Appendix B

DERIVATION OF PRICING RECOMMENDATIONS

In this appendix, we derive the pricing recommendations found in Chapter Five. Through five cases, we illustrate the effects of various pricing schemes on the behavior of commands and wings and the cost of that behavior to the Air Force. These cases were chosen to capture many of the characteristics of repair activities within the Air Force depot maintenance system. In the first case, the DLR has only one type of repair that can be performed at either the local level or at the depot. In the second, the DLR may need an easy or a difficult repair. The easy repair can be done at the local level; however, the difficult repair can be done only at the depot level. In the third case, the DLR is an avionics box that can be screened at the local level. The box contains only one electronic card, so cannibalization is not possible. In the fourth case, the avionics box contains two cards; therefore, wings can alter the condition of the returned carcasses through cannibalization. In the fifth case, the wing can affect the probability that a mechanical item is condemned. Effort to reduce the condemnation rate is costly to the wing. Table B.1 summarizes the main attributes of these cases.

In each case, we first examine the costs of depot-level repair and local repair to the Air Force. Next we examine the costs of the two sources of repair to customer commands and wings based on the current structure of DLR prices. We then demonstrate that the current price structure distorts customer incentives toward local repair (or, in case 5, a higher probability of condemnation). Finally, we examine customer incentives based on the multipart pricing scheme for DLRs recommended in Chapter Five. In each case, the recom-

Table B.1

Summary of Illustrative Cases

Case	Condemnations	No. of Different Repair Actions	Possible Wing Actions Affecting Repairs at Depot
1	No	1	None
2	No	2	Sorting
3	No	2	Sorting
4	No	3	Cannibalization
5	Yes	2	Change condemnation rate

mended pricing scheme leads customers to take actions that are cost-effective for the Air Force.

At the end of Appendix B, we derive the cost of exchanging an unserviceable for a serviceable DLR when the item is in excess supply.

CASE 1

In case 1, the reparable is an item that has only one type of repair. When the item does not perform correctly in the aircraft, it is removed at the flight line. The repair can take place either locally (at the wing level) or at the depot. We assume that the item is never condemned. For simplicity, we assume that the command has only one wing and that the command decides whether or not to provide repair resources to the wing no more than once a year. Thus, costs are calculated on a yearly basis.

Air Force View of Costs

If the wing does not have its own repair capability, the Air Force expects the annual repair cost for this NSN attributable to the wing to be $F_d + Nr_d$,

where F_d is the yearly fixed cost associated with having depot-level repair for this NSN attributable to the wing;[1]

[1]The wing's portion of depot-level fixed costs can rise or fall as the total number of customers decreases or increases. Also, F_d may be small if not many fixed costs can

N is the expected number of items that the wing will have to remove from its aircraft during the year; and

r_d is the marginal cost of depot repair (to include direct labor, direct material, pipeline inventory, transportation, etc.).

This cost includes the wing's share of the fixed cost of the depot repair capability and the expected marginal cost of repairing the unserviceables exchanged by the wing.

If the command establishes (or maintains) a wing-level repair capability, the wing will repair each unserviceable item and have no dealings with supply for this DLR as long as the wing's marginal cost of repair is less than the DLR exchange price. In this case, the Air Force anticipates that the command and wing will incur costs for the year equal to $F_w + Nr_w$,

where F_w is the yearly fixed cost associated with having wing-level repair; and

r_w is the marginal cost of repair at the wing (to include direct material, manpower, etc.).[2]

This cost includes the fixed cost of having the repair capability at the wing, and the expected marginal cost of repairing unserviceable units at the wing. We assume that the depot incurs no repair cost for this DLR that can be attributed to the wing.

Comparing the two costs, we find that the total cost to the Air Force for the year is lower with local repair than without when

$$F_w + Nr_w < F_d + Nr_d .$$

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be allocated to specific NSNs. We assume that F_d is not proportional to demand for the NSN. However, adding this complication would not change the essential nature of the conclusions of the analysis.

[2]For organic repair, we include manpower costs in marginal rather than fixed costs, despite manpower strengths being fixed in any fiscal year, because there are alternative uses for manpower. The marginal cost of local contract repair is the price charged to the wing.

