis. Separate data files are used to store scenarios, which can be saved and loaded using the main spreadsheet.

Different scenarios are created in Table III using Excel spreadsheet to input different configuration into the model for analysis. Countries are sorted by return volume and customs duty. Since, almost all the return volume from Xeptron dataset exhibits a normal distribution probability curve, the mean volume, maximum volume and standard deviation are used to generate the return volume during simulation.

<table>
<thead>
<tr>
<th>Country</th>
<th>Volume per cent per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>27.4</td>
</tr>
<tr>
<td>Australia</td>
<td>20.7</td>
</tr>
<tr>
<td>South Korea</td>
<td>16.5</td>
</tr>
<tr>
<td>Thailand</td>
<td>6.9</td>
</tr>
<tr>
<td>Singapore</td>
<td>5.7</td>
</tr>
<tr>
<td>Taiwan</td>
<td>4.7</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>4.1</td>
</tr>
<tr>
<td>Indonesia</td>
<td>3.4</td>
</tr>
<tr>
<td>New Zealand</td>
<td>3.2</td>
</tr>
<tr>
<td>Philippines</td>
<td>2.6</td>
</tr>
<tr>
<td>Malaysia</td>
<td>2.2</td>
</tr>
<tr>
<td>China</td>
<td>1.5</td>
</tr>
<tr>
<td>India</td>
<td>0.8</td>
</tr>
<tr>
<td>Vietnam</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table II. Percentage of volume return (in good condition) by individual country versus total volume of returns in the Asia Pacific region
China has low return volumes with zero tariffs while India has low return volumes but with slightly higher tariff. Japan and South Korea have high return volumes while Thailand has the highest tariff for imported goods. The tariff rates are extracted from customs directory of each country using harmonized standard code 8,472 indicating computer products. The air freight rates are standard rates used by Xeptron for freight from each country to the USA.

To simulate the different quality of returns, Table IV is constructed using Excel spreadsheet and incorporated into each simulation run. Details for the input values into the model can be found in Appendix 2.

Validating the model

The system dynamics literature stresses the importance of model validity. Specifically, in order to determine the validity of a model, and to develop confidence in it as a useful tool for system understanding and policy evaluation, a number of validity checks are performed here. These checks include behaviour reproduction tests, repeatability, transparency, dimensionality, process reliability and time step.

The behaviour reproduction test – the model is validated by using inputs from two different sets of inputs, Xeptron raw data and the simulated data. Profits generated from each set of input are compared using measure of fit $R^2$ and $R$ Pearson coefficient. The $R^2$ value can be interpreted as the proportion of the variance in Xeptron’s raw data attributable to the variance in the simulated data. If the model replicates exactly the actual series, $R^2 = 1$; and if the model output is constant, $R^2 = 0$. $R^2$ is the square of the correlation coefficient, $r$, which measures the degree to which two series converge.

In Appendix 3, $R^2$ obtained from five different part transactions confirms that outputs from the simulated inputs are very close to the outputs from the raw inputs as their $R^2$ values are 0.9 or above.

<table>
<thead>
<tr>
<th>Supply and cost parameters</th>
<th>China Low</th>
<th>India Low</th>
<th>Taiwan Medium</th>
<th>Thailand Medium</th>
<th>Japan High</th>
<th>South Korea High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean acquisition volume (pcs)</td>
<td>7</td>
<td>7</td>
<td>34</td>
<td>34</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>Max acquisition volume (pcs)</td>
<td>10</td>
<td>10</td>
<td>50</td>
<td>50</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Std deviation for acquisition (pcs)</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>7</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Air freight cost per kg ($/pcs)</td>
<td>2</td>
<td>1.4</td>
<td>2.5</td>
<td>0.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Customs duty for import ($/pcs)</td>
<td>0</td>
<td>0.15</td>
<td>0</td>
<td>0.4</td>
<td>0</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Table III.
Data used as inputs to simulate returns from each country

