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IT Support for Managing Aircraft Spares in a Closed-Loop Supply Chain Track

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ABSTRACT

This paper reports on the development of elements of an e-supply chain management system for managing maintenance, repair and overhaul (MRO) relationships in the aerospace industry. A standard systems development methodology has been followed to produce a process model (i.e. the AMSCR model); an information model (i.e. business rules) and a computerised information management capability (i.e. automated optimisation). The proof of concept for this web-based MRO supply chain system has been established through the collaboration with a sample of the different types of supply chain members. The proven benefit is a reduction in the stock-holding costs for the whole supply chain whilst also minimising non-flying time of the aircraft that the supply chain supports. This type of system is now vital in an industry that has continuously decreasing profit margins, which in turn means pressure to reduce servicing times and increase the interval between maintenance actions.

Industrial Research Motivation

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 information processing technology:

- Business models developed recently include point-to-point low fare carriers, which aim to eliminate complex ticketing agreements and sell direct to the consumer, offering value over comfort. Low fare carriers tend to favour streamlined operations, with a single aircraft type and the attendant efficiencies in purchasing power, maintenance and crew utilisation.
- 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. Many older generation aircraft were retired in recent years due to a drop in utilisation following the Gulf War. Further, 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. The consequence for maintenance costs has been pronounced, and the value of the aircraft MRO (maintenance, repair and overhaul) market fell to $34.6bn in 2003 from $43bn in 2001 (Back, 2003). There is continuing consolidation in the market, with constant pressure to innovate and create competitive advantage.
- This is where the third major environmental change comes into play: supporting technology for the maintenance side of the industry, where airlines are the customer at the end of a supply chain. In particular inventory management of spare parts for aircraft, which are not consumed and replaced; instead they are repaired and re-stocked, making the decision process for inventory planning different to the conventional production-based view of ERP systems. While many information systems functions are internal, clearly there are opportunities to link information systems to external processes.

Key questions that have arisen from action research and motivate this work are:

1. What is the composition of the aircraft maintenance (MRO) supply chain?
2. What factors encourage transactional exchange between different companies in MRO supply chains?
3. Should optimisation objectives (for example inventory minimisation) for MRO supply chains be the same as those for primary production supply chains, and why?

Purpose and Scope of the Research

In general, the purpose of the work is to promote the increased use of computer-based systems to automate, communicate and optimise business information processes in the aircraft maintenance industry. This is in response to the perception that the industry lags others in its adoption of technology, and that the scope to apply technology is large and offers large potential benefits.

The information modelling approach described in the next section aims to move from the general to the specific in three levels: starting with a structured mapping of the supply chain (a 'business process model'), moving to the facilitation of transactions between members of the supply chain (the 'information model' level), and finally performing complex optimisation on inventory data (the 'computerised information management' level).

The first activity described (mapping the supply chain) aims to span the industry with a generic model of organisation types and their processes. The second step (building an e-commerce exchange) covers the governing transactions between a repair service provider and their maintenance agency customer. The third project (inventory optimisation) is yet more specific and detailed, applying a mathematical solution to a well-defined and large-scale planning problem (Laudon 2000).

Methodology: Systems Development

This work uses a standard information modelling approach (Stevens et al, 1998) as shown in Figure 1.

The use-case scenarios were developed from an airline (Aer Arann) and a primary maintenance provider (Shannon MRO). From this scenario, the *'process model'* was defined. This model is referred to in this paper

- there is greater visibility of work order status by customers (this may be a cause for concern, as vendors have less control over managing customer expectations).

However the downsides of such systems are that:

- participants are reluctant to have enterprise data held on external systems;
- Integrating of exchanges into internal ERP systems would be expensive and difficult: the economic benefit must be clearly evident.

The opportunities that such systems provide include:

- enhanced ability for customers to track vendors' status reporting
- increased consistency and frequency of inventory status reporting
- greater transparency and speed of communication should facilitate reduction in inventory levels through faster repair cycle turn-around times.

The development of such systems is currently threatened by:

- little interest in e-commerce initiatives, as most companies have been party to failed projects with unclear potential benefits;
- the immature state of middleware technologies, solutions and service management;
- such systems often act as an unwelcome force for standardisation to the vendors' advantage.

The *rotable* inventory optimisation system was prototyped with a small number of parts, giving forecast reduction in inventory of 40% with no consequent loss of service. On the strength of these prototype results, the company collaborating in the research provided resources to build a full-scale enterprise application, drawing data from a range of sources, including ERP for material holding, cost and mean-time-between-failure (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.