This holds when the expected total cost of repairing these items locally is less than the expected total cost associated with depot repair.[3]

Customer Decisionmaking Under Current DLR Price Structure

Under the existing pricing structure, there is a single exchange price, P, for each item. If the wing does not have its own repair capability, the command expects the wing to pay NP because it must exchange each unserviceable item. If instead the command provides the wing with its own repair capability, the command sees costs equal to $F_w + Nr_w$ because it pays all the costs of local repair (directly through equipment and manpower and indirectly through the wing's maintenance budget). The command will thus find that it is less costly for the wing to have its own repair capability when

$$F_w + Nr_w < NP .$$

This occurs when the expected cost associated with repair at the wing is less than the expected payments for depot-level repair.

This fixed pricing scheme will give commands excessive incentives to provide wings with their own repair capability when $P > r_d + F_d/N$, as is the case for most items under the current DLR pricing scheme. However, when there is uncertainty about the exact value of N, the command may have an excessive incentive to repair locally even if $P = r_d + F_d/N$.

If the realized number of repairs, N', exceeds the expected value, N, the command will pay too much to the depot; that is, the depot will overrecover its costs by $(N' - N)\left(F_d/N\right)$, where $N' - N$ is the amount by which the actual number of repairs exceeds the expected

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[3]We recognize that there are strategic non-cost-related concerns associated with level-of-repair decisions. This aspect of the decision could be easily addressed in the following way. Let V_w denote the value associated with local repair (in comparison to depot repair). For example, repair capability may reduce the risk of having planes that are not mission-capable because of supply backorders. This value is subtracted from the cost associated with local repair when comparing the cost of level-of-repair alternatives. For the rest of Appendix B, we will assume that level-of-repair decisions are based solely on costs.

number. If the realized number of repairs is less than expected, the command will pay too little and the depot will underrecover its costs. If the consequences of overpayment are serious, the command may be unwilling to take a chance of overpaying the depot and decide to provide the wing with its own repair equipment anyway. (For example, the wing may not accomplish its flying program if N' exceeds N and will save O&M funds if N' is less than N. In most instances, the penalty for not accomplishing the flying program will be greater than the benefit from achieving financial savings, so the command will prefer to provide wings with their own repair capability.)

Customer Decisionmaking Under Two-Part Pricing Structure

Now suppose that Air Force implements a two-part price structure for DLRs. The command must specify prior to the beginning of the year whether or not the wing will be sending unserviceable items of a given type to the depot. If it will be doing so (i.e., the command does not provide the wing with its own repair capability), the command is charged the yearly fee F_d for the yearly fixed costs of depot repair attributable to the wing. When the wing exchanges an unserviceable item for a serviceable one, it pays only the additional expenses incurred by the fund resulting from that transaction. That is, the wing is charged an exchange price $P = r_d$. If the wing will be repairing its own unserviceables of this type of item, the command pays nothing for depot-level repair, and the wing avoids paying the exchange price.

Under the new price structure, the command still expects itself and the wing to incur costs during the year equal to $F_w + Nr_w$ if the wing has its own repair equipment. However, if it does not provide equipment to the wing, the command now expects total cost to equal $F_d + Nr_d$, which is the expected cost incurred by the fund for that item on behalf of the wing. Therefore, under the two-part pricing scheme, the command will want to provide the wing with its own screening capability only when

$$F_w + Nr_w < F_d + Nr_d .$$

This means that when it is less expensive from the Air Force point of view to send all items that fail directly to the depot for repair, the command will have no financial incentive to maintain repair capability at the wing level. Conversely, when the Air Force benefits from local repair, the command will want to provide the capability.

We will now compare the ability of the alternative price structures to recover all costs associated with depot-level repair of an item. With a fixed single exchange price, total costs are best recovered by setting the price equal to the average cost of repair, $P = r_d + F_d / N$ (based on the expected level of demand). However, as noted above, costs will be over- or underrecovered if the realized level of demand differs from the estimate used to set the price. In contrast, costs are always recovered under the two-part price scheme. The fixed costs are paid up front, and the marginal cost of each repair is recovered as the repairs are performed.[4]

CASE 2

In case 2, the reparable item has two types of repairs: easy and difficult. The item might be a mechanical item that is out of alignment (easy repair) or have worn-down parts (difficult repair). The difficult repair can be performed only at the depot, but the easy repair can be made at the wing as well as at the depot. There are no condemnations.

