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Pooling of spare components between airlines

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Abstract

The purpose of providing component availability service is to maximize aircraft utilization by keeping spare units ready to be installed whenever needed. Since the size of the fleet supported by the spare component inventory is the most important driver behind the inventory cost, inventory pooling among a number of airlines is an intuitive way of exploiting the scale economies of availability services. This study demonstrates the savings potential of balanced inventory pooling arrangements among various airlines. Managerial implications of successful cooperation are discussed.

Keywords: Inventory pooling; Aircraft components; Airline management

1. Introduction

An important driver of airline performance is the high utilization of aircraft. While reliable and modular components increase utilization, fast replacement service is paramount in case of failure. Keeping functional replacement units at hand shortens the delay of the service and allows the repair work to be performed later on. The costs of this component availability service are caused mainly by the capital tied up in the spare components. In this study, managing the number and location of spare components is considered as availability service, which can be produced in-house, purchased from subcontractors or offered to external customers. These three alternatives constitute a make–buy–sell decision for the maintenance organization regarding every component type it supports. Maintaining in-house capability is an alternative that sustains sovereignty but also ties up valuable capital in a property that is steadily losing its value. Subcontracting component availability replaces capital costs with a constant cash flow, increasing business flexibility. This alternative also increases transaction costs and possibly lead times. Providing availability service to external customers is normally an eligible addition to providing service to one's own organization.

This study considers a fourth alternative of providing availability service, which helps to decrease the spare parts inventory by means of pooling the aircraft components among several airlines. The idea here is to combine the best features of the make–buy–sell decisions of several airlines into a cooperative effort of pooling the inventories of certain spare components. Here it does not matter where or by whom the repair work and other maintenance operations on the components are performed. Inventory pooling is a method of utilizing economies of scale. Fig. 1 shows an example of how economies of scale work in the component availability service. The graphs in the figure have been produced using the model presented below, in section 2.1. with typical parameter values. The number of aircraft in the fleet does not mean the whole fleet of the airline, but just the fleet of one aircraft type or family operated by the airline.

As can be seen in Fig. 1, the more aircraft there are in the fleet, the lower is the spare component need per aircraft. Spare needs are random by nature because they are initiated by a random phenomenon, aircraft component failure. The law of large numbers reduces variation when the number of random events increases. Considering a cooperative setting between airlines it is evident that participants with relatively small fleets have much more to gain than their larger counterparts.

Antti Wäre, Vice President of system business at Nokia Investment Company China, has said (Morais, 2001, p. 104) that 'there is no point transferring your

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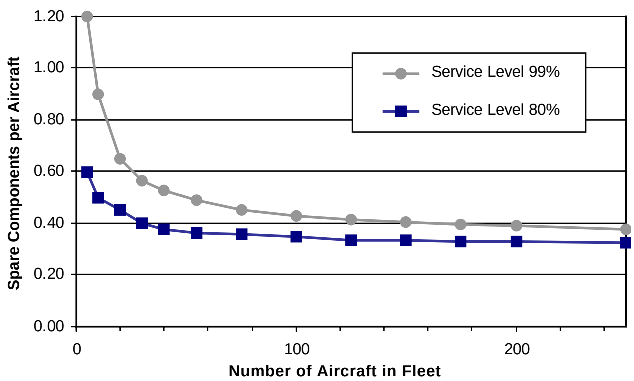


Fig. 1. Economies of scale in component availability service.

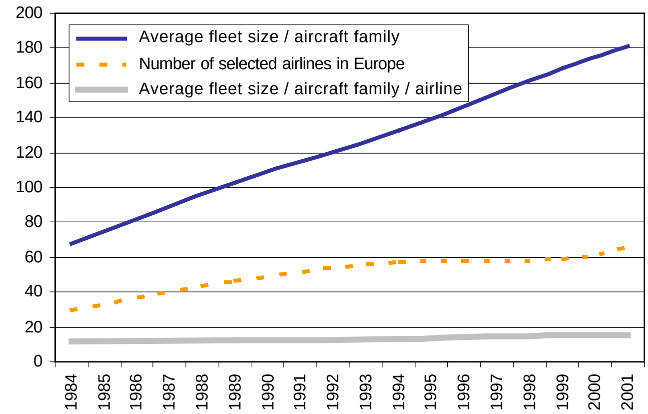


Fig. 2. Trends in the fleet composition of selected European airlines. The airline selection behind the trends has been made as follows. First of all, it only includes aircraft designed and manufactured outside the former Soviet Union area. It excludes all the so called regional jets, i.e. jet aircraft that are mainly designed for thin and reasonably short routes. Thirdly, it only includes European commercial airlines which at some point during the 17 year period operated at least 10 aircraft fulfilling the criteria above. The empirical data behind the trends is based on the World Airline Reports published every year by the Air Transport World magazine. The report is published every summer, and reports from the following issues have been used here: May 1985, June 1990, June 1995, July 2000, July 2002.

inventory to a supplier, because it will then have the inventory cost, and you will see it showing up sooner or later. But if you can reduce the whole chain's inventory, it will make you more competitive'. This study is not merely suggesting that the airlines rid themselves of the spare unit inventories, it suggests a way of lowering the total amount of tied up capital considering the whole value chain.