<table>
<thead>
<tr>
<th>Make parts</th>
<th>Inferior</th>
<th>Average</th>
<th>Superior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make part versus scrap ratio</td>
<td>0</td>
<td>0.66</td>
<td>1</td>
</tr>
<tr>
<td>Reuse versus repair ratio</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Repair failure rate</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table IV.
Data used as inputs to simulate returns with different quality

<table>
<thead>
<tr>
<th>Buy parts</th>
<th>Inferior</th>
<th>Average</th>
<th>Superior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buy part versus scrap ratio</td>
<td>0</td>
<td>0.66</td>
<td>1</td>
</tr>
<tr>
<td>Ratio of credit versus exchange</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>
Simulation results
The following results in Table V are obtained from the simulation. Volume of returns is grouped into countries with different return volumes and different qualities for make or buys parts. The demand of resale part is simulated using the market attractiveness factor (starting at 0.25) to represent the market perception of resale parts. The value of attractiveness of the market is adjusted upward from 0.05 until the gross profit is positive. This is the minimal percentage of the original sales price for reselling their refurbished or exchange parts.

From Table V, we can deduce that the following behaviour exists for reverse logistics:

- Quality of returns has a significant impact on the profitability for reverse logistics. Returns with lower quality generate losses regardless of return volume and type of parts.
- Make parts need to maintain a higher resale price (20 per cent or more) in order to break even as compared with buy parts (10 per cent or more). This is due to the additional costs incurred to repair or repackage the parts in addition to transporting them to the facility centres. In the case of buy parts, the only costs incurred are transportation, administration and storage only.
- The return volume does not seem to have an impact on the profitability of reverse logistics. The minimum resale price needed to break even is the same regardless of volume for both make and buy parts. This result is interesting as there is a minimum flat charge for air transportation for shipment below 45 kg and a fixed storage charge for space based on each pallet size (regardless of quantity stored). Lower return volume would have incurred higher costs from transportation and storage charges but the result shows otherwise.

Delays within the reverse logistics do have an impact on profitability depending on the type of delays involved. Delays are simulated by adjusting upward one delay factor from the current 1-2 weeks to the maximum of 10 weeks while keeping the rest of the delay factors constant.

<table>
<thead>
<tr>
<th>Item type</th>
<th>Return volume</th>
<th>Return quality</th>
<th>Min. percentage of original sales prices</th>
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</thead>
<tbody>
<tr>
<td>Make</td>
<td>High</td>
<td>High</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mid</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>- ve</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mid</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>- ve</td>
</tr>
<tr>
<td>Buy</td>
<td>High</td>
<td>High</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mid</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>- ve</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mid</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>- ve</td>
</tr>
</tbody>
</table>

Note: - ve * – gross profit stays negative for all values of attractiveness of the market

Table V. Profitability analysis from the simulation
From Figure 6 representing delays for make part, graph line number 1 which does not include any delay takes about 24 weeks to reach $5,900 of profit. During this period, the return pipeline is filling up with return inventory and therefore, the analysis of profitability should be examined from week 24 onward to be realistic.

We can deduce that from graph line number 4 in Figure 6 which involves delays in transportation that it has the most significant impact on profitability as compared with other forms of delays. It takes 56 weeks \((80 - 24\) weeks to reach equilibrium) to reach the same profit level ($5,900). This means that every week of transportation delay will cause 5-6 weeks delay in achieving the same profit level. Transportation delays will incur additional storage costs as well as causing delays to other downstream activities. Thus, shifting the mode of transportation from sea to air could be one way to reduce the delay and thus increase profitability assuming a moderate increase in the air freight cost as compared with sea freight cost. Another option is to use direct shipment and avoid shipment consolidation.

