# Managing IT investment for aircraft sustainment

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## *Abstract*

Airlines have massive investment in equipment and systems; while there have been well-documented IT successes in the business of selling and operating air travel, the technical side of the industry is considered a slower innovator and offers great scope for efficiency improvement and cost reduction. In terms of value chain systems, airlines can be said to have succeeded in business-to-consumer initiatives, while business-to-business success is more complex and elusive. Further, successful design and implementation of value chain systems in the aerospace engineering community can be expected to influence development in other technology sectors.

The commercial aircraft maintenance industry is on a scale similar to the aircraft manufacturing industry in terms of both annual revenue and the scale and complexity of its value chain. Operations practices (and supporting business systems) based on manufacturing models do not cope with the non-linear, stochastic nature of maintenance operations. Field research into IT strategy and practice has been conducted with a selection of companies that represents a cross-section of the maintenance value chain. Common findings include a lack of support for e-commerce initiatives and substantial opportunities for intra- and inter-organisational solutions to automate and improve business decisions and operations.

A strategy is outlined to approach IT initiatives in three steps: documenting value chain and enterprise processes, automating the value chain and optimising complex planning problems. Several projects have been built around this strategy, lending support to the approach. Outputs of recent research include a process reference model for the commercial aircraft maintenance value chain, e-commerce demonstrators for repair order management and a decision support system for managing investment in aircraft spares.

Case study 1: the process reference model, referred to as the Aircraft Maintenance Supply Chain Reference Model (AMSCRM) aims to categorise companies in relation to each other: for example, an airline interacts with a prime Maintenance and Repair Operator (MRO), which

business type in the AMSCRM can be characterised by the transactions supporting the processes connecting them to other business types: for example, an airline sends aircraft on a scheduled basis to the MRO for a prescribed level of action – what information is transacted, between which agents or systems and when? What value flows between firms and how is this optimised?

Case study 2: an e-commerce demonstrator has been built to simulate maintenance transactions at two levels: automating transactions and the operation of contract terms as business rules. The main transaction is a repair order, which is analogous to a purchase order in a manufacturing operation, but lacking in certainty and potentially requiring many process steps. The first system step is to simply convey the transaction over a network in an agreed format. The second is to filter transactions using pre-determined business rules, for example: if the majority of a batch of parts is deemed un-repairable, do not repair the remainder.

Case study 3: a large-scale mathematical model has been constructed to optimise the provisioning of spare parts to support aircraft operations. Airlines and maintenance providers typically follow manufacturers' recommendations in determining stock levels for spares. Most of these spares are rotable, meaning that they will be repaired and re-stocked, not consumed. They are also typically maintained on an un-scheduled basis, so forecasting demand is stochastic and requires good reliability data. Conventional Enterprise Resource Planning systems do not manage this problem. The problem has been formulated as a system-wide constrained optimisation model to maximise aircraft despatch rates for a given capital investment, or more normally, to minimise capital investment while ensuring a stipulated level of reliability. A full-scale system has been installed at a major repair agency, where recommendations have been produced to give real capital reduction of tens of millions of dollars. This optimisation applies to all commercial airlines and promises reduction of 20 to 30% in rotable asset investment, which is several hundred million dollars for a medium-sized airline – **replacing inventory with information**.

Lessons learnt about supply chain processes in aircraft operations have obvious potential in other industries with similar characteristics, namely, the sustainment of valuable systems. Examples include railways, ships, power generation and electronic and medical device manufacture.

The three-step strategy presented here - model, automate, optimise - is now being adapted to the telecommunications equipment manufacturing industry, where there are complex supply chain relationships involving subcontract manufacturers and expensive capital equipment.

## *Industry background: driving forces and research motivation*

The principal market within which airlines operate is in selling seat capacity to passengers: most people are airline customers and the business receives much attention in financial markets and the media due to its size and importance. On the supply side, airlines are large employers and purchasers. Probably the most complex supply area for airlines is managing the maintenance of their aircraft: this involves managing technical knowledge, making operational and strategic decisions and meeting regulatory obligations. A simple objective for the management of this activity is to minimise cost while maintaining a standard of aircraft availability (service level). There has been a trend in recent years for airlines to subcontract as many processes as possible to minimise overhead and maintain flexibility. However, given the business models currently succeeding in the industry, it has often been said that the winners in the current market will be those who manage their costs, which is not necessarily consistent with an outsourcing strategy. In particular, the ability to innovate in areas like maintenance scheduling and inventory management is diminished where these functions are bought in.

Three major changes in recent years need to be taken into account in considering how to manage an airline fleet: business models, aircraft technology and supporting technology.

1. Business models developed recently include point-to-point low fare carriers (LFCs), which aim to eliminate complex ticketing agreements and sell direct to the consumer, offering value over comfort. LFCs tend to favour streamlined operations, with a single aircraft type and the attendant efficiencies in purchasing power, maintenance and crew utilisation.
2. Aircraft technology has changed since the 1980s in that maintenance, in particular where engines are concerned, has a lower fixed-schedule component (i.e., planned preventative) and a greater diagnosed, or measured performance element (referred to as on-condition scheduling). As newer aircraft employ more solid-state systems with fewer mechanical instruments and controls and improved material and system design, their overall maintenance needs are less. A drop in demand has reduced new aircraft prices by as much as 50% (OnBusiness 2002), leasing rates have come down and thus many older generation aircraft have been retired in the past few years. Therefore, while a five-year-old airplane performs the same task as a thirty-year-old, lower ownership costs, lower maintenance costs and lower fuel costs have led to a demographic shift to younger fleet in recent years. Coupled with a drop in aircraft utilisation, the consequence for maintenance costs has been pronounced, and the value of the aircraft MRO

in 2003 from $43bn in 2001 (Back 2003). There is continuing consolidation in the market, with constant pressure to innovate and create competitive advantage.

3. This is where the third major environmental change comes into play: supporting technology. There have been major advances in information technology in recent years - greater processing and storage speed and capacity, greater connectivity between systems and users and proliferating specialised applications, such as on-board systems for aircraft management. Information systems for managing airlines and their various functions have also advanced greatly in the past decade, especially where processes are common with other industries and Enterprise Resource Planning applications have made advances in integration and automation. Such processes include sales management, accounting and HR. On the maintenance side of the industry, where airlines are the customer at the end of a supply chain, adoption of generic ERP tools has worked less well, simply because many of the processes are different to other industries. Further, the processes involve a large amount of specialised engineering expertise, regulatory compliance and complex decisions. A good example is inventory management: spare parts for aircraft are not consumed and replaced, rather they are repaired and re-stocked, making the decision process for inventory planning different to the conventional production-based view of enterprise systems. While many information systems functions are internal, clearly there are opportunities to apply ICT to external processes. While e-commerce has had many great successes in the airline industry, most obviously in ticket sales, but also in aircraft and crew resourcing, the maintenance market has not made the same advances.

Several general questions that arise from observation of the industry may be considered as motivation for the research into, and design of, an appropriate strategic approach to making best use of ICT tools for business benefit. These questions are considered in discussion, in the light of the case studies presented.

1. What is the composition of the supply chain and can a better understanding help in the use of information systems?
2. Can an Aircraft Maintenance Supply Chain Reference Model (AMSCRM) be shown to be a good fit to most companies in the industry?
3. How well do current ERP offerings meet the needs of the industry?
4. Should companies in the aircraft maintenance industry make or buy software solutions for specialist functions?
5. Do ERP systems support supply chain operations? If not, is the AMSCRM helpful in devising new solutions?

6. Is there an inherent problem with technical managers innovating and adopting technology (such as ICT solutions) from outside their core area? If so, how can this be addressed?
7. Are there obvious inhibitors to the growth of inter-organisational systems in the supply chain? If so, how can they be addressed?

### *Case study 1: the Aircraft Maintenance Supply Chain Reference Model*

Systems development is predicated on a definitive model of the business processes involved: a detailed series of studies has been conducted to record the processes used in a sample of firms representing a contiguous view of the supply chain. A reference model has been built at the industry level and is depicted in figure 2. There are two constituencies of process: internal (many of which are included in ERP applications) and external (the domain of e-commerce). Existing ERP and e-commerce applications were audited to give an indication of the degree to which known processes are already automated, the complement representing the potential for automation. Further, the mapping exercise helped to highlight process areas where there may be scope for optimisation applications due to (a) the complex nature and scale of process information and (b) the trapped business value in the decisions, i.e., the degree of perceived inefficiency in the processes.

Core processes were identified, mapped and refined in four organisations: a small airline, a Maintenance, Repair and Overhaul provider (MRO), a specialist repair vendor and a parts trading company. It is important to note that at the lower levels of detail, most of the processes are performed manually, are often not well served by incumbent system applications and are often not well defined or standardised. Mapping of each organisation took an average of 6 person weeks in house per company.

A highly functional process modelling tool, CaseWise, was used to build detailed process maps.