1.1. Pooling opportunities in the aviation industry

In the aviation industry there has been a constant strain of driving down the number of spare units. It has even been said that the potential for savings through tighter management of spares in the supply chain is greater than any existing revenue opportunities in the airline business (McDonald, 2002). It was estimated in 1995 that the aviation supply chain held US$45 billion in inventory, nearly 80% of which was owned by the operators (Flint, 1995). Despite a lot of serious talk about reducing inventory levels, the figure was estimated to be over US$50 billion in 2002 (McDonald, 2002).

If the inventory value of the aviation supply chain is considered per aircraft in operation, the dollar amount has actually dropped from about US$3.75 million per aircraft in 1995 to about US$3.35 million per aircraft in 2002. This is because the global airline fleet has increased from about 12,000 to about 15,000 aircraft during that period. New aircraft taken into operation lately represent new technology which means considerably lower need for spare parts than industry average. On the other hand the new technology parts are more expensive than their low technology predecessors. So it is unclear whether the spare inventory glut has actually increased or decreased.

In 2002 the expenditure in commercial aircraft maintenance was estimated to be US$34 billion, 52% of which was accounted for by work on engines and other components (Flint, 2002). Compared to this figure the holding cost of the US$50 billion worth of spares inventories seems quite remarkable. Of the total operating costs of an airline, maintenance costs typically represent some 10–15% (Seristö, 1995).

Fig. 2 shows some trends in the fleet composition of selected European airlines from the year 1984 to 2001. More new jet aircraft were taken into use during that period than ever before, as the total fleet increased from under 1100 to over 2700 aircraft. The average total fleet of an aircraft family increased even more rapidly than the number of aircraft in use. As the number of airlines has more than doubled during the period, the average fleet of an aircraft family per airline has increased relatively slowly.

The setting in the industry is such that the real potential of utilizing economies of scale to reduce costs is beyond the reach of most individual airlines. Continuously growing total fleets of different aircraft families ensure that the cost reduction potential keeps increasing. A cooperative arrangement between two or more airlines operating common aircraft family is one way of utilizing the potential.

The idea of cooperative pooling is in no way new to the air transport industry. In the 1960s there was a lot of fleet commonality between European airlines, which provided a foundation for two maintenance consortiums called KSSU and Atlas (Lombardo, 2000). KSSU was a joint effort of KLM, SAS, Swissair and UTA while the airlines behind Atlas were Air France, Alitalia, Iberia and Lufthansa. Lufthansa and Air Canada are also planning to extend their cooperation regarding the component maintenance of the CRJ aircraft to the pooling of spare component inventories (Flint, 2000). It is significant that these cooperative efforts have this far been isolated exceptions to the general rule of each airline maintaining its own inventories.

1.2. Decreasing spare component inventories

Aircraft components are complex high level modules consisting of dozens or hundreds of parts. The life span of a component may exceed two decades, during which it is probably repaired or overhauled more than a dozen times. These issues, accompanied by the usual aviation specialties like authority requirements for certification and traceability, as well as reliability and safety issues increase the cost of obtaining and keeping aircraft components. Since the majority of the inventory value in aviation supply chain is tied up in spare components, they represent the primary target for inventory value reduction.

There are four factors affecting the cost of providing availability service: reliability of the component, turnaround time (TAT) of the component repair process, required service level of the spares supply, and the number of units supported by the spares.

Improved component designs with higher reliability have been introduced to extend the time between failures. This goal has been shared by the numerous studies in the area of preventive maintenance. Decreasing turnaround times of the repair processes has been addressed in several studies especially as a method of lowering the value of spare part inventories (e.g. Cobb, 1995). Higher service levels lead to fewer stock out occasions at the cost of higher inventory levels. In spare parts optimization the service levels are set, commonly by utilizing information systems, so as to balance the cost of stock outs against the inventory costs. Two examples of commercial spare parts optimization software are OPUS10 and Xelus (Alfredsson and Eriksson, 1998; McDonald, 2002). Proprietary systems developed by airlines include CMAM by Scandinavian Airlines (Reed, 1989) and CIMLINK by Delta Airlines (Henderson, 2000).