Delays due to repair, reuse, sorting and sales from graph line numbers 2, 3, 5 and 6 in Figure 6 have moderate impact on its profitability since they will take 32 weeks \((56 - 24\) weeks to reach equilibrium) to reach the same profit level ($5,900). This is consistent with the results obtained from van der Laan et al. (1999) research, where increasing the remanufacturing lead-time will increase the total expected costs. Some companies prefer to accumulate their returns in batches before processing them to achieve economies of scale. This will result in delays in repair and reuse which will in turn impact on profitability.

In the case of buy parts, delay caused by supplier from graph line number 2 in Figure 7 has shown significant impact on its profitability as compared to other delays. In this case, delay by supplier causes a two folds build up of inventory at the supplier exchange stock as shown in Figure 4 and resulting in additional storage costs incurred.

**Figure 6.** Impact due to delays on profitability for make part (attractiveness at 50 per cent)
This leads to the lowering of the profits eventually as shown in graph line number 2 in Figure 7.

Delays caused by transport and sales for scraps are not significant as compared to delays caused by sales of exchanged stocks and sorting as shown in graph line numbers 3 and 5 in Figure 7. These delays take almost twice the amount of time to reach the same profit level (48 weeks instead of 24 weeks).

Delays by supplier to collect the defective stocks will increase the storage cost for holding these stocks. In addition, if the warranty period for these buy parts expires due to delays by supplier, the manufacturer may have to incur losses since the customers returned the parts before its expiry date as shown in Table VI.

From Table VI, the best position for profitability is when the warranty from supplier is still valid while the warranty offers to customer is already void. Customer will have to pay for the full service charge even though it is performed free of charge by supplier. This situation happens sometimes when the supplier gives longer warranty period than the standard warranty given to customer. As for valid warranty associated from supplier to manufacturer and from manufacturer to customer, there is no gain or loss as it is the supplier’s obligation to service the returns. In the case of invalid warranty associated from supplier to manufacturer and from manufacturer to customer, the margin is determined by the customer willingness to pay for the service versus buying a new part.
Conclusions and future research recommendations
The dynamic model has provided a comprehensive evaluation of profitability for reverse logistics under different settings that is closer to actual operations. With increasing demand for reverse logistics in Asia, this model will assist the decision makers to explore new opportunities in reverse logistics applications. The findings show that the make parts need to maintain a higher resale price than buy parts in order to breakeven or be profitable. Moreover, quality of returns has significant impact on reverse operations and effective gate-keeping will avoid additional logistics costs due to unnecessary transportation and storage of scrap. Finally, the delays have significant impact on the profitability of reverse logistics operations. Delays associated with make part caused by transportation have the most impact on its profitability while delays associated with buy part caused by suppliers in collection has the most impact and will result in losses.

Despite the model’s limitations, it can be extended to 3PL offering reverse logistics services. This can be accomplished by setting the acquisition cost to a non-zero value since there is a need to purchase those faulty parts and it varies according to the quality of returns. With more 3PLs offering reverse logistics, it is logical to expand this model to examine their business viability. The other limitations are exchange rate fluctuation and product depreciation which are not incorporated in the model. Exchange rates can be introduced to capture currency fluctuations over time in the dynamic model. This is especially true in Asia where each county has its own currency which fluctuates with time. In addition, product depreciation should be considered for future model especially with industry where product life cycle is short. The model can be applied to other industries to determine its applicability, for example, in the consumer goods, chemical, and automotives industries.

In conclusion, managing reverse logistics in a global context involves more international issues than with managing reverse logistics operations within a country. The model will assist decision-makers to test new policies related to reverse logistics, for example, liberal versus conservative return policy from supplier, shipment consolidation (longer delays) versus direct shipment, batch (longer delays) versus JIT remanufacturing, pricing of new parts versus re-condition parts, as well as to examine its long-term viability.

As more countries become more active in environmental control, the model developed can also assist companies to examine how the changes in regulations or law could affect impact their profitability or losses.