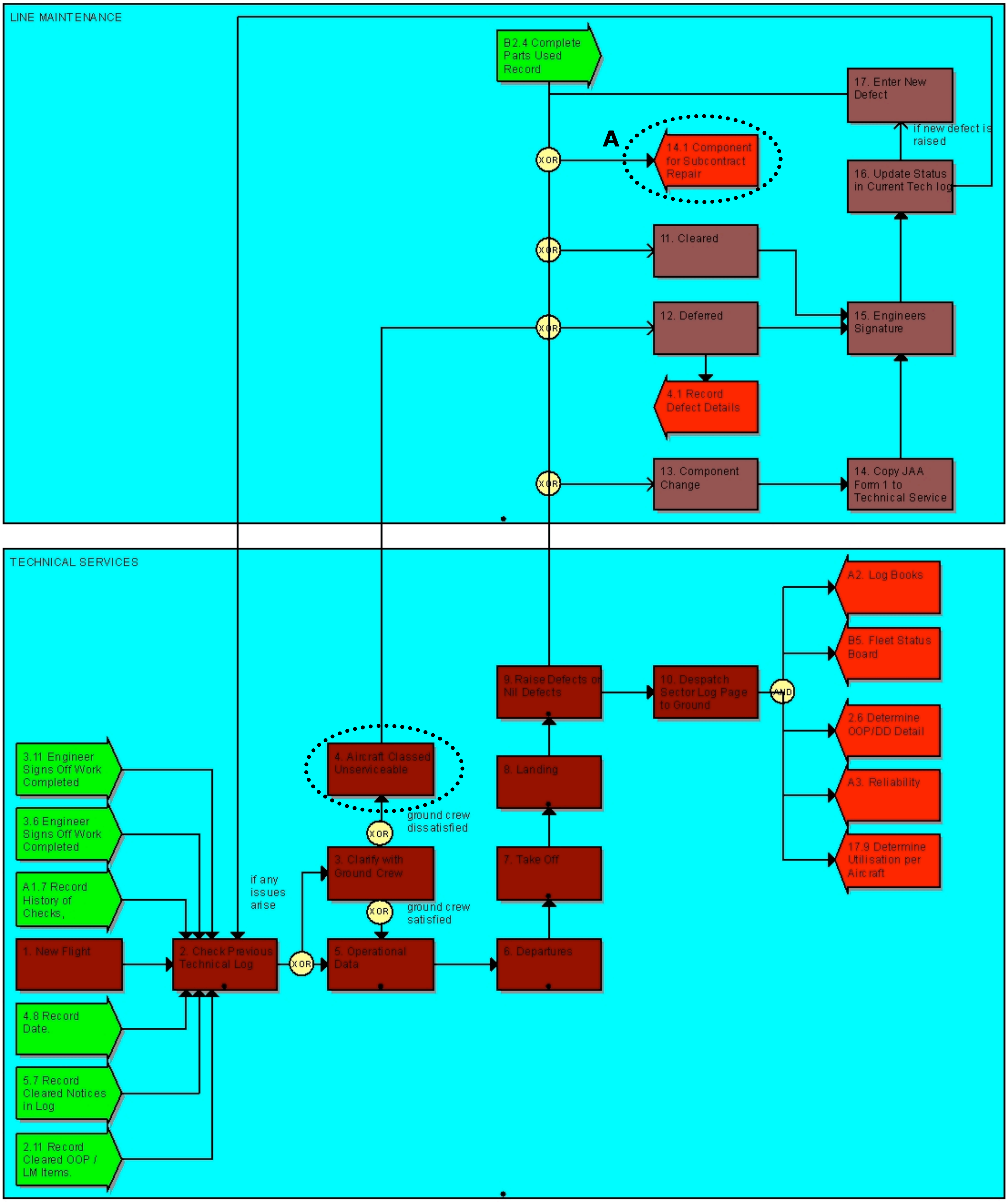



Figure 1: process map 1 – technical log (O'Brien 2004)

Figure 1 shows the technical log process – this is where aircraft defects are noted and processed prior to and following a flight. If a defect is noted, the aircraft may be cleared for operation and the defect noted for later action or the aircraft might be removed from service. Both options have implications for maintenance action, and in the case that a flight operates without defect, utilisation records are updated to increment time accumulated on the aircraft. Starting with the event of a flight, all maintenance processes are triggered at the airline, leading to value chain operations where service providers take items needing work and replace them with serviceable units.

Note that the technical log process spans two functional areas, labelled Line Maintenance and Technical Services: Line Maintenance is the function that dispatches aircraft, dealing with checks and clearance on the line (during stops between flights). Technical Services is the records function of the operator, where a history of activities is compiled for regulatory and engineering use. Different companies may perform the two functions shown – for example, many airlines use third-party line maintenance providers at remote bases. Thus the lines crossing between functions may represent inter-organisational communications.

Referring to the events circled on figure 1, if an aircraft is deemed unserviceable (e.g., radio malfunction), a trigger event occurs: component sent for subcontract repair. This starts another process in a different map.

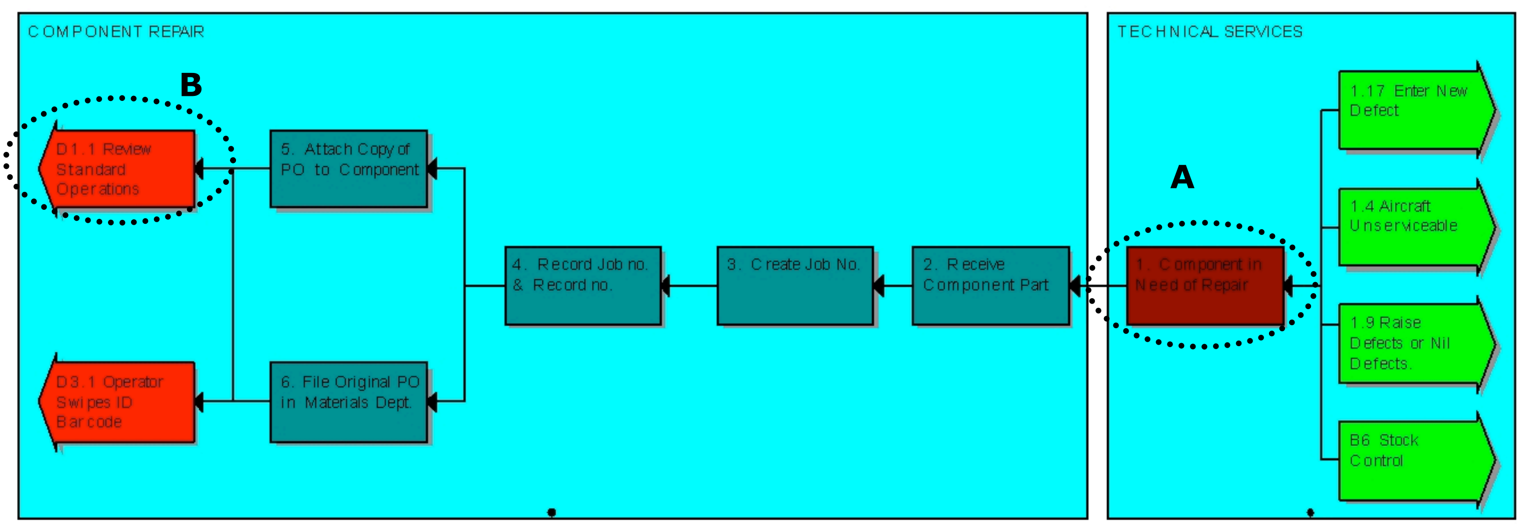



Figure 2: process map 2 – component for repair

Event A corresponds with A in figure 1; output B corresponds with event B in figure 3.

Right-handed arrows show external events fed by processes in other maps, left-handed arrows show external results, feeding into processes in other maps.

Figure 2 shows the Technical Services (Engineering) function of an airline sending an item for repair to a component repair agency, where it is received and routed for work (review standard operations). As figure 1, the two diagram areas indicate different functions, which will typically exist in different companies.