The economies of scale associated with the number of units supported can be seen in Fig. 1, since this factor depends directly on the number of aircraft in the fleet. Possible ways to affect the number of units supported include standardizing the fleet composition, subcontracting the availability service and inventory pooling. The connection between an airline's fleet composition and maintenance related costs has been pointed out by Seristö (1995) and Seristö and Vepsäläinen (1997). The effective number of units supported can be increased by subcontracting the availability service to an organization that already enjoys economies of scale or, by offering the availability service to other organizations. Possible subcontracting partners include Original Equipment Manufacturers (OEMs), independent service providers as well as those airline maintenance organizations (e.g. Hill, 2002; Reed, 1992) that offer component availability as an auxiliary service of their maintenance services. Some caution is advisable regarding outsourcing from OEMs even if they control the highest economies of scale in the industry. Keeping a significant share of the business on the airline side prevents OEMs from gaining a market position too close to a monopoly. Active presence in the maintenance business also helps airlines to dampen the effects of fluctuations in passenger demand, as it is inherently less cyclical and more profitable than the core airline business.

In the basic case of inventory pooling all the inventory locations belong to a single organization, for example, a company or military force. In this case the pooling can be considered successful if the total benefit is positive. In cooperative pooling the inventory locations belong to several different organizations. An arrangement like this is successful only if every participant benefits from it. Additionally, the benefits should be reasonably evenly distributed between the participants, if the cooperation is going to last. Even if these conditions are fulfilled, managing a pooling arrangement can still be challenging, as is the case with any inter-firm cooperation.

Concerning aircraft component availability a mutually beneficial arrangement would distribute the provision of the availability service evenly between the partners, instead of one airline selling the availability service of all the components to the other cooperating airlines. As regards one component the arrangement would be unbalanced, but regarding all the components under the cooperative effort, there would be a balance.

2. Modeling availability

The purpose of this study is to show the possibilities of lowering the number of spare components through inventory pooling. A rather standard statistical model of component availability is used and the results are verified by computer simulations. The focus is on the spare units needed to cover unscheduled removals assuming that all the components follow the principle of 'fly until fail'. Inventory needs for any scheduled removals can be handled independently.

2.1. Basic model of component availability

The basic model illustrates the relations between the four factors of availability (reliability, turnaround time, service level and the number of units supported) and the number of spare units needed.

In the aviation industry the most widely used measure of reliability is the mean time between unscheduled removals (MTBUR). If it is known only as a meter value, the average utilization of the component also needs to be known for converting the MTBUR into calendar time. Repair TAT is measured as the elapsed time between the event when a failed component is removed from an aircraft and the moment when it is stored after the repair and ready to be used as a spare unit. The required service level of the spares supply is measured as the share of the number of times the request is fulfilled on a certain component when this very component is requested from the supply. The number of units supported is measured as the total number of the components in question that are installed in all the aircraft in the airline's own fleet as well as in other fleets supported by the inventory.

According to Palm's theorem the stationary distribution for the number of units in the pipeline is a Poisson process with an assumption that the interval between the arrival of units in the pipeline is negative exponentially distributed (Palm, 1938). The theorem has been acknowledged widely in the area of queuing theory (e.g. Baccelli and Brémaud, 1987). For example, Takács (1962) and Jardine (1973) have applied Palm's general idea in studies of maintenance and system reliability. Alfredsson (1997) has clearly stated that the theorem is suitable to be applied when studying aircraft components. Airbus Industries (2002) apply the same theorem for average demands up to 10 but suggest Gauss distribution to be used instead of Poisson when demand exceeds that value. Using Gauss distribution would not change the results significantly as far as the service levels are higher than 75%.

For the component failure process to be a Poisson process it is assumed that the failure process is independent of the number of spare units available. This assumption is typically violated if there are shortages in the system, since shortages momentarily reduce the number of operational units thus decreasing the demand of spare units. Nevertheless, this assumption is commonly acknowledged when the expected number of shortages is small compared to the number of units in the spares supply (Graves, 1985).

Using Poisson distribution it is possible to calculate the probability for a certain number of unscheduled removals occurring during a certain time period (Alfredsson, 1997). If the time period is set equal to Repair TAT, the formula is as follows:

$$p(k) = \frac{D^k e^{-D}}{k!}, \tag{1}$$

where D equals the expected demand of spare units during TAT, k equals the number of unscheduled removals during TAT, e equals the base for the natural logarithms and $p(k)$ equals the probability of exactly k unscheduled removals to happen during TAT.