This prototype solution has demonstrated the validity of a new algorithm, which will be tested on a larger set of operational data. The key difference between current practice and the new algorithm is that the current approach minimises each line item of inventory to achieve a stated level of performance, while the new approach minimises the set of inventory items to achieve the target performance level for the whole set. This difference has been shown to offer significant potential for inventory reduction without loss of performance.

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. Furthermore, the owner of the inventory can increase its return on these assets by selling inventory support to other operators of the same fleet. To date, over 6 man years of development effort have been put into developing this system.

IMPLICATIONS FOR SUPPLY CHAIN IMPROVEMENT

With regard to the AMSCRM, an industry-specific model of the supply chain is useful in proposing new IT initiatives, both e-commerce and intra-firm. It can also be used as a context within which to consider material flows, in particular the potential for inventory reduction through demand pooling and better inventory control information.

The e-commerce prototype tested here serves to underline the pitfalls experienced by earlier initiatives, namely issues of systems integration and trust.

The rotable inventory optimisation algorithm and application demonstrate the potential to apply known management science techniques in new settings for major benefit. In an environment where MROs are struggling to enhance their value proposition, a more analytical approach to resource management is a useful route to commercial survival and growth.

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REFERENCES

Aircraft Technology Engineering and Maintenance 2001. '*Maintenance software integration*'. Dec – Jan 2001.

Back 2003. Outlook, Autumn 2003. http://www.backaviation.com/Newsletters/Autumn%202003%20Newsletter%20Final.pdf.

Laudon, K and J Laudon 2000. '*Management Information Systems*', 6th edition. Prentice Hall , New Jersey. p 37.

MacDonnell, M and B Clegg 2004. 'Managing IT Investment for Aircraft Sustainment'. MIT Engineering Systems Division Symposium, 31st March 2004, Massachusetts Institute of Technology.

Melão, N and M Pidd 2000. 'A conceptual framework for understanding business processes and business process modelling'. Information Systems Journal, 10, 105-129, 2000.

Rainbird, M 2004. '*Demand and supply chains: the value catalyst*'. International Journal of Physical Distribution and Logistics Management, 34: 3 / 4, 230-250, 2004.

Stevens, R., Brook, P., Jackson, K, Arnold, S., 1998. '*Systems Engineering: Coping with Complexity*'. Prentice Hall Europe. Pp 262-263.

SBAC 1999. Annual Report of the Society of British Aerospace Companies. http://www.sbac.co.uk.

Singh, N 2003. '*Emerging Technologies to support Supply Chain Management*'. Communications of the ACM, September 2003, Vol. 46, No. 9.

Stephens, S 2001. '*Supply Chain Operations Reference Model Version 5.0: A New Tool to Improve Supply Chain Efficiency and Achieve Best Practice*'. Information Systems Frontiers, 3:4, 471 - 476, 2001.

Tedone, M 1989. '*Repairable Part Management*'. Interfaces 19: 4, 61-68, 1989.

Williams T, R Maull, B Ellis 2002. '*Demand chain management theory: constraints and development from global aerospace supply webs*'. Journal of Operations Management 20 (2002) 691-706.

Figure 1. Derivation of the system

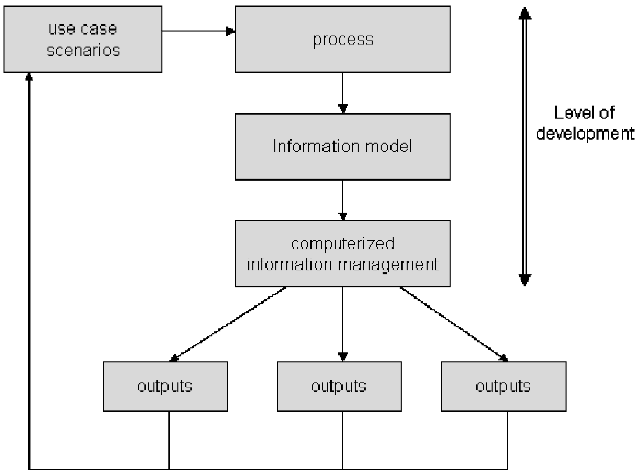
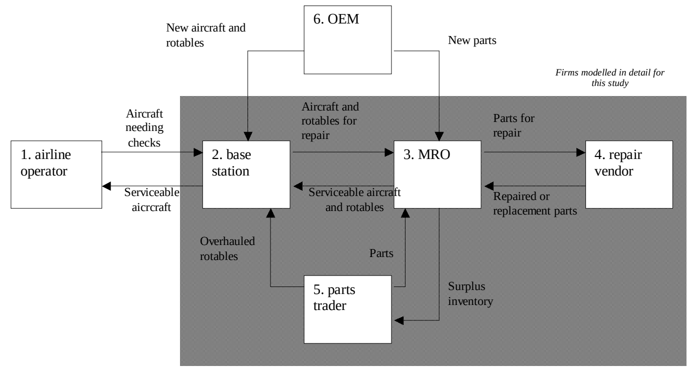


Figure 2. The aircraft maintenance supply chain reference model – top-level view



as the *'Aircraft Maintenance Supply Chain Reference (AMSCR) Model'* and is intended to coordinate with other standard models such as the Society of British Aerospace Companies Supply Chain Relationships in Action (SCRIA) model (SBAC 1999) and the Supply Chain Operations Reference (SCOR) model framework (Stephens 2001).