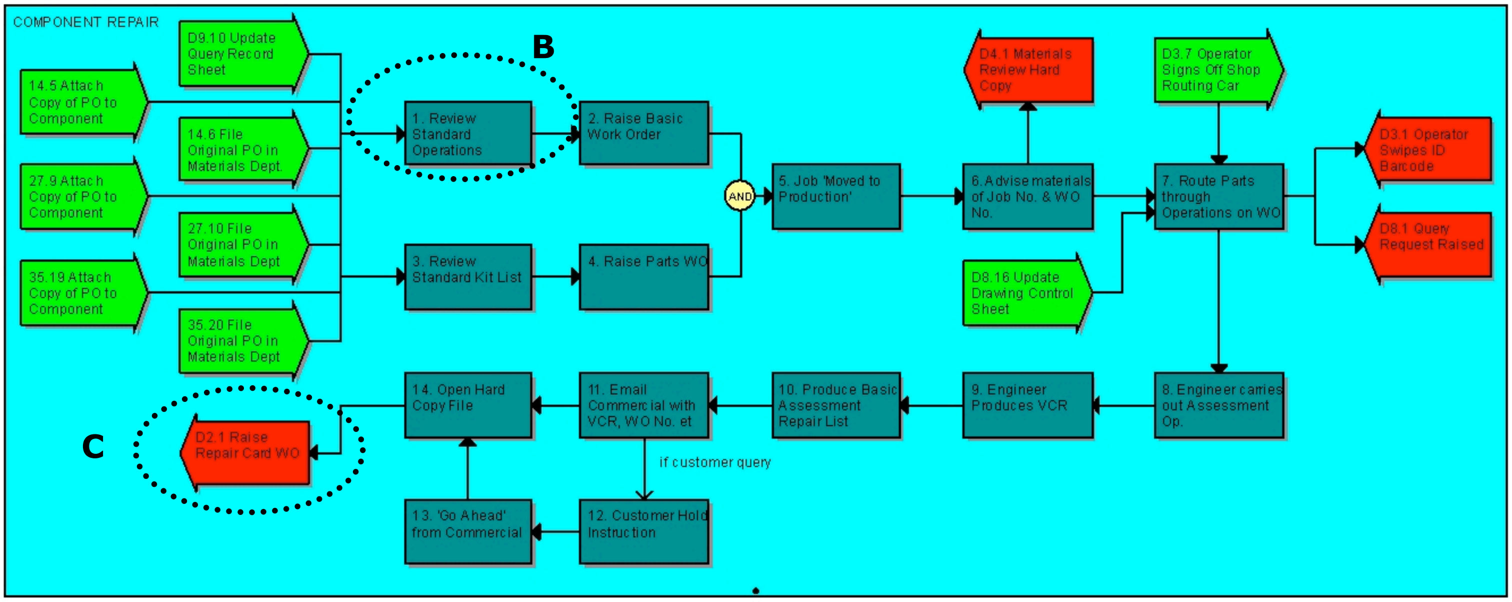



Figure 3: process map 3 – production process 1

Event B corresponds with output B in figure 2; output C corresponds with event C in figure 4.

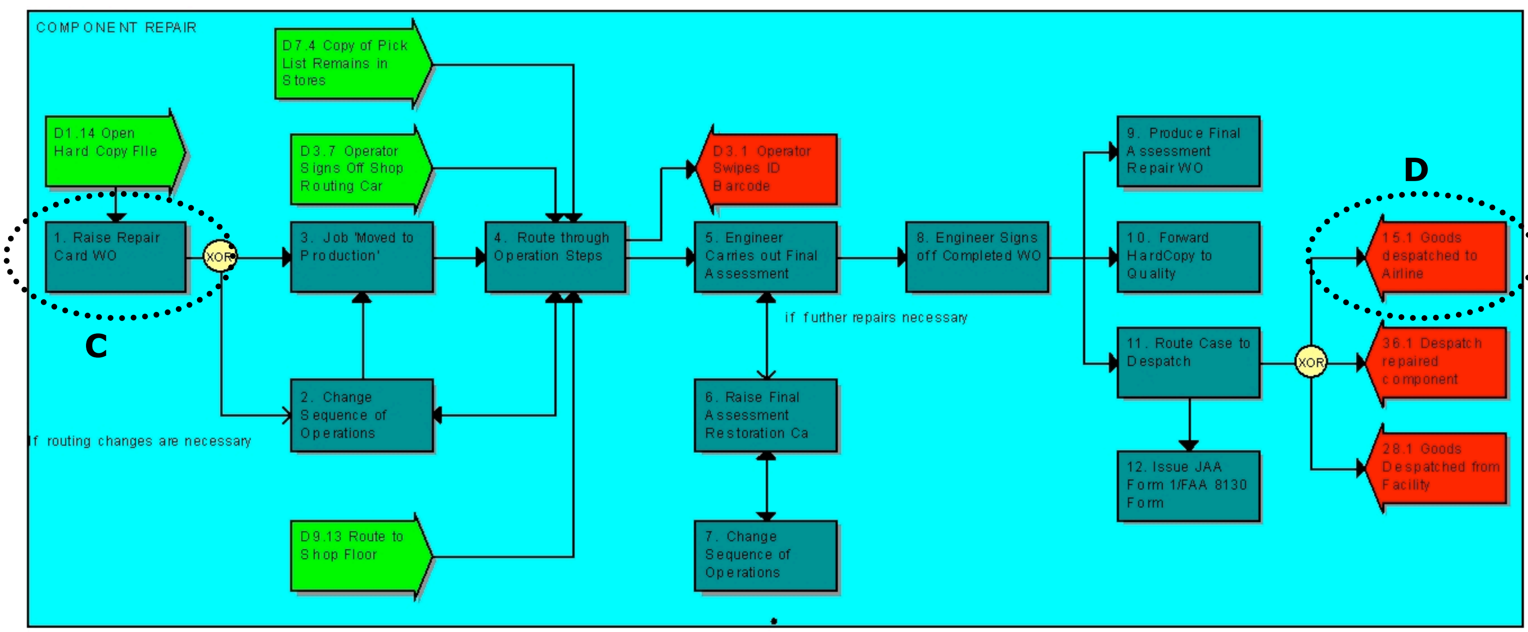



Figure 4: process map 4 – production process 2

Event C corresponds with output C in figure 3; output D corresponds with event D in figure 5.

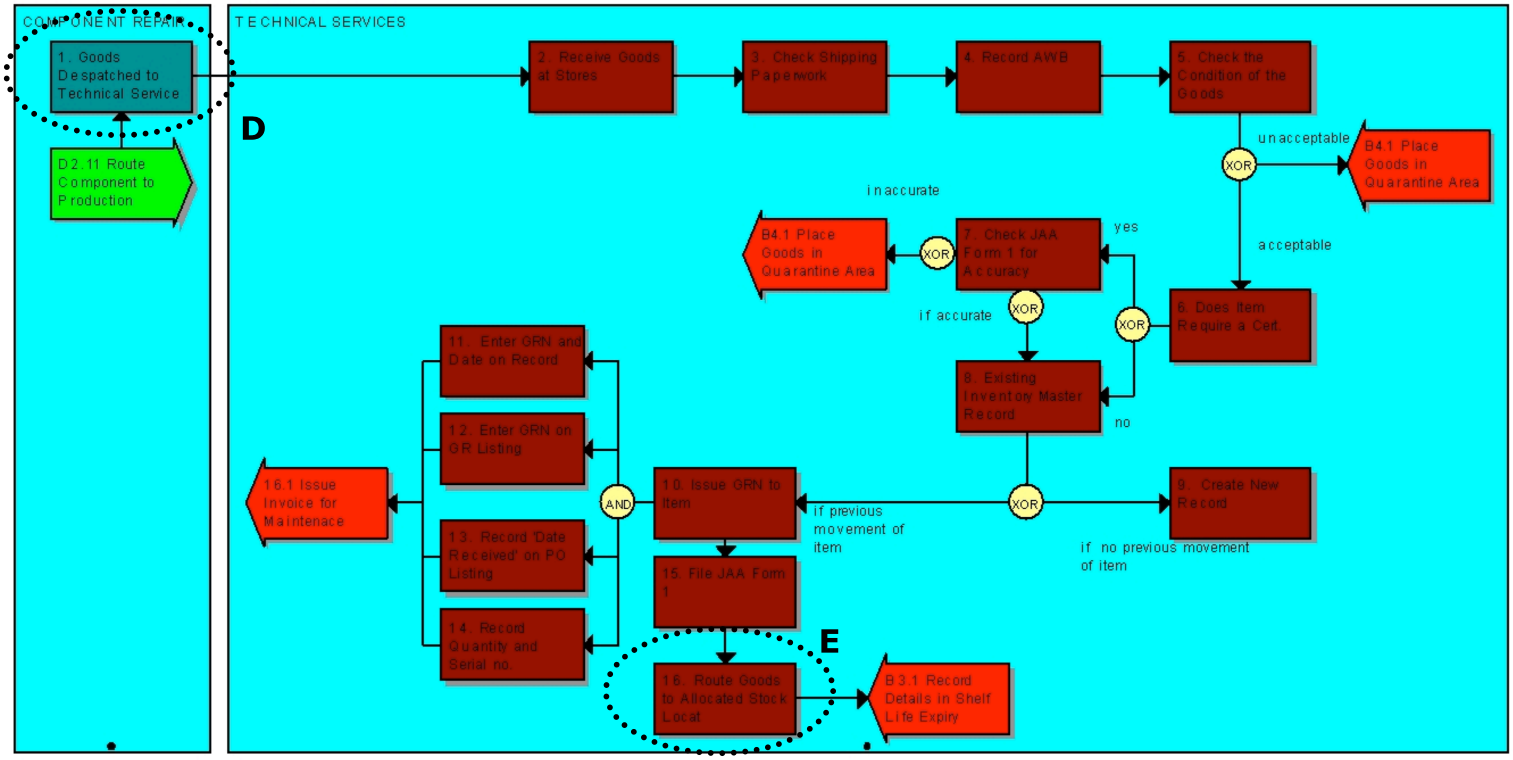



Figure 5: process map 5 – repaired parts received

Event D corresponds with output D in figure 4; event E is a final event in this model.