As $p(k)$ is the probability of exactly k unscheduled removals happening during the repair TAT, it is by definition also the probability of exactly k units to be in repair at any given moment. It can also be seen that $p(k)$ equals the probability of exactly $u-k$ spare units being left in the spares supply at any given moment, where u stands for the total number of spare units and $u \geqslant k$.

The demand is caused by the unscheduled removals that occur during the repair TAT. So the expected demand D also means the expected number of unscheduled removals during the repair TAT. It can be calculated as follows:

$$D = \frac{\text{TAT}}{\text{MTBUR}_{\text{ct}}}\text{QTYU}, \tag{2}$$

where TAT equals repair TAT of the component, MTBUR_{ct} equals the MTBUR of the component in calendar time, QTYU equals the number of units supported by the spares and D equals the expected demand of spare units during TAT.

At this point it is necessary to introduce two new concepts. They are the expected risk of shortage and the expected confidence of no shortage. The expected risk of shortage $r(u)$ concerning a spares supply with u units, gives the share of the number of times a shortage is expected on a certain component when this very component is requested from the supply. It is assumed that the service discipline (Walrand, 1988; Baccelli and Brémaud, 1987) of the shortage queuing system is plain FIFO. This means that, in case of a shortage, every unit coming from repair is delivered to fulfill the shortage that occurred first, i.e. the one that has been waiting for the longest time. Some references use the term priority rules instead of service discipline (Jardine, 1973).

The expected confidence of no shortage or just expected confidence $c(u)$ concerning a spares supply with u units, is the inversion of the expected risk of shortage $r(u)$. Since both $c(u)$ and $r(u)$ are relative measures, this means that $c(u) + r(u)$ equals 1. The measures $c(u)$ and $r(u)$ are usually expressed as percentages.

It can be seen that the expected confidence of a spares supply with k units $c(u)$ equals the probability of less than u units being in repair at any given moment. Similarly the expected risk of shortage $r(u)$ equals the probability of exactly u or more units being in repair at any given moment. The corresponding formulas for values of $u > 0$ are as follows:

$$c(u) = \sum_{n=0}^{u-1} p(n), \tag{3}$$

$$r(u) = \sum_{n=u}^{\infty} p(n) = 1 - c(u), \tag{4}$$

where u equals the number of units in spares supply, $p(k)$ equals the probability of exactly k units to be in repair at any given moment, $c(u)$ equals the expected confidence of no shortage with u units in spares supply and $r(u)$

Table 1
Results of a basic availability example

k/u	Probability $p(k)$	Expected confidence $c(u)$ (%)	Expected risk of shortage $r(u)$ (%)
0	0.681430	0.00	100.00
1	0.261370	68.14	31.86
2	0.050126	94.28	5.72
3	0.006409	99.29	0.71
4	0.000615	99.93	0.07
5	0.000047	99.99	0.01
6	0.000003	100.00	0.00

equals the expected risk of shortage with u units in spares supply.

With zero units in spares supply, the expected confidence of no shortage $c(0)$ equals zero, since there cannot be any fulfilled requests with no spares. Consequently, the expected risk of shortage $r(0)$ equals one.

An example illustrates the application of the formulas above. If the repair TAT of a component is 14 days, its MTBUR is 730 days and the number of units supported is 20, the average demand of 0.38356 can be calculated for it using (2). Using Eqs. (1), (3) and (4) it is possible to calculate the expected confidences and risks of shortage for this demand with different number of spare units. The results can be seen in Table 1.

When describing the formulas, it was assumed that the service discipline of the shortage queuing system is FIFO. If this assumption is held, the service level of the spares supply $s(u)$ equals the expected confidence $c(u)$. With this observation the formulas described above form a basic model, using which it is possible to explore the effects of the four initial factors on the number of spare units needed.

2.2. The impact of the factors on inventory levels

The basic model is first used to produce graphs picturing the relative effect of each factor on the number of spare units needed. A suitable relative measure for comparing the factors is the number of spare units needed per each unit supported by the spares supply. The following figures present this measure as a function of each of the four factors. In each figure two factors remain constant and one factor is given three different values, while the factor under examination is given a selection of values.