If the wing does not have its own repair capability, each unserviceable item is exchanged for a serviceable one, and the wing pays the exchange price. If the wing has its own repair capability, it will examine each unserviceable to see if the failure was caused by the problem that is easy to fix. If so, the wing repairs it locally (as long as the marginal cost of local repair is less than the exchange price). If the item requires the difficult repair, the wing exchanges it for a serviceable item and pays the exchange price.

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[4]Depot labor is quasi-fixed even though it is included in the marginal cost of repair. Thus, realizations of demand that differ from the predicted level will lead to a mismatch between revenues and costs under either of the alternative price structures. Because the two-part price structure is designed to capture fixed costs exactly, the discrepancy between costs and revenues will be less under this structure than under the fixed single exchange price.

As in the preceding case, costs are calculated on a yearly basis.

Air Force View of Costs

If the wing does not have its own repair equipment, the Air Force anticipates incurring the following cost annually:

$$F_{1d} + N(1-p)r_{1d} + F_{2d} + Npr_{2d},$$

where F_{1d} is the wing's share of the yearly fixed cost associated with having depot-level capability for the easy repair;

F_{2d} is the wing's share of the yearly fixed cost associated with having depot-level capability for the difficult repair;[5]

r_{1d} is the marginal cost of performing the easy repair at the depot;

r_{2d} is the marginal cost of performing the difficult repair at the depot;

N is the expected number of items that the wing will have to remove from its aircraft during the year; and

p is the probability that a broken item will need the more difficult repair. This probability is assumed to be unaffected by the wing's actions.

The annual cost to the Air Force includes the wing's share of the cost of the repair capability at the depot and the expected cost of repairing each unserviceable unit from the wing.

If the command decides to supply the wing with its own repair capability, the command must notify the depot that the wing will not be sending any of the easy repairs during the year. In this case, the Air Force anticipates incurring costs for the year equal to

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[5]For some items, the capability to perform the difficult repair is sufficient to perform the easy repair. Thus, there would be a single fixed cost associated with any degree of depot repair.

$$F_{1w} + N(1-p)r_{1w} + F_{2d} + Npr_{2d},$$

where F_{1w} is the yearly fixed cost associated with having wing-level capability for the easy repair; and

r_{1w} is the marginal cost of the easy repair at the wing.

The Air Force's total costs include the cost of having the capability for the easy repair at the wing and the capability for the difficult repair at the depot, the expected marginal cost of performing easy repairs at the wing, and the expected marginal cost incurred by the depot for the items with difficult repairs that the wing exchanges.

Comparing the two costs, we find that the total cost to the Air Force for the year is lower with local repair than without when

$$F_{1w} + N(1-p)r_{1w} < F_{1d} + N(1-p)r_{1d}.$$

This holds when the expected cost of performing the easy repair at the wing is less than the expected cost at the depot.

Customer Decisionmaking Under Current DLR Price Structure

Suppose that the exchange price for an unserviceable is P, regardless of the repair needed. If the wing has its own repair capability, the command expects the following costs during the year:

$$F_{1w} + N(1-p)r_{1w} + NpP .$$

The command incurs a fixed cost associated with the local capability. The wing incurs a marginal cost of repair for each item that requires only the easy repair, and it pays the exchange price for each item that requires the difficult repair.

If the wing does not have its own repair capability, the command expects the wing to pay NP during the year because it must exchange each unserviceable item. The command will thus find that it is cheaper to provide the wing with its own repair capability when

$$F_{1w} + N(1-p)r_{1w} < N(1-p)P \ .$$

This occurs when the expected cost associated with the easy repair at the wing is less than the expected savings from not exchanging items that need only the easy repair. Thus, the command will provide the wing with its own repair capability for the easy repair when $P > F_{1w} / N(1-p) + r_{1w}$.