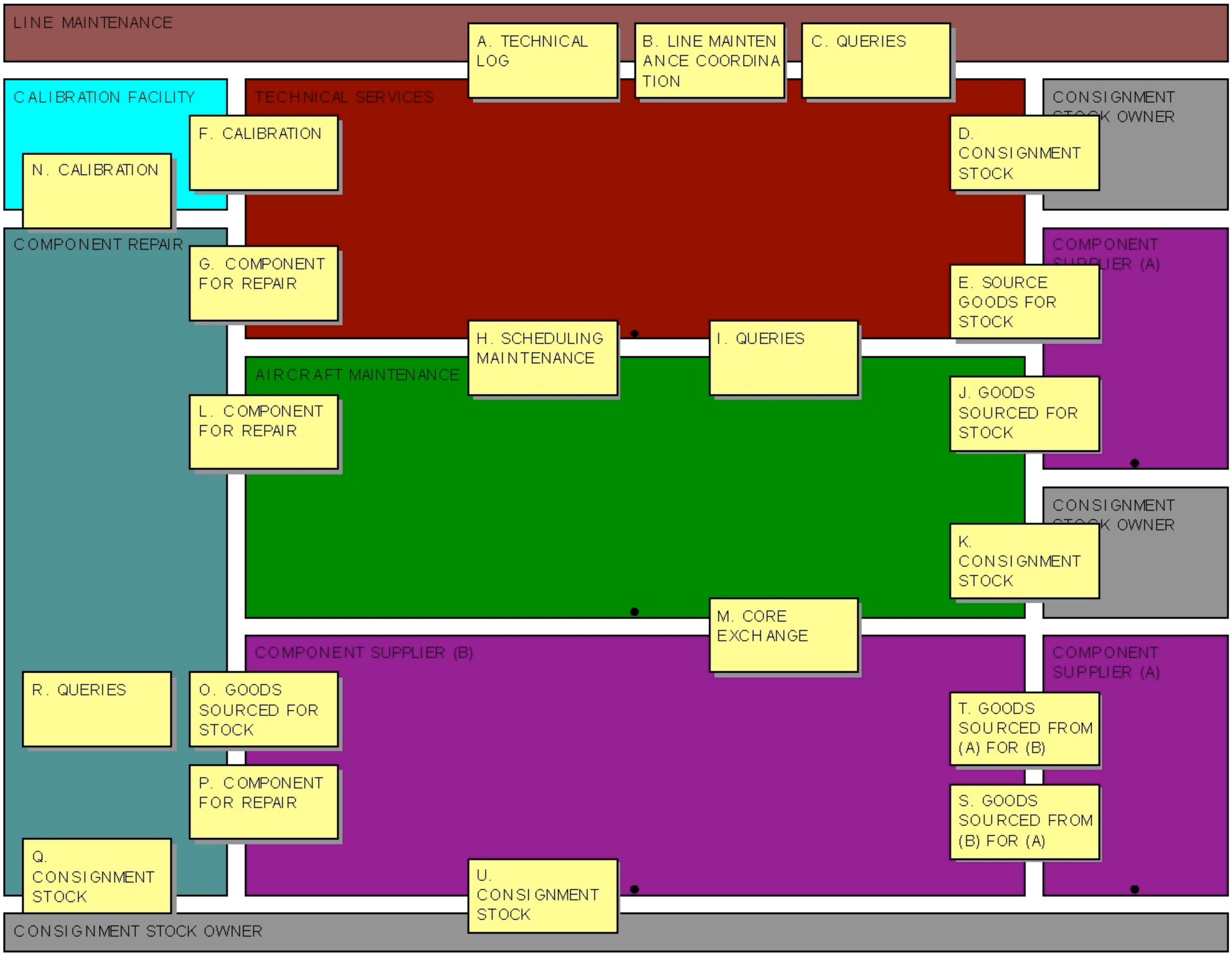



Figure 6: process map – generic highest level

Figure 6 is generated from the modeling software used to capture processes in the four companies studied – some entities are shown more than once (e.g., consignment stock owner) to illustrate the potential links between firms. Not all processes have been completed in all firm types shown as this calls for further access to expert users and development time. However, the areas modelled have been used to demonstrate how processes connect within and between organisations with a view to building a definitive set of maps. This reference model is useful in standardising processes and identifying potential for automation and optimisation.

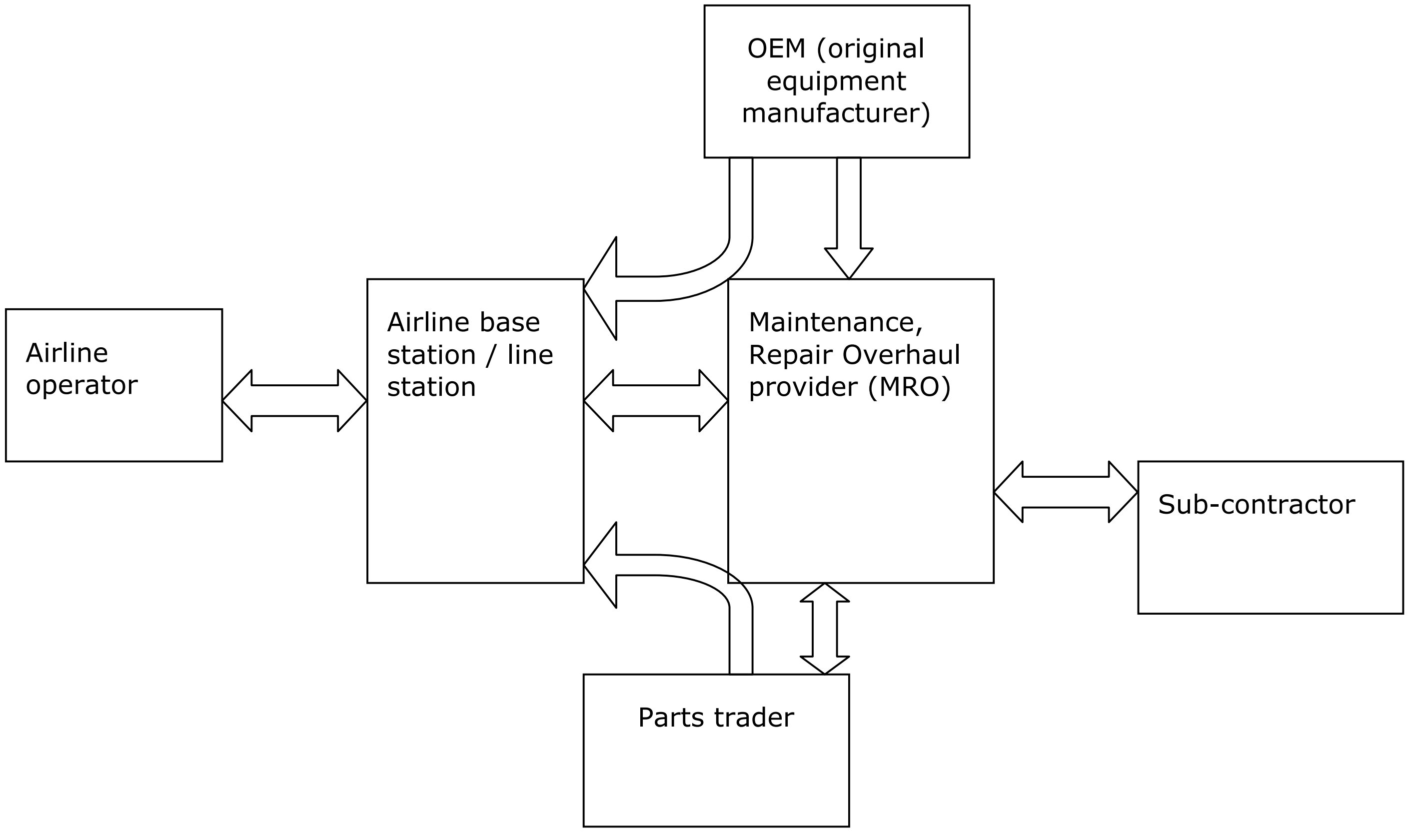



Figure 7: simplified highest-level process map: the bi-directional supply chain

Movements of material (and associated information flows) between partners operate in both directions: this is in contrast to generic supply chain models, where there is a predominantly one-way flow of materials toward the customer. In a typical manufacturing supply chain, there are physical flows in the opposite direction, referred to as reverse logistics. These upstream movements deal with warranty and exchange returns and are considered exceptional. In the maintenance scenario, however, there is an even flow of unserviceable items from customer to supplier, with maintained items flowing in the conventional (downstream) direction.

Each arrow between companies represents an opportunity for an inter-organisational system, which may be implemented as an e-commerce exchange. While e-commerce offers advantages in efficiency and speed, the level of adoption in the aircraft maintenance industry remains low.

## *Case study 2 e-commerce demonstrator for repair order management*

Mainstream ERP applications envisage the purchasing process between customer and supplier as a well-defined sequence of well-defined transactions:

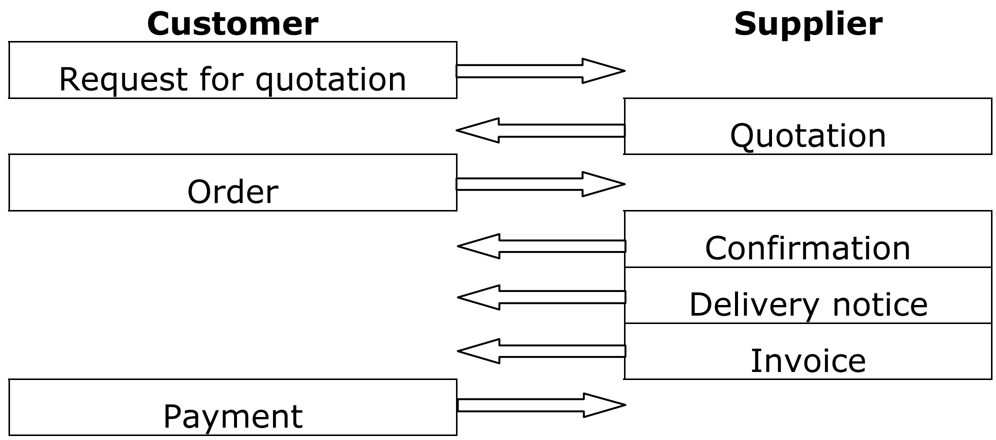



Figure 8: generic purchase order process

The governing purchasing operation in maintenance is the repair order process: while some materials are purchased, many operations involve sending an item for repair. Current ERP systems do not capture this process and use the purchase order model as an approximation, based on a conventional manufacturing model. This gives rise to two problems:

1. The repair order process needs to be managed manually (or the ERP application modified, which is happening gradually)
2. The automation of the (external) process between customer and supplier cannot be automated if it is not sufficiently connected to internal ERP systems.