Fig. 3 shows that it is possible to decrease the need of spares by increasing the reliability of the component. As the reliability of an aircraft component is heavily dependent on the quality of its design and manufacturing, an advisable situation for an airline to affect this factor is an initial provisioning process of a new aircraft type or another occasion, including selection of new

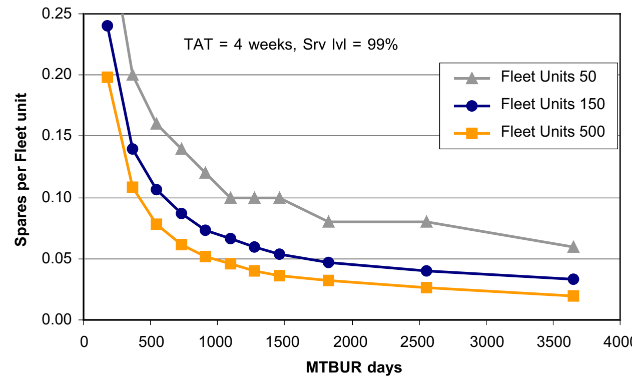


Fig. 3. Spares per fleet unit as a function of MTBUR days.

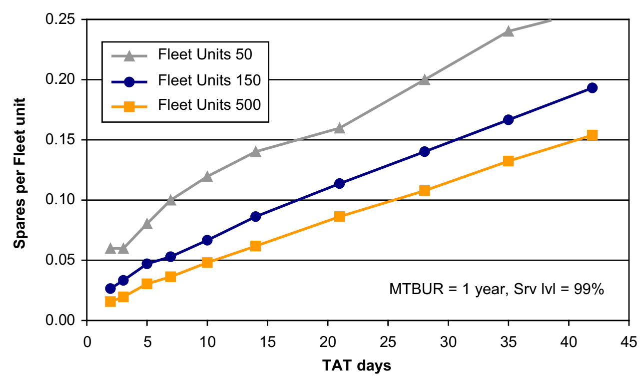


Fig. 4. Spares per fleet unit as a function of the repair TAT days.

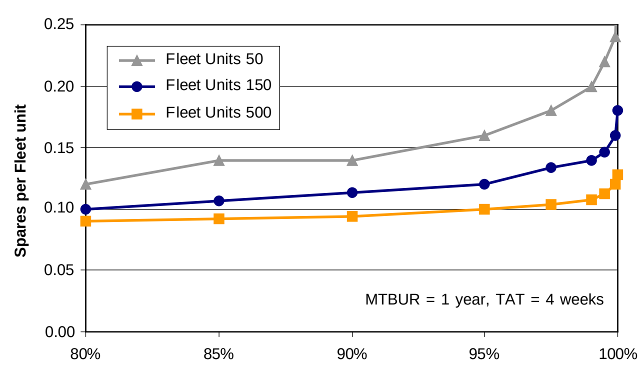


Fig. 5. Spares per fleet unit as a function of the service level.

components. Concerning components already in use, there are maintenance related means to increase the reliability, like applying optimal inspection, overhaul and replacement intervals (Jardine, 1973).

In Fig. 4 it is clearly visible that the relative spare need is directly proportional to the repair TAT as the curves are upward sloping and more or less linear. Thus it is possible to decrease the relative need of spares by squeezing the repair TAT.

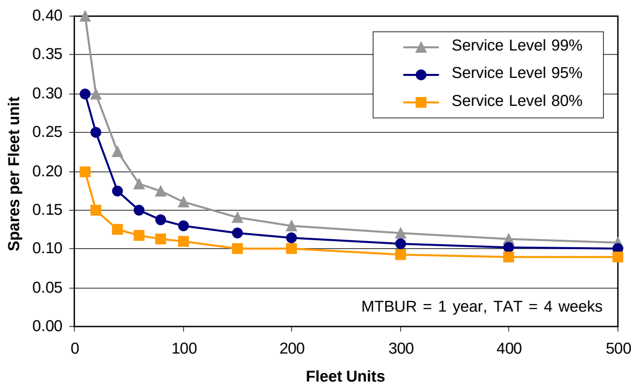


Fig. 6. Spares per fleet unit as a function of the number of fleet units.

Fig. 5 shows that it is possible to decrease the relative need of spares by decreasing the required service level. As can be seen in the curve, there is a considerable increase in the need of spares above the service level of 95%. The closer the service level gets to 100%, the more extra spares are needed per each fraction of a percentage unit.

In Fig. 6 it is clearly visible that increasing the fleet size decreases the relative need of spares. As can be seen from the steepness of this curve compared to the others, this factor has a very strong effect on the spare need. It is the number of fleet units in particular which can be affected by the make–buy–sell decisions of the component availability.