References


Further reading


Appendix 1. Variables used in the dynamic model

The level variables in this model are mainly used to represent stock level:

- Returns – total quantity of returns collected.
- Manufacturing returns – total quantity of make parts returned for processing.
- Supplier exchange stocks – total quantity of buy part returned for exchange or credit with suppliers.
- Repair return stocks – stocks accumulated for repair.
- Repaired stocks – total number of parts repaired and ready for sales.
- Reuse return stocks – stocks accumulated for repackaging.
- Reuse stocks – total quantity of parts repackaged and ready for sales.
- Scrap stocks – total quantity of parts for scrap or cannibalization.
- Recovered stocks – total quantity of parts recovered after processing and exchanging with suppliers.

The delay variables in this model are key ones that are likely to have an impact on reverse logistics operations:

- Delay in sorting – time delayed during sorting.
- Delay from supplier – time delayed in exchanging defective parts with supplier.
- Delay in transportation – time delayed in transporting to facility centre or storage.
- Delay in repair – time delayed during repair.
- Delay in reuse – time delayed during repackaging.
- Delay in scrapping stock – time delayed before defective parts are sold as scrap.
- Delay in stock sales – time delayed before parts are sold.

The flow variables in this model are used to represent flow rates:

- Acquisition rate; Return rate for manufactured or supplier stocks; Return rate for reuse, repair or exchange or scrap stocks; and sales rate for recovered stocks or scrap.

The initial return stock returns accumulate its returns stock from the flow variable acquisition rate. The return quantity is not a constant but commonly exhibits a normally distributed probability distribution based on the two years data from a computer company. This can be generated by inputting the maximum rate, mean and standard deviation of each part return history to simulate real-time situation.

Acquisition rate = INITIAL (RANDOM NORMAL (0, max acquisition, mean acquisition, standard deviation for acquisition, 0))
Level variables

Returns(t) = \int_0^t [\text{Acquisition rate}(t) - \text{Return rate for manufactured stocks}(t) - \text{Return rate for scrap stocks}(t) - \text{Return rate for supplier stocks}(t)]dt + \text{Returns}(0)

{where \( t \) is the last period of the time horizon and \( \text{Returns}(0) \) is the initial stock returned at time 0}

Supplier exchange stocks(t) = \int_0^t [\text{Return rate for supplier stocks}(t) - \text{Stock exchange rate to supplier}(t) - \text{Stock credit rate for supplier}(t)]dt + \text{Supplier exchange stocks}(0)

{where \( t \) is the last period of the time horizon and Supplier exchange stocks(0) is the initial stock for supplier exchange at time 0}

Manufactured return(t) = \int_0^t [\text{Return rate for manufactured stocks}(t) - \text{Return rate for repair stocks}(t) - \text{Return rate for reuse stocks}(t)]dt + \text{Manufactured return}(0)

{where \( t \) is the last period of the time horizon and manufactured return(0) is the initial stock for returned make parts at time 0}

Recovered stocks(t) = \int_0^t [\text{Delivery rate for repaired stocks}(t) + \text{Delivery rate for reuse stocks}(t) + \text{Stock exchange rate to supplier}(t) - \text{Sales rate for recovered stocks}(t)]dt + \text{Recovered stocks}(0)

{where \( t \) is the last period of the time horizon and Recovered stock(0) is the initial stock for parts recovered at time 0}

Cost variables

Fixed unit costs = \text{Customs duty} + \text{Acquisition cost} + \text{Handling cost}

{where customs duty = Duty percent * Item resale price; acquisition cost = 0; and Handling cost = Labour cost per hour * Number of hours per transaction}

Transport cost = \text{Freight cost} * \text{Unit weight}

{where the minimum weight for air freight is 45 kg}

Storage cost = \text{INTEGER} (\text{Average quantity stored per month/Maximum number of items per pallet}) * \text{Cost of storage per pallet}

Total reverse logistics costs = \text{Total exchange cost} + \text{Total repair cost} + \text{Total reuse cost} + \text{Total scrap cost}