The repair order process was modelled and implemented in a web-based environment to allow transactions between firms. The application was further developed to incorporate business rules, thereby automating routine decisions.

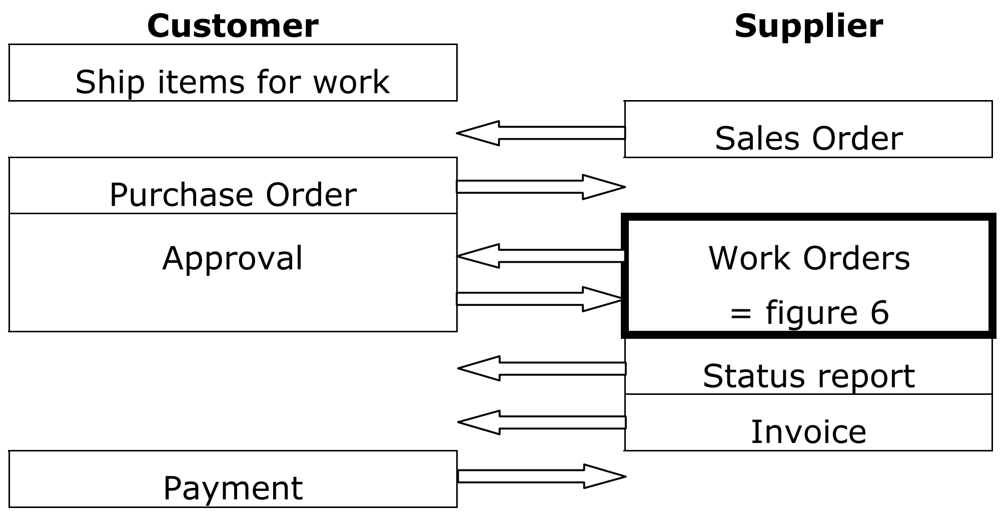



Figure 9: the Repair Order process

While the overall sequence of the repair order process (figure 9) is similar to the purchase order model for standard ERP (figure 8), there is greater complexity and uncertainty, with a repeating loop (figure 10), calling for a more complex database structure to manage this information.

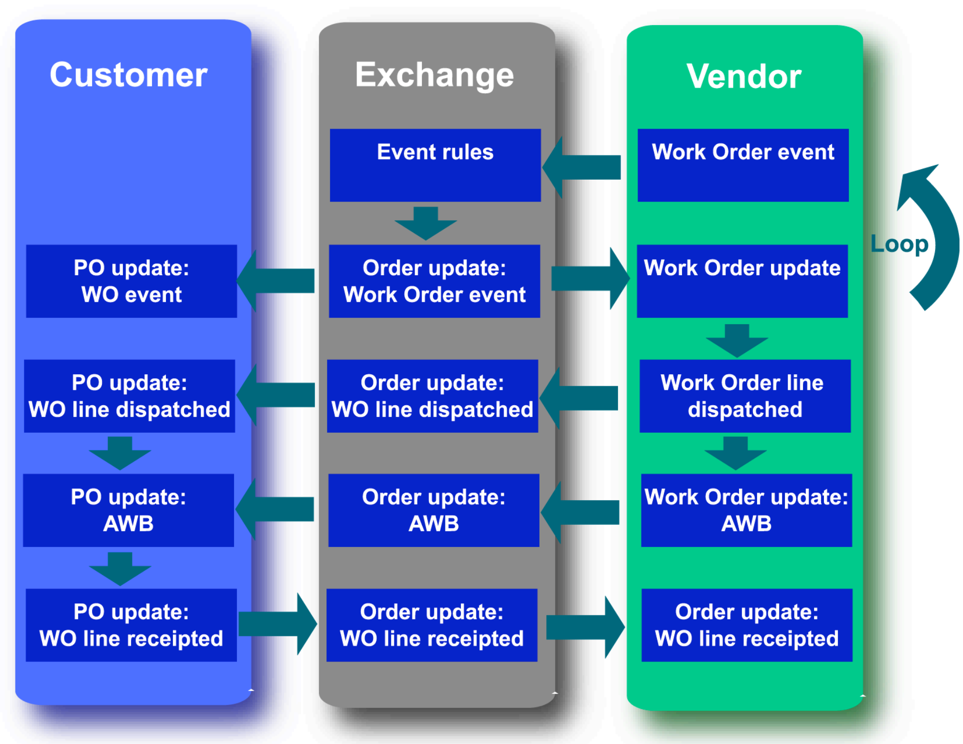



Figure 10: Work order event processing of repair orders on an e-commerce exchange (Sexton 2003)

Figure 10 shows the core of the repair order management process, conducted over an e-commerce exchange using event rules to streamline the interaction between customer and vendor. Before this process is initiated, the customer sends unserviceable items to the vendor *without a purchase order*, the vendor generates a sales order (if appropriate), the customer responds with a purchase order and the transaction begins. As the work progresses, work orders are generated by the vendor and attached to the sales order, these changes are communicated to the customer and may be used to update their purchase order.

Some business rules were prototyped for the purpose of user testing.

An example: a set of 48 matching blades from a jet engine is sent for repair:

> IF fewer than 10 are scrapped, replace scrapped items with new;
>
> OR IF between 10 and 20 are scrapped, replace with reconditioned parts and reduce the status of the set;
>
> OR IF more than 20 are scrapped, overhaul and retain the remainder for spares.

This is a typical example of clear business rules that are agreed between customer and vendor in order to maximise the value of the parts over their life and to simplify decisions involving both parties.

Thus an exchange can serve to automate on two levels:

1. Controlling the business process and carrying appropriate transactions;
2. Applying business rules to the process to enforce customer policies.