3. Fictional example of airline cooperation

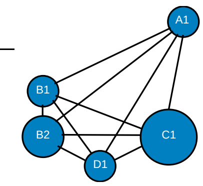
To illustrate the effects of cooperation in component availability, it is necessary to present a fictional example. In this example there are four airlines (A, B, C and D) operating the same aircraft type from five different bases in the same geographical area. These airlines have decided to cooperate in providing availability of one commonly used aircraft component Z. Their plan is to pool their spare component inventories in effort of reducing the total number of spare units needed and effectively lowering the capital tied into owning them.

Airline B operates the aircraft type from two different bases (B1, B2). Each of the other three airlines operates from a single base (A1, C1, D1). The component Z in the example has been chosen so that there are four identical units of Z installed in each aircraft. The fleets of each airline are shown in Table 2. Beside the table there is a figure showing the fleet sizes and geographical locations of each base.

The component manufacturer provides the mean time between unscheduled removal (MTBUR) of 6570 flight hours for component Z. It is assumed in this example that the four airlines all have an equal level of aircraft

Table 2
The fleets and geographical setting of the example

Airline	Base	Fleet aircraft	Fleet units
A	A1	20	80
B	B1	45	180
	B2	15	60
C	C1	60	240
D	D1	25	100



utilization and fly their aircraft on the average nine flight hours each calendar day. This produces an effective MTBUR of two years or 730 calendar days for component Z.

Even if in theory there is an equal chance per each flight hour and landing for a component to fail, most of the component removals are actually performed in the airline's own base. This is because most of the component failures do not compromise flight safety or require immediate actions. The costs of replacing a component in a foreign location are also very high in form of expenses associated with return flight delay as well as transportation of service personnel and required parts. In this example it is assumed that all the component removals are performed in each airline's own base.

In this example the repair TAT for component Z is assumed to be three weeks or 21 calendar days regarding each of the four airlines. Although it is not significant here where or by whom the repair work is performed, it is necessary to notice that after repair the component always returns to the same base where it was removed after failure.

3.1. *Modeling an inventory pool*

Different inventory models for repairable items have been introduced by a number of authors. Among those models Lee (1987) and Dada (1992) consider the idea of inventory pooling. With certain restrictions these models can be used to approximate transactions and stocking levels in inventory systems that include pooling. Here the basic model of component availability is applied to illustrate how cooperating airlines can pool their spare component inventories. The initial situation before pooling is that each airline holds its own inventory in its base. The basic model can be used to calculate how many spares each base needs to maintain acceptable service level.

In a pooling arrangement the combined inventory of all the participants can be treated like one spares supply even if it is located in five different bases. This observation was also made by Lee (1987). The basic model can now be used to calculate how many units the cooperating airlines together need to maintain the same acceptable service level as before. This total number of spares they may distribute between the bases as they please.

Since the bases of the cooperating airlines in this example are located apart from each other, the pooled inventory cannot serve them as quickly and effortlessly as an unpooled inventory could. If the spare unit request cannot be fulfilled from local inventory, an emergency transshipment from another base is performed. The whole idea of pooling separate inventories depends on emergency transshipments, because they offer means for one base to exploit an inventory that is located in another base. For the basic model of component availability to work, it is assumed that every emergency transshipment is sooner or later returned. This means that when the receiving base of the emergency transshipment later on regains units in its inventory, it sends one unit back to the sender of the emergency transshipment.

Even if all reasonable means are used to hasten emergency transshipments, they are always slower than deliveries from the local inventory. This means that the airlines have to accept logistics delays regarding the spares deliveries from other bases than their own. The maximum logistics delays of the emergency transshipments between the bases are shown in Fig. 7. The delays in the figure are fictional but could easily represent a typical European setting.

The logistics delays between two different bases range from 5 to 12 h. In addition to the actual flight time and waiting for the flight to depart, the delay consists of locating the unit, packing, loading, unloading and finally receiving and unpacking it. A1 and D1 form the only pair of bases with the longest delay of twelve hours. One-hour delay is assumed in the most common case when the request for spare unit can be fulfilled in the base where it was made.

Component Z is assumed to have an important role in the aircraft dispatch reliability, so its service level requirement is relatively high. It is assumed that all the airlines in the cooperation agree on the service level requirement of component Z being at least 99% without pooling. In the pooling arrangement the service level requirement is set so that it should be at least 99% regarding the combined inventory. It is also important not to totally compromise the internal service level in any of the bases. Because of that the service levels provided by the local inventory in each base should exceed 75%.

Origin \ Destination	A1	B1	B2	C1	D1
A1	1	11	10	9	12
B1	11	1	5	7	8
B2	10	5	1	6	6
C1	9	7	6	1	6
D1	12	8	6	6	1

Fig. 7. Maximum logistics delays between bases (in hours).