{where Total exchange cost = (Supplier exchange stocks * Fixed unit costs) + Storage cost + Transport cost + (Storage cost * Delay from supplier)}

Total repair cost = \text{Repaired stocks} * (\text{Average cost to repair per piece} + \text{Fixed unit costs}) + \text{Storage cost} + \text{Transport cost} + (\text{Storage cost} * (\text{Delay in repair} + \text{Delay in transportation}))
Total reuse cost = \(\text{Reuse stocks} \times (\text{Average cost to repackage per piece + Fixed unit costs}) + \text{Storage cost + Transport cost + (Storage cost} \times (\text{Delay in transportation + Delay in repackaging}))\)

Total scrap cost = \(\text{Scrap stocks} \times (\text{Average cost to scrap per piece + Fixed costs}) + \text{Storage cost + Transport cost + (Storage cost} \times (\text{Delay in scrapping stock}))\)

**Profit variables**

Total gross profit = Gross profit from exchange stock + Gross profit from repair stock + Gross profit from reuse stock + Gross profit from scrap stock

Gross profit from exchange stock = \([\text{Sales rate for recovered stocks}(t) \times (\text{Supplier exchange stock/Total return stock})] \times (\text{Item resale price - Unit exchange cost})\)

\{where Unit exchange cost = Total exchange cost/Supplier exchange stock\}

Gross profit from repair stock = \([\text{Sales rate for recovered stocks}(t) \times (\text{Repaired stock/Total return stock})] \times (\text{Item resale price - Unit repair cost})\)

\{where Unit repair cost = Total repair cost/Repaired stocks\}

Gross profit from reuse stock = \([\text{Sales rate for recovered stocks}(t) \times (\text{Reuse stock/Total return stock})] \times (\text{Item resale price - Unit reuse cost})\)

\{where Unit reuse cost = Total reuse cost/Reuse stocks\}

Gross profit from scrap stock = \([\text{Sales rate for recovered stocks}(t) \times (\text{Item weight} \times \text{Price of scrap per kg}) - \text{Unit scrap cost}]\)

\{where Unit scrap cost = Total scrap cost/Scrap stocks\}

---

### Appendix 2. Constant variables used for the dynamic model

<table>
<thead>
<tr>
<th>Time data</th>
<th>Week</th>
<th>Cost and price data</th>
<th>US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay in sorting</td>
<td>2</td>
<td>Price of new make part – for example, motherboard (2 kg)</td>
<td>1,180</td>
</tr>
<tr>
<td>Delay in transportation</td>
<td>2</td>
<td>Price of new buy part – for example, 3.5&quot; hard drive (2 kg)</td>
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<td>Delay in repair</td>
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<td>Average cost to repair per PC</td>
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<tr>
<td>Delay in repackaging</td>
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<td>Average cost to repackage per PC</td>
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<tr>
<td>Delay by supplier</td>
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<td>Average cost to scrap per pc</td>
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<tr>
<td>Delay in scrap sales</td>
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<td>Storage cost per pallet per week</td>
<td>100</td>
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<td>Delay in stock sales</td>
<td>2</td>
<td>Cost of shipment per kg (min 45 kg)</td>
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<tr>
<td>Transport time</td>
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<td>Labour cost per hour</td>
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<td>Delivery time</td>
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<td>Price of scrap per kg</td>
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<td>Collection time</td>
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<td>Sorting time</td>
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<td>Exchange time (with supplier)</td>
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<td>Dispatch time to scrap</td>
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</tr>
<tr>
<td>Sales cycle time for scraps</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales cycle time for recovered stock</td>
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Table A1.
Appendix 3. Results obtained in validating raw inputs against simulated inputs

<table>
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<tr>
<th>Part no.</th>
<th>Inputs</th>
<th>Outputs</th>
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<td>Raw HP</td>
<td>Raw Sim</td>
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Table AII. Decision-making model for reverse logistics
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