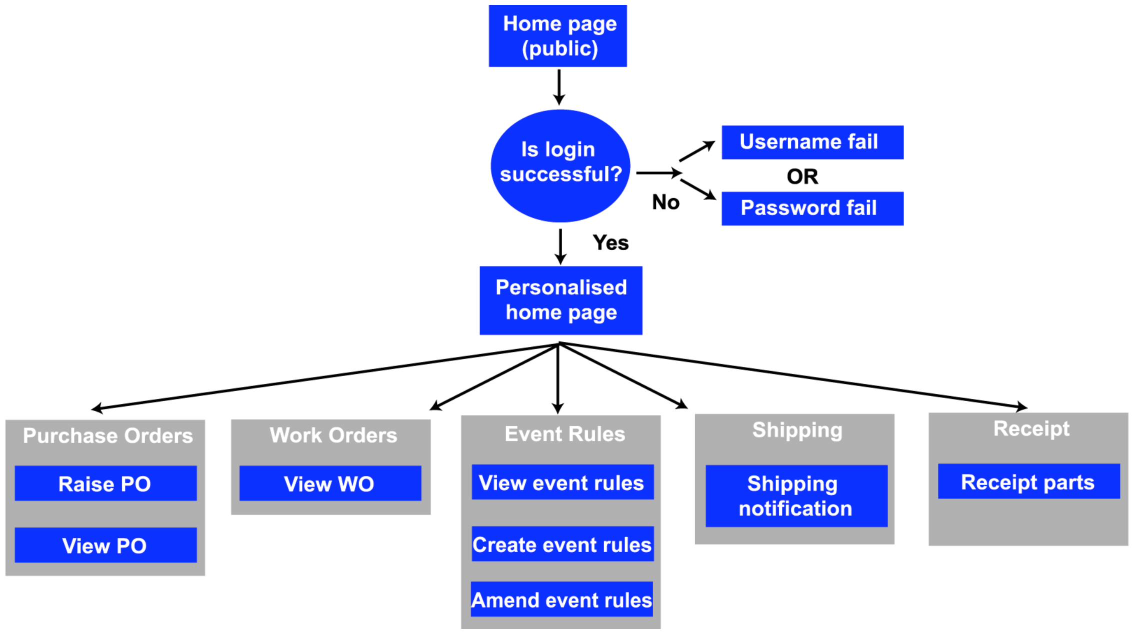



Figure 11: Customer functionality workflow

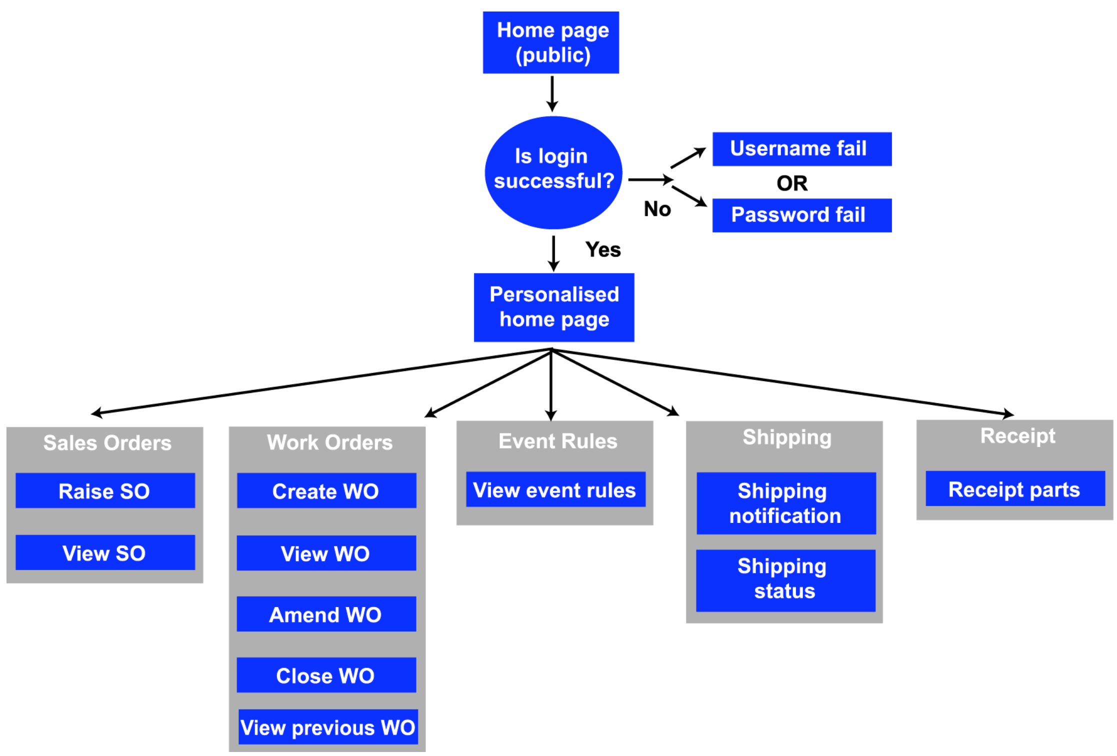



Figure 12: Vendor functionality workflow

Figures 11 and 12 show the logical design of the repair order exchange for customer and vendor. The main differences between the two are that the customer controls business rules, while the vendor controls the generation of work orders. The application was developed as a web-based system using Cold Fusion, a popular database-driven web development environment.

The repair order application was demonstrated to three companies: a Maintenance and Repair Operator (MRO), a component trading company and a specialist repair vendor. The following is a summary of their observations:

1. The application accurately captures the process beyond the capability of available ERP solutions, particularly as a focus for external transactions;
2. The automation of the process could be helpful in standardising procedures and reducing error and uncertainty in inter-organisational communication;
3. There is greater visibility of work order status by customers – this is a cause for concern, as vendors like to manage customer expectations carefully;
4. None of the participants favour the exchange model – even though it is an efficient method for gathering and communicating information, they will not entrust critical data to an external intermediary;
5. Integrating the exchange into internal ERP systems would be expensive and difficult: the economic benefit of doing this is not evident;
6. The consensus was that the application is of greater benefit to customer than vendor, as it would be very useful in monitoring vendor status reporting and would standardise this process for all vendors. At present, vendors provide status information in a range of formats and reports are not as regular as customers would like.
7. In general, there is little interest in e-commerce initiatives, as most companies have been party to a failed project and have been exposed to extensive negative publicity on the many unsuccessful attempts by the major industry players to launch exchanges.

On balance, while there are benefits to be had from the application, the companies that reviewed the prototype would not support the full development due to the absence of a compelling business case.

The issue of public and private exchanges is a key strategic problem: at a conference in 2000, an aircraft manufacturer announced that all customers would have to use their site in future to purchase parts. In the following presentation, a major flag-carrier airline (and one of the largest customers of the aforementioned manufacturer) announced their own e-commerce initiative, whereby all of their parts purchasing would be conducted on their new web site. This created an immediate stalemate, resulting in the failure of the airline’s project and a low initial uptake of the supplier’s service. While a public exchange makes sense from a technical perspective (see figure 13), it calls for standardisation and integration among all users’ systems, which calls for strong leadership in an industry. The larger problem, however, is that it requires an intermediary to hold critical data (as point 4 above), which is not acceptable to the industry partners.

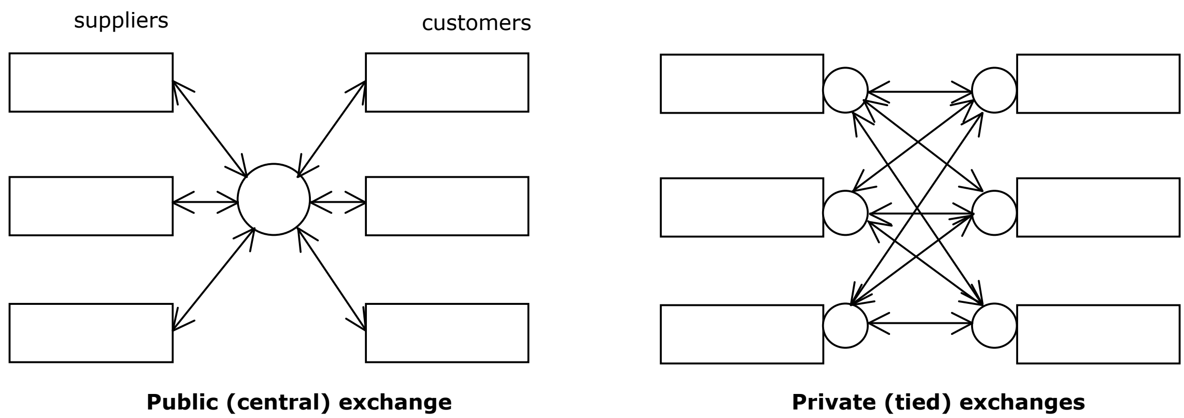



Figure 13: network configuration for public and private exchanges

From the perspective of network connections, and more importantly, message format standards, the public model creates O(n) possible links, where n = number of suppliers + customers, while the private model implies $O(n^2)$ links. Each supplier could have incompatible messages for every customer – in practice, this occurs already as suppliers and customers must deal with information in faxes, e-mails and spreadsheet files.

A public exchange requires a central intermediary to host applications and data, while coordinating with supplier and customer applications; private exchanges are operated and controlled by the supplier or customer company. The private exchange model is hampered by the difficulty in establishing which exchange should prevail in a supplier-customer relationship. In practice, successful sites, like Boeing's parts ordering facility, are not exchanges, as they require manual operation by the customer.

### *Case study 3 optimisation model for forecasting spare parts inventory levels*

In the course of the above research, a major MRO expressed concern with current practice for planning spare part inventory holdings. It was believed that there was excessive investment in inventory due to the lack of a systematic approach to forecasting requirements. An airline's main investment in inventory is in items that are maintained and re-used. These are referred to as rotable (as they rotate through inventory) and need to be managed in a manner different to consumable material, which is the generic model for ERP inventory systems. Current practice takes manufacturer's guideline reliability data for each part number and makes a simple calculation based on several factors:

*Recommended holding for part X = f(MTBR, TAT,QPA, FleetUtil, SL)*

Where

- MTBR = manufacturer's Mean Time Between Removals figure, for example, 5,000 flight hours
- TAT = Turn Around Time: time taken to route, maintain and replace item in inventory
- QPA = quantity per aircraft, e.g., 2 hydraulic pumps
- FleetUtil = total hours flown by the aircraft type in a fixed period (e.g. a year)
- SL = target service level: the probability of the part being available

Note that no account is taken of the time taken to order a new item, as items are maintained.

Since the actual time at which a part is needed is stochastic, a probability distribution is used to determine a realistic holding. The Service Level (SL) is the specified probability of a part being available: for a MTBR of 5,000 hours, a SL of 95% means that there is a 95% chance of the part being available at times on a chosen distribution about 5,000 hours. The guarantee 100% SL would require a full duplication of all items in service, which is excessively costly. IN practice, a target SL of 95% is used for essential items (parts without which the aircraft cannot operate, referred to as 'no go'). There are lower SLs for 'go if' items (e.g., one radio may be unserviceable if two other are working) and 'go' items (e.g., galley equipment).

It was proposed that the current approach was deficient in its analysis since it considered individual parts without regard to the others. This ignores two major considerations:

1. The relative cost of parts: it is acceptable to ground an aircraft for a $100,000 dollar part, but less so for a $100 part;

2. The relative failure rates of parts: rather than calculate failure rates at the individual part level, the real business problem is to maximise the number of requests satisfied for spares, regardless of the part number. In other words, each time a request is made to stores, there is a required probability of 95% that it be fulfilled.

By re-stating the problem, a linear programming formulation was outlined to achieve the following:

*Minimise Total Inventory Cost*

*Subject to required SL*

The model was prototyped with a small number of parts, which gave a forecast reduction in inventory of 40% with no consequent loss of service. This is explained by the relative frequency of failure, where the system recommended reducing holdings of parts drawn less often and increasing holdings of parts needed more frequently.