3.2. Results of the example

In Table 3 there are the spare units and service levels of the separate bases in an initial situation, when there is no cooperation between the airlines. 12-hour service level in the right hand column means the service level that is achieved with a maximum of 12-hour logistics delay. As can be seen in the table, inventory pooling is already used by airline B between its own two bases.

Regarding airlines A, C and D, the basic model of component availability is applied to their fleets separately. As a result the number of spare units that offers a service level of at least 99% is found. For airline B the model is first applied to the combined fleet of bases B1 and B2 in effort of determining the total number of spares offering the acceptable 12-hour service level. The spares of airline B are then divided between the two bases by applying the model to the separate fleets and finding as equal service levels as possible.

Considering the airline cooperation setting, the model is first applied to the combined fleet in effort of determining the total number of spares offering the acceptable 12-hour service level. The total number of spares is then divided between the five bases by applying

Table 3
Spare units and service levels without cooperation

Airline	Base	Fleet units	Spare units	Service level 1 h (%)	Service level 12 h (%)
A	A1	80	7	99.06	99.06
B	B1	180	10	96.12	99.49
	B2	60	5	96.87	99.49
C	C1	240	15	99.49	99.49
D	D1	100	8	99.05	99.05
		660	45	98.12	99.32

Table 4
Spare units and service levels with cooperation

Airline	Base	Fleet units	Spare units	Service level 1 h (%)	Service level 12 h (%)	Spares down (%)
A	A1	80	4	79.91	99.31	43
B	B1	180	8	84.74	99.31	20
	B2	60	4	90.29	99.31	
C	C1	240	10	84.01	99.31	33
D	D1	100	5	83.55	99.31	38
		660	31	84.50	99.31	31

the model to the separate fleets and finding as equal service levels as possible. This is done keeping in mind that the service levels provided by the local inventory in each base should exceed 75%. In Table 4 there are the spare units and service levels of the separate bases in a cooperative situation.

As can be seen by comparing Tables 3 and 4, the total number of spares needed has decreased by over 30% by sacrificing 10–20 percentage units of one-hour service level. Every participant has gained in inventory carrying costs, small ones relatively more than large ones. If the one-hour service levels in the bases seem arbitrary, it is because each base can only accommodate whole spare units and adding or subtracting one unit significantly changes the service level. In an optimal situation, however, the one-hour service levels are equal among the bases. If the cooperation is expanded to concern a large number of components, the deviations between one-hour service levels of different components balance each other.

Even if the one-hour service levels are considerably lower in the cooperative setting, it very seldom takes full 12 h to satisfy a spare need. Actually only bases A1 and D1 may experience delays that long. It is easy to see that a centrally located base generally experiences shorter logistics delays than a remote base.

One-hour service levels are achieved by using local inventories. Emergency transshipments are performed to achieve 12-hour service levels. There are a number of possible sourcing rules to be used when selecting the supplying base of an emergency transshipment. Some usable sourcing rules are presented in the following list:

- Select randomly between the bases with sufficient inventory;
- Select the base with shortest logistics delay and sufficient inventory;
- Select the base with relatively highest available inventory; and
- Select the base with sufficient inventory according to preset priorities.

The sourcing rules can also be combined so that one is selected as a primary rule and another as a secondary rule to be used if the primary one results in a tie.

The random selection is probably the least biased one towards any of the cooperating airlines in the long run, since no base will be preferred at any time. The second alternative minimizes the logistics delay, but clearly favors remote bases. The third alternative minimizes the harm that could be caused for the availability in the supplying base. Regarding this alternative it is for obvious reasons important to use relative inventory measures instead of absolute ones. The sourcing rules could also be set so that they favor one or other base in a premeditated way. As airlines with relatively large fleets gain less from the cooperation than their smaller partners, it is possible to compensate them by making the sourcing rules more favorable for them. It seems that the models of Lee (1987) and Dada (1992) would be suitable for determining the effects of different sourcing rules.

After applying the model to various different cooperation settings certain conclusions can be drawn. It can be seen that the savings potential of the cooperation is directly proportional to the number of its participants, assuming that the participants' fleets are reasonably similar in size. On the contrary, the one-hour service levels are inversely proportional to the number of the participants in the cooperation. It is possible to see that there is a saturation point in the number of cooperation participants when the one-hour service levels approach the 75% limit.