This fixed pricing scheme will give commands excessive incentives to provide wings with the capability to perform easy repairs when $P > F_{1d} / N(1-p) + r_{1d}$, that is, when the DLR price is greater than the average cost of performing an easy repair at the depot (based on the expected number of repairs). If $P = F_{1d} / N(1-p) + r_{1d}$, the command will provide the equipment to the wing only when it is the least-cost way to provide the easy repair from the point of view of the Air Force. Note, however, that the depot would not recover its costs if it charged this price. If the forecast of the number of easy repairs is correct, the depot would recover these costs, but it would lose money on the difficult repairs.

Customer Decisionmaking Under Two-Part Pricing Structure

Now suppose that the Air Force implements a two-part pricing scheme for DLRs. If the command provides repair capability to the wing, it notifies the depot that the wing will not be sending any easy repairs and is charged a yearly fee of F_{2d} for the wing's share of the yearly fixed costs associated with difficult repair at the depot level. If the command does not provide wing-level repair capability, the command pays a yearly fee of $F_{1d} + F_{2d}$. When the wing exchanges an unserviceable for a serviceable item (regardless of whether it has its own repair capability), it pays only the additional expenses incurred by the depot resulting from that transaction. That is, if the item requires only the easy repair, the wing is charged r_{1d}. If it requires the difficult repair, the wing is charged r_{2d}.

The command now expects itself and the wing to incur the following costs during the year if the wing has its own repair resources:

$$F_{1w} + N(1-p)r_{1w} + F_{2d} + Npr_{2d} \, .$$

The command pays for the repair capability at the wing and the wing's share of the cost of repair capability at the depot. The wing pays the marginal cost of easy repair locally, and the marginal cost of difficult repair at the depot (the wing sends in only items that need the difficult repair). If it does not provide equipment to the wing, the command expects total cost to equal

$$F_{1d} + N(1-p)r_{1d} + F_{2d} + Npr_{2d},$$

which is the expected cost incurred by the depot on behalf of that wing.

Therefore, under the two-part pricing scheme, the command will want to provide the wing with its own screening capability only when

$$F_{1w} + N(1-p)r_{1w} < F_{1d} + N(1-p)r_{1d}.$$

Under this pricing scheme, when it is less expensive from the Air Force point of view to send all of the unserviceables to the depot for repair, the command will have no financial incentive to maintain repair capability at the wing level. Conversely, when the Air Force benefits from local repair, the command will want to provide the capability. Finally, the customer pays the total cost that it imposes upon the depot maintenance system.

CASE 3

Case 3 is much like case 2. The DLR is an avionics LRU containing one SRU (an electronic card). When a failure is believed to have occurred, the avionics box is removed at the flight line; however, a removal does not necessarily mean that the electronic card needs to be repaired. The repair process consists of two steps. First, the box is screened to see whether the failure can be duplicated, implying that the card needs to be repaired. If the box fails the screen, the card is repaired and the box is returned to supply. If the failure cannot be duplicated, then the box is immediately returned to supply. Repair of electronic cards takes place only at the depot; however, wings can screen avionics boxes if they have the appropriate personnel and equipment. When a wing has this capability, it avoids exchanging boxes for which the failure cannot be duplicated. We assume that there are no condemnations.

Suppose that an avionics box has been removed at the flight line because of an indication of failure. If the wing does not have its own screening equipment and personnel, it pays the exchange price and exchanges the unserviceable box for a serviceable one. If the wing has its own screening capability, it screens the unserviceable box to determine whether it is a false failure. If the box passes the screen, the wing keeps it. If the box fails, indicating that the electronic card is broken, the wing pays the exchange price and exchanges the box for a serviceable one.

Air Force View of Costs

If the command does not provide the wing with its own screening capability, the expected cost to the Air Force during the year is

$$F_d + Ns_d + Npr_d,$$

where F_d is the wing's share of the yearly fixed cost associated with having depot-level screening and repair;

N is the expected number of avionics boxes that the wing will have to remove from its aircraft during the year;

s_d is the marginal cost of screening an additional box at the depot;

r_d is the true marginal cost of repairing one electronic card at the depot; and

p is the probability that the card in an avionics box will fail during the screening process given that it had problems at the flight line. This probability is assumed to be unaffected by the wing's actions.

The Air Force incurs the wing's proportion of the depot's fixed cost as well as the expected cost associated with screening and repairing the unserviceable boxes.