On the strength of the prototype results, the company collaborating in the research provided support to build a full-scale enterprise application, drawing data from a range of sources, including ERP for material holding, cost and MTBR figures, and engineering databases for aircraft utilisation rates.

The results of the first test on a limited range of data gave similar cost reduction: a group of parts valued at $8M could be reduced to $5M without affecting service levels.

The system is now undergoing integration for full fleets and parts listings, where it will be used on a pool of inventory valued at $250M. It is expected that savings of 20% will result in the system use (if the company acts on recommendations and sells off excess inventory).

In addition to reducing current holdings, the application permits better forecasting at the provisioning stage, when fleet purchase is being considered. Further, the owner of the inventory can increase its return on these assets by selling inventory support to other operators of the same fleet: if you hold spares to support 25 aircraft, the additional investment to support several more aircraft is negligible.

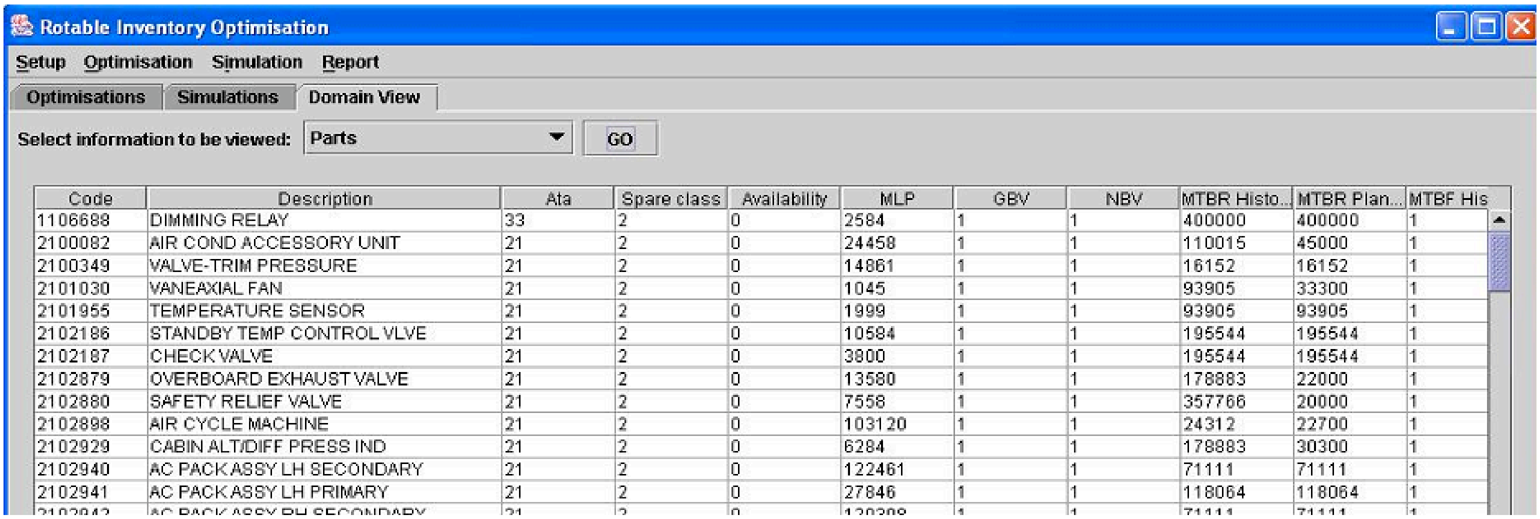
The fully developed system allows an alternative configuration for improved planning:

*Maximise SL across all parts*

*Subject to a fixed investment*

This is useful in planning asset reduction, as it allows the company to ask questions like: “if we cut our inventory value by $100M, what is the resultant SL?”. The system will skew its recommendation by value: the most valuable parts will run out first, giving the greatest saving and causing the smallest number of items to fall short, making it easier to respond case by case.

1. Improve on the statistical assumptions used – current practice is based on manufacturers' rules of thumb. With sufficient data, it will be feasible to build distributions on actual data, rather than using approximations, such as normal or Gauss.
2. Track individual items rather than quantities under the same part number: when a part fails is dependent on how long is has been in service, which is not catered for by current techniques. Thus, for a new fleet, it is not necessary to buy all spares at the outset, but accurate tracking and forecasting will indicate when items should be bought, and how many.
3.




| Code | Description | Ata | Spare class | Availability | MLP | GBV | NBV | MTBR Histo... | MTBR Plan... | MTBF His |
|---|---|---|---|---|---|---|---|---|---|---|
| 1106688 | DIMMING RELAY | 33 | 2 | 0 | 2584 | 1 | 1 | 400000 | 400000 | 1 |
| 2100082 | AIR COND ACCESSORY UNIT | 21 | 2 | 0 | 24458 | 1 | 1 | 110015 | 45000 | 1 |
| 2100349 | VALVE-TRIM PRESSURE | 21 | 2 | 0 | 14861 | 1 | 1 | 16152 | 16152 | 1 |
| 2101030 | VANEAXIAL FAN | 21 | 2 | 0 | 1045 | 1 | 1 | 93905 | 33300 | 1 |
| 2101955 | TEMPERATURE SENSOR | 21 | 2 | 0 | 1999 | 1 | 1 | 93905 | 93905 | 1 |
| 2102186 | STANDBY TEMP CONTROL VLVE | 21 | 2 | 0 | 10584 | 1 | 1 | 195544 | 195544 | 1 |
| 2102187 | CHECK VALVE | 21 | 2 | 0 | 3800 | 1 | 1 | 195544 | 195544 | 1 |
| 2102879 | OVERBOARD EXHAUST VALVE | 21 | 2 | 0 | 13580 | 1 | 1 | 178883 | 22000 | 1 |
| 2102880 | SAFETY RELIEF VALVE | 21 | 2 | 0 | 7558 | 1 | 1 | 357766 | 20000 | 1 |
| 2102898 | AIR CYCLE MACHINE | 21 | 2 | 0 | 103120 | 1 | 1 | 24312 | 22700 | 1 |
| 2102929 | CABIN ALT/DIFF PRESS IND | 21 | 2 | 0 | 6284 | 1 | 1 | 178883 | 30300 | 1 |
| 2102940 | AC PACK ASSY LH SECONDARY | 21 | 2 | 0 | 122461 | 1 | 1 | 71111 | 71111 | 1 |
| 2102941 | AC PACK ASSY LH PRIMARY | 21 | 2 | 0 | 27846 | 1 | 1 | 118064 | 118064 | 1 |

Figure 14: spare part listing

Figure 14 shows part numbers and values. Due to table sorting, all parts shown have 0 availability, meaning that there are no spares or that any units owned are in a repair cycle.