The cost level achieved by the participants is determined quite intuitively by the total fleet size of the cooperation. It also seems that, the smaller the airline's fleet is in comparison to the total fleet size of the cooperation, the higher is the savings potential for that particular airline. On the other hand, the more similar the sizes of the cooperating airlines are, the higher is the savings potential of the total cooperative effort. Even two airlines with fleets of equal size can realize considerable savings by cooperating with each other.

3.3. Managerial implications of inventory pooling

In practice a cooperative effort like the one illustrated in this example requires certain prerequisites to be fulfilled. The most important one is a common forum, some event or working group that makes it possible to start planning cooperation. In today's environment in the aviation industry the alliances are gathering airlines around the same table. Between alliance partners it is easier to initiate a cooperative effort like this than it would be between separate airlines possibly competing against each other in various business areas.

Doz and Hamel (1998) have stated that the playing field in alliances is generally very unstable and turbulent. Today's partner may be tomorrow's rival. In another study they have emphasized that successful companies should never forget that their partners' aim may be to disarm them (Hamel et al., 1989). This uncertainty leads into avoiding such cooperative arrangements that could be damaging if the relationship abruptly changes. Kleymann and Seristö (2001) have concluded that one challenge in an alliance relationship is to learn to balance the cooperative benefits and the loss in flexibility and sovereignty. Gulati (1995) has stated that mutual trust between partners counteracts fear of opportunistic behavior, thus reducing the transaction costs associated with the relationship. These challenges of cooperation need to be addressed before entering into inventory pooling arrangement.

A major obstacle between isolated spare inventories and cooperative setting is that airlines with relatively large fleets have less incentive to participate in cooperation than airlines with smaller fleets. In absolute terms all the players achieve the same cost level but smaller participants descend from much higher level. This contradiction leads to cooperation between reasonably equally sized participants or, in the case of unequal sizes, to some method of compensation from relatively small partners to their larger counterparts. Future research needs to examine how the differences in participants' incentives affect the composition of the cooperative arrangements.

Airlines have a long history of customizing their aircraft (Feldman, 2000), thus providing the industry with a huge variety of differently configured planes all looking the same from the outside and almost the same from the inside. There has been an ongoing argument among the airlines and aircraft manufacturers about the standardization and its potential benefits, but so far not much has changed. This means that it is a major challenge for airlines to find common components to cooperate with, even if they are operating the same aircraft type. In the long run the cooperating airlines could give in to some level of standardization when configuring new aircraft or planning modifications to the existing fleets.

Historically airlines are quite suspicious about each other's maintenance philosophies and the quality of their maintenance work. Before starting to cooperate, the airlines should agree on common standards concerning all maintenance related issues of the components in question.

To provide reliable and stable delivery times between every base in the cooperation, a streamlined logistics system is needed. A commonly accessible IT system is required for providing transparent real-time information about the stock levels in the bases. If the airlines actually cooperated in providing availability for only one component, the cost of logistics and IT systems could be prohibitive. It is, however, assumed here that real life cooperation would concern such a large number of components that the cost of maintaining logistics and IT systems would be negligible in comparison to the inventory savings.

The bases of the cooperating airlines are tightly connected with their own flights, which can normally transport one or two components at very short notice and with not much extra cost. For the logistics system to work it needs procedures for issuing and receiving spare components efficiently. Like many other industries, the aviation industry is also building electronic marketplaces such as Cordiem and Aeroxchange in the internet (Mecham, 2002a, b). These marketplaces are beginning to offer services like inventory listing with near-on-line updating and partner specific viewing rights, which would be quite adequate for supporting inventory pooling.

4. Concluding remarks

Based on the scale economies in the component availability service, a conclusion can be made that even relatively large airlines should stay away from the pure make alternative in the make–buy–sell decision. Preferred options include subcontracting (buy), service providing (sell) and inventory pooling (buy and sell combined).

It has long been known that inventory pooling between airlines in the area of spare components would be a source of definite savings. It has been shown here that in a perfectly feasible pooling arrangement the inventory levels can be decreased by over 30% by making a minor sacrifice in short time service levels. Furthermore, proactive replenishments and new repair priorities can compensate for this sacrifice. Transshipments from bases with available inventory could replenish the stock before it reaches zero, thus reducing the need for emergency transshipments. Service disciplines other than FIFO, that has been reported here, can be used not only to improve service levels but also to reduce costs with the same number of spare components.

The combination of the undeniable awareness of the beneficial effects of cooperation and reluctance of exploiting its potential is a situation with long history but reasonably short foreseeable future. In today's highly cost sensitive and competitive business environment it should not take too long for airlines to start overcoming the obstacles and adding the pooling of spare components into their widening selection of cost reduction methods.

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