The *'information model'* is an e-commerce exchange demonstrator, which facilitates the simulation of real business processes in a computer-based system. This involves transactions between more than one organisation in the MRO supply chain. This model tries to encompass the principles of demand chain management (DCM): a closer integration between providers and consumers of goods and services with a high level of e-commerce capability (Williams 2002).

The *'computerised information management model'* embodies algorithms for dynamic inventory control embedded in the e-commerce exchange demonstrator with inputs from back-end MRO inventory management ERP systems. The outputs were then validated against the original use-case scenarios to create off-line MRO SCM simulations.

Each of these levels is now described in greater detail.

1. **Process Level: The AMSCR Model**
   Central to this research is the application of business process modelling techniques (Melão 2000). These normally focus on the internal structure and operation of organisations (e.g. those covered by ERP systems). This research anticipates breakthroughs in understanding and improvements in the information flows that connect firms (e.g., e-commerce).
   The system shown in Figure 2 depicts an industry where demand drives inter-organisational transactions, so that the supply chain could almost be referred to as a *demand chain* (Rainbird 2004). It is a key feature of aircraft MRO supply chains that material moves in both directions: this contrasts to standard supply chains producing 'consumable products', where there is a predominantly one-way flow of materials - toward the customer.
   Physical flows in the opposite direction towards the supplier (often referred to as reverse logistics) are considered exceptional in 'consumable product' supply chains. However, in the MRO scenario, there is a flow of serviceable items from customer to supplier, and maintained (or re-manufactured) items flowing in the conventional downstream direction. Thus the supply chain is a *closed loop*. Items that are maintained and re-used are called *rotable*, since they *rotate* through inventory.
   Figure 2, along with more detailed figures produced by this research, addresses research question 1.
2. **Information Level: E-Commerce Demonstrator**
   This section addresses research question 2 in greater depth: what factors encourage transactional exchange between different companies in MRO supply chains?

Developments in technology in recent years offer potential for firms to increase their use of automated systems to perform routine supply chain operations (Singh 2003). A database with a web-based interface was designed to allow suppliers and customers to transact business over a common e-business exchange, where each could log in and manage orders. The motivation for this was the lack of automation in managing the MRO supply chain as there is currently a diverse range of internal systems in operation across the different organisations and scant resources to connect these systems or bring transactions to a common standard.

Standard ERP applications envisage the purchasing process between customer and supplier in a 'consumable product' supply chain to be a well-defined sequence of transactions, shown as a timed sequence of events from 1 to 7 as in Figure 3.

However, the nature of MRO transactions is different: while some materials are purchased, many operations involve sending an item for repair; other items may be recycled or disposed of altogether. Current ERP systems often do not reflect this process accurately in their informational relationships and use the standard 'consumable product' purchase order model as an approximation. This gives rise to two problems:

- The repair order process needs to be managed manually or the ERP application modified; which often happens incrementally by trial
- If customers' and suppliers' ERP systems are not interconnected, it is not possible to perform automatic transactions or optimisations between organisations.

In response to these problems the repair order process was observed and modelled, as shown Figure 4 below, (in time order from 1 to 8) and implemented in an e-commerce demonstrator that allows transactions between firms.

An e-commerce exchange prototype application was built, allowing customers and suppliers to conduct the above process in a rule-based environment and sharing a central database. While technically successful, there are limitations to the implementation of such a system in the need for integration into internal ERP systems, and the reluctance of companies to hold transaction data on a central (external) database.

In addition to the purchasing transactions, there is a need to manage technical records between organisations: for instance when an aircraft is sent for maintenance, it is accompanied by a detailed status pack about the maintenance level and history for all major components and a list of required upgrades and modifications as called for by the airline, aircraft manufacturer and regulatory authorities. There is thus ample scope for further work to model and prototype systems for the