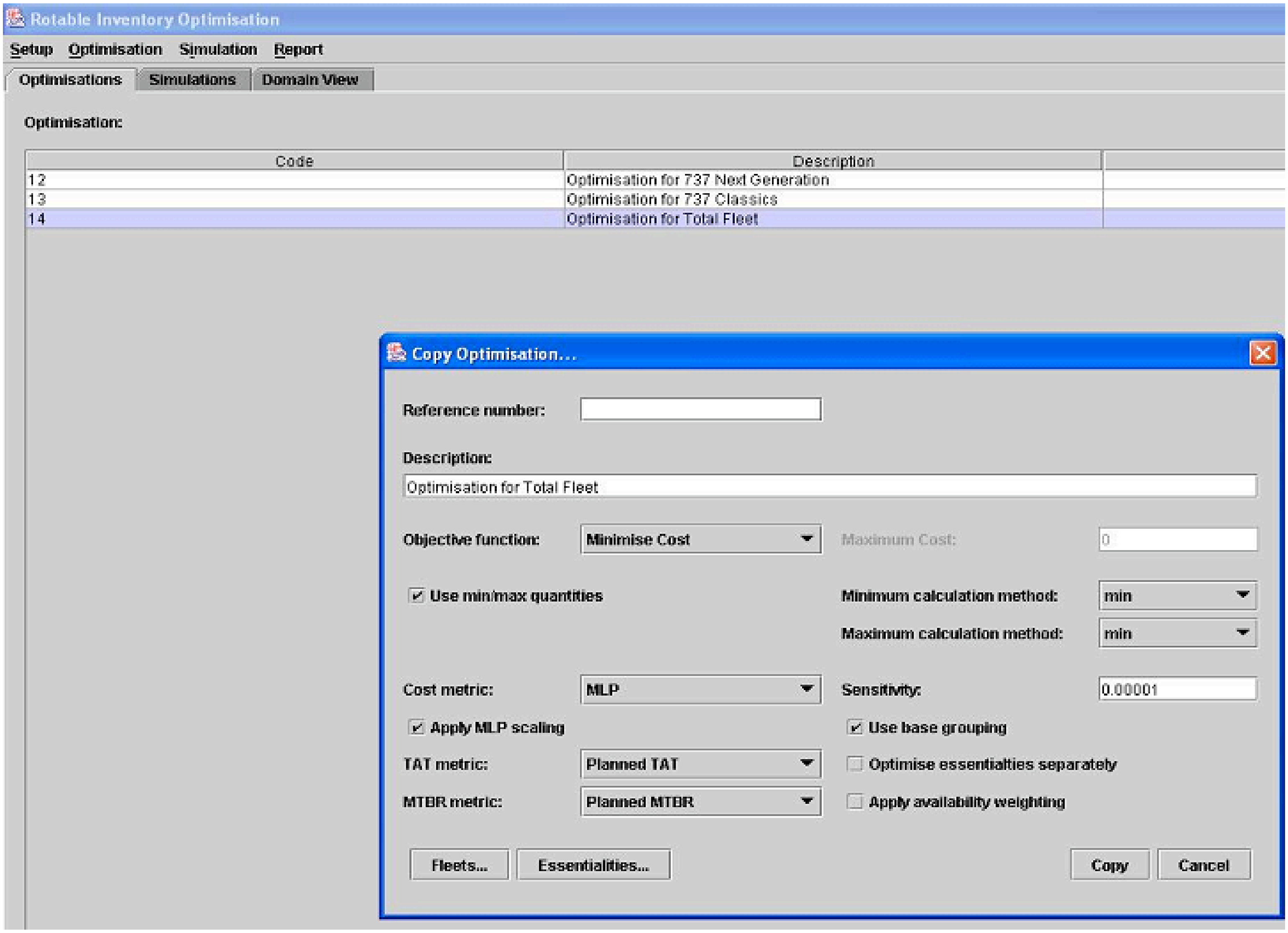



Figure 15: optimisation settings

Figure 15 shows the controls of the optimisation application – select fleet grouping, choose to minimise cost for a defined SL or to maximise SL for a define cost, maintain set minimum and maximum quantities and pool demand across several airport bases, which assumes that spares can be easily moved between locations when required.

## Optimised Part Distribution Report

OPTIMISATION 1

| | | Base | Base Qty | Base SL | Global Qty | Global SL |
|---|---|---|---|---|---|---|
| **Ess Code** | **1** | | | | | |
| | PART1 | | | | | |
| | | DUB | 1 | 0.9825217410 66704 | 2 | 0.97327204 5098884 |
| | | JFK | 0 | 0.92889713724 9931 | 2 | 0.97327204 5098884 |
| | | LHR | 1 | 0.9800309170 7769 | 2 | 0.97327204 5098884 |
| | PART2 | | | | | |
| | | DUB | 2 | 0.98074073 6582044 | 6 | 0.98781 5590 631844 |
| | | JFK | 1 | 0.98131 4481377375 | 6 | 0.98781 5590 631844 |
| | | LHR | 3 | 0.99683591 3110226 | 6 | 0.98781 5590 631844 |
| **Ess Code** | **2** | | | | | |
| | PART3 | | | | | |
| | | DUB | 3 | 0.994013124 606055 | 6 | 0.994013124 606055 |
| | | JFK | 0 | 1.0 | 6 | 0.994013124 606055 |
| | | LHR | 3 | 0.994013124 606055 | 6 | 0.994013124 606055 |
| | PART4 | | | | | |
| | | DUB | 0 | 0.97732942185 2211 | 0 | 0.97678244 2413596 |
| | | JFK | 0 | 0.978052 0453 2353 | 0 | 0.97678244 2413596 |
| | | LHR | 0 | 0.9751829 58593153 | 0 | 0.97678244 2413596 |
| **Ess Code** | **3** | | | | | |
| | PART5 | | | | | |
| | | DUB | 0 | 0.9769813 93902399 | 0 | 0.97823487 0958483 |
| | | JFK | 0 | 0.9863947 69129754 | 0 | 0.97823487 0958483 |
| | | LHR | 0 | 0.9749759 58971494 | 0 | 0.97823487 0958483 |

Figure 16: optimised part allocation among operating bases

Figure 16 shows the forecast SL for Part X at each base and for the combined network (note that the sum of base quantities is the same as the global quantity). Ess Codes 1, 2 and 3 are 'no go', 'go if' and 'go' levels of essentiality – code 1 is required to operate, code 2 depends on a condition and code 3 is not essential.

## *Actual Vs Optimised Report*

*Optimisation* 3

RIO

| *Part Number* | *Actual* | | | *Optimised* | | | *Difference* | |
|---|---|---|---|---|---|---|---|---|
| | *Qty* | *Cost* | *SL* | *Qty* | *Cost* | *SL* | *Cost* | *SL* |
| *Ess Code 1* | | | | | | | | |
| 7300845 | 0 | 0 | 0.5417711021 | 1 | 176,000 | 0.8738289426 | -176,000 | -0.332057840 |
| 3208190 | 0 | 0 | 0.8437803950 | 1 | 89,960 | 0.9871074758 | -89,960 | -0.143327081 |
| 2709262 | 0 | 0 | 0.8406858228 | 1 | 47,584 | 0.9865761408 | -47,584 | -0.145890318 |
| 2709277 | 0 | 0 | 0.7399498846 | 1 | 31,423 | 0.962802677 | -31,423 | -0.222852792 |
| 7700449 | 0 | 0 | 0.6981070667 | 2 | 11,000 | 0.9940770935 | -11,000 | -0.295970027 |
| 7700356 | 1 | 10,101 | 0.9533153309 | 2 | 20,202 | 0.9948346685 | -10,101 | -0.041519338 |
| 7801227 | 0 | 0 | 0.9027239414 | 1 | 9,657 | 0.995107342 | -9,657 | -0.092383401 |
| 2701449 | 0 | 0 | 0.8989097039 | 1 | 7,688 | 0.9947089293 | -7,688 | -0.095799225 |
| 2709300 | 0 | 0 | 0.9044836236 | 1 | 7,688 | 0.9952857112 | -7,688 | -0.090802088 |
| 2709299 | 0 | 0 | 0.9044836236 | 1 | 7,688 | 0.9952857112 | -7,688 | -0.090802088 |
| 2709301 | 0 | 0 | 0.9044837505 | 1 | 7,688 | 0.995285724 | -7,688 | -0.090801974 |

Figure 17: report of differences between actual and recommended holding

Figure 17 compares stock on hand with forecast need. The report is sorted by cost, so shows negative cost impact for the parts shown.

### *Discussion of results and proposed strategy*

The cases presented support a simple proposed strategy:

1. Model – understand and refine business processes across the supply chain and use this intelligence to identify the most beneficial areas for implementation. This also helps to identify prospective quantitative optimisation problems, whereas current management science practice tends to begin with the assumption that the problem is well defined and deserves a solution.
2. Automate – the domain of most ICT efforts, applications such as ERP and e-commerce solutions should only be built with a clear, refined process model view. This may be the basis for strategic justification of inter-organisational systems in particular.
3. Optimise – look for opportunities to build solutions employing management science techniques. This is a difficult step to achieve, since it requires:
    - A full and comprehensive view of all processes;
    - Knowledge of operations research tools, such as linear programming, sorting and routing algorithms, also other management science areas like decision analysis;
    - Considerable luck in framing complex problems with a feasible solution.

Returning to the general questions posed by this research:

1. What is the composition of the supply chain and can a better understanding help in the use of information systems? The supply chain is fully bi-directional and contains some complex processes, however it is realistic to model these processes, e.g., repair orders.
2. Can an Aircraft Maintenance Supply Chain Reference Model (AMSCRM) be shown to be a good fit to most companies in the industry? Yes, some companies cover several organisation types, but the high level of regulation means that there is a high degree of standardisation in work practices.
3. How well do current ERP offerings meet the needs of the industry? Results are mixed: core internal processes are modelled on generic manufacturing models, some are being modified, external process automation is very low.
4. Should companies in the aircraft maintenance industry make or buy software solutions for specialist functions? Having a clear process view is important – there are some product versions specialising in MRO so it is worth looking at market offerings. However, at least one specialist product is known to have been built around poorly planned processes in a collaborating company.

5. Do ERP systems support supply chain operations? If not, is the AMSCRM helpful in devising new solutions? Supply chain automation is low, due to the unpredictable and complex nature of maintenance. The model is helpful for process understanding, however there are serious limitations to e-commerce adoption in the industry.
6. Is there an inherent problem with technical managers innovating and adopting technology (such as ICT solutions) from outside their core area? If so, how can this be addressed? This appears to be the case from observation. Also, many managers appear to make IT investment decisions as followers, not innovators. It is problematic to generate empirical data on this question. It appears that dominant players in the market continue to exert the greatest influence in technology strategy.
7. Are there obvious inhibitors to the growth of inter-organisational systems in the supply chain? If so, how can they be addressed? Concerns about data ownership – new intermediaries are not welcome. There is a lack of a business case for smaller companies to embark on e-commerce projects. Most companies expect the industry leaders (such as Lufthansa Tecnik in EU and Singapore International Airlines Engineering in Asia) to set the standards in coming years and are happy to follow their lead.

### *Further work*

The simple three-step strategy outlined has been reviewed with a group of IS academics in session, with the consensus that it is useful to use a process modelling approach to help discover optimisation problems. A further session is planned with industry professionals to review the strategy and seek feedback.

The experience in the aircraft maintenance industry has led to the creation of a major initiative in the telecommunications industry, where a long-term research capability is being created in an attempt to connect supply chain and industry strategic driving forces with low-level device design. For example, the decision to use contract manufacturers has a bearing on how telecommunications switches should be designed.

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