If the command provides the wing with its own screening equipment, the expected cost to the Air Force is represented by

$$F_w + Ns_w + F_d + Np(s_d + r_d),$$

where F_w is the yearly fixed cost associated with having wing-level screening; and

s_w is the marginal cost of screening an additional box at the wing.

The wing screens each box that is removed at the flight line. It keeps the box when it cannot duplicate the failure, and it exchanges the box when the card is bad.

The Air Force prefers the wing to have screening equipment when

$$F_w + Ns_w < N(1-p)s_d,$$

which holds when the expected additional cost incurred from screening at the wing is less than the expected cost of screening unserviceable boxes at the depot (the total number of broken electronic cards remains the same).

Customer Decisionmaking Under Current DLR Price Structure

Suppose that the wing is charged a fixed price, P, each time it exchanges an unserviceable box for a serviceable one. If the wing does not have the capability to screen boxes, the command expects the wing to incur a yearly cost of NP.

If the command provides the screening capability to the wing, it anticipates that its costs combined with those of the wing will equal

$$F_w + Ns_w + NpP.$$

The wing screens each box that is removed at the flight line prior to exchanging it and only exchanges those boxes with broken cards.

With a fixed price, the command will desire to provide the wing with its own screening capability when

$$F_w + Ns_w < N(1-p)P \,,$$

which occurs when the expected cost of the local screening capability is less than the expected cost of returning serviceable boxes to the depot. However, the Air Force as a whole saves only $N(1-p)s_d$, so the command will have excessive incentives (from the Air Force point of view) to provide the wing with its own screening capability when $P > s_d$. This inequality holds under current DLR prices. Exchange price $P = s_d$ aligns command and Air Force incentives, but this price leads to an underrecovery of the fixed cost of having the capability at the depot and the cost of repairing broken electronic cards.

Customer Decisionmaking Under Two-Part Pricing Structure

Now suppose that a two-part price system is put into place. The command pays a fee, F_d, to cover the wing's portion of the fixed cost of the repair capability at the depot. Each time the wing exchanges an unserviceable avionics box for a serviceable one, the wing is charged an exchange price that reflects the cost of the depot repair services required to restore the box to serviceable condition. If the wing turns in a box that passes the screening process at the depot, the wing is charged s_d. If the wing turns in a box with a broken card, the wing is charged $s_d + r_d$.

Although the Air Force's view of costs has not changed, the command views the cost of level-of-repair decisions differently under this price scheme from that under the fixed price scheme. When the wing must send all of its boxes to the depot because it does not have its own screening capability, the command expects costs equal to

$$F_d + N(1-p)s_d + Np(s_d + r_d) \text{ or } F_d + Ns_d + Npr_d \,.$$

When the wing has its own screening capability, the expected cost equals

$$F_w + Ns_w + F_d + Np(s_d + r_d).$$

These two expressions reflect the exact expected cost to the Air Force of each level-of-repair alternative. Thus, the command prefers to provide the wing with its own screening capability only when it is cost-effective for the Air Force, that is, when

$$F_w + Ns_w < N(1 - p)s_d,$$

which aligns command and Air Force incentives.

Through multipart pricing that varies according to the condition of the item, the Air Force provides total visibility of costs to the command. The command finds that it is cheaper for the wing to screen prior to giving a box to supply only when the Air Force saves money through local screening. Alternatively, if there are true economies of scale associated with screening at the depot, the command will recognize them.

CASE 4

Case 4 is much like case 3 except that each avionics box now contains two electronic cards, implying that cannibalization is possible. For simplicity, we assume that the cards are interchangeable; however, the results of the analysis are identical when they are not interchangeable. We are concerned only with a two-day period. At the end of the second day, the wing must not have any aircraft that cannot be flown because it needs an avionics box (as long as the wing supply contains serviceable ones), and the wing must not be holding an unserviceable box. There is no discounting.