Figure 3. Transactions for the consumable purchase order process

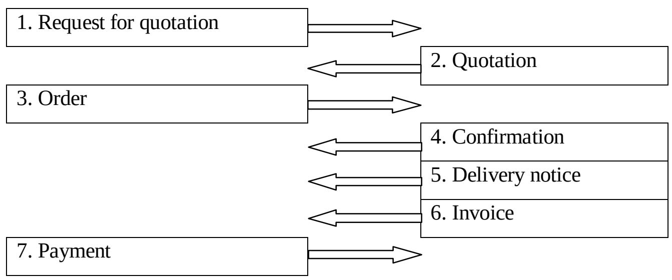
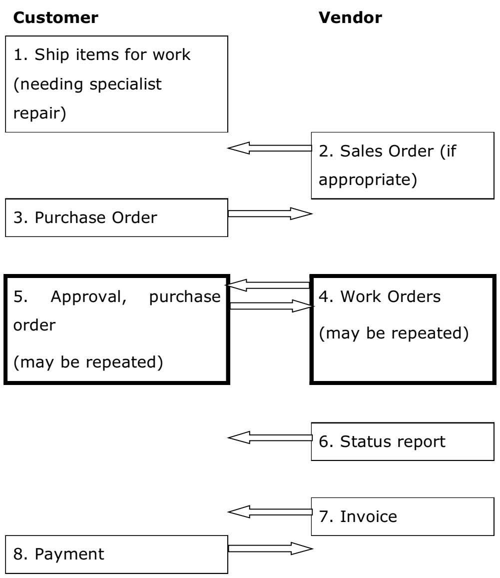


Figure 4. Transactions for the MRO repair order process



automation of commercial transactions between the various members of the MRO supply chain.

3. COMPUTERISED INFORMATION MANAGEMENT LEVEL: OPTIMISATION FOR FORECASTING SPARE PARTS INVENTORY

This section addresses research question 3: should optimisation objectives (for example inventory minimisation) for MRO supply chains be the same as those for primary production supply chains, and why?

In the course of this research, a major MRO supply chain operator (FLSA) has identified deficiencies with current practice for planning spare part inventory holdings. Often excessive inventory exists due to the lack of systemic forecasting. Solutions are required for both consumable inventory and inventory that is maintained and re-used (i.e. non-consumables); these are referred to as *rotable* (as they *rotate* through inventory and are not consumed). Rotable stock needs to be managed differently to consumable material. While there have been some systems developed for this problem, usually looking at the problem of dividing inventory around several airports (Tedone 1989), specialist solutions are not in widespread use in the industry. Major ERP systems are modelled on manufacturing, so they do not cater for *rotable* inventory (Aircraft Technology Engineering and Maintenance, 2001).

The standard model followed by ERP inventory systems takes manufacturer's guidelines for reliability and makes a 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, e.g., 30 days
- QPA = quantity per aircraft, e.g., 2 hydraulic pumps
- FleetUtil = total hours flown by the total number of aircraft of the same type (e.g. Boeing 737-800) in a fixed period , e.g., 1,000 hours per month
- SL = target service level: the probability of the part being available

The calculated number will be a quantity of a given part number: for example, the recommended holding level for hydraulic pump (part number 123-4567) might be 6. This means that holding 6 parts in stock should satisfy a certain availability level (e.g., available 95% of the time) or 'service level'.

Since the actual time at which a part is needed is stochastic, a probability distribution for times 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. To guarantee 100% SL would require a full duplication of all items in service, which is often prohibited by cost. Therefore, in practice, a target SL of 95% is used for essential items (parts without which the aircraft cannot operate, and are referred to as 'no go'). There are lower SLs for 'go if' items (e.g., one radio may be unserviceable if two others are working) and 'go' items (e.g., galley equipment, without which the aircraft can operate safely).

The major outcome of this research is a new algorithm that has been implemented as a batch decision support application for *rotable* inventory management. Instead of aiming for a target service level (e.g. 95% chance of availability) for each part, the objective function optimises the entire stock of parts (i.e., 95% chance of *any* part being available). The solution allows for relative failure rates of parts. It also accounts for the relative value of parts, unlike current practice. The solution achieves target service levels while substantially reducing the total value of inventory required (MacDonnell and Clegg 2004).

Results and discussion

Three levels of the MRO supply chain have been reproduced: the Aircraft Maintenance Supply Chain Reference Model ('process' level), a repair order e-commerce exchange prototype ('information' level), and a *rotable* inventory optimisation system ('computerised information management' level). Each different level of development in this research has illuminated new issues in aircraft MRO supply chain management.

The AMSCR model has achieved:

- participants gaining clarity and consensus about their own processes;
- a basis for devising supply chain solutions.

The e-commerce exchange has been validated with a maintenance, repair and overhaul (MRO) operator, a component trading company and a specialist repair vendor. The observable strengths were that:

- the e-commerce system accurately captures the process beyond the capability of available ERP solutions, particularly as a focus for external transactions;
- the automation of the process is helpful in standardising procedures and reducing error and uncertainty in inter-organisational communication;

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