Assume that an avionics box has been removed at the flight line because of an indication of failure. If the wing does not have its own screening equipment and personnel, it pays the exchange price and exchanges the unserviceable box for a serviceable one immediately. If the wing has screening capability, it screens the unserviceable box to determine how many electronic cards (if any) need to be repaired. If the box passes the screen, the wing keeps it. If both cards are broken, the wing pays the exchange price and exchanges the box for a serviceable one. If the box has only one broken card, the wing immediately draws a serviceable box from supply; however, it keeps the unserviceable one until the next day on the chance that another box will be removed and the broken cards can be consolidated. If no box is removed from another plane the next day, the wing returns the unserviceable box to supply. If another box is removed and it has one broken card, the cards are consolidated (a second serviceable box is not purchased), and the box with two broken cards is returned to supply. We refer to this as cannibalization. Assume that as long as the wing turns in a carcass before the end of the second day, it is charged the exchange price, rather than the standard price, for the serviceable box.

Air Force View of Costs

Suppose that an avionics box has just been removed at the flight line. If the wing does not have its own screening capability, the expected two-day cost to the Air Force is

$$F_d + s_d + 2p(1-p)r_d + p^2(2r_d) + \theta s_d + \theta\left(2p(1-p)r_d + p^2(2r_d)\right),$$

where F_d is the wing's share of the two-day fixed cost associated with having depot-level screening and repair;

s_d is the marginal cost of screening an additional box at the depot;

p is the probability that a card in an electronic box will fail during the screening process given that the box had problems at the flight line (we assume that cards fail independently of one another and that the wing cannot affect this probability);

r_d is the marginal cost of repairing one electronic card at the depot; and

θ is the probability that a second box will have problems within a day, given that one box has already been removed from an aircraft.

The Air Force incurs the wing's proportion of the depot's fixed cost as well as the expected cost associated with screening and repairing the unserviceable box(es) at the depot.

If the command provides the wing with its own screening equipment, the expected cost to the Air Force is represented by

$$
\begin{aligned}
&F_w + F_d + (1-p)^2\Big(s_w + \theta\big(s_w + 2p(1-p)(s_d + r_d) + p^2(s_d + 2r_d)\big)\Big) \\
&+ 2p(1-p)\left[\begin{aligned} &s_w + I + (1-\theta)(s_d + r_d) \\ &+ \theta\big(s_w + (1-p)^2(s_d + r_d) + 2p(1-p)(s_d + 2r_d) \\ &\qquad + p^2(s_d + r_d + s_d + 2r_d)\big) \end{aligned}\right] \\
&+ p^2\Big(s_w + s_d + 2r_d + \theta\big(s_w + 2p(1-p)(s_d + r_d) + p^2(s_d + 2r_d)\big)\Big),
\end{aligned}
\tag{1}
$$

where F_w is the two-day fixed cost associated with having wing-level screening;

s_w is the marginal cost of screening an additional box at the wing; and

I is the pipeline inventory cost associated with the day that the wing keeps a box with one bad card in hope of cannibalizing. The pipeline inventory cost of one LRU day is approximately equal to $(1/365) * (i + d) *$ FAC, where i is the yearly interest rate and d is the yearly depreciation rate.

The wing screens the box before deciding what to do with it. The third term in line 1 of Expression (1) shows the expected cost when the wing cannot duplicate the failure [which occurs with probability $(1-p)^2$] and thus keeps the box. In this case, the Air Force incurs the cost of screening the box at the wing and the expected cost of wing screening and depot repair associated with a second box that fails with probability θ. Line 5 of Expression (1) shows the expected cost when the wing immediately exchanges the box because screening indicates that it contains two bad cards (probability p^2). Here, the

Air Force incurs the cost of screening the box at the wing, the cost of screening the box and repairing the two cards at the depot, and the expected cost associated with a second box that may fail.

Lines 2–4 of Expression (1) show the expected cost when there is one bad card [probability $2p(1-p)$]. In this case, there is a chance of cannibalization (if another box comes in with one bad card). Thus, the wing holds onto the box in case another one fails. The Air Force incurs the cost of screening this box at the wing, the pipeline inventory cost associated with the wing's decision to hold onto the box, the cost of depot repair for this box if another box does not fail (probability $1-\theta$), and the expected cost of wing screening and depot repair if another box does fail (probability θ). If another box fails, then the Air Force incurs the cost of screening it at the wing. If the wing cannot duplicate the failure for the second box [probability $(1-p)^2$], the Air Force incurs the cost of depot repair for the first box. If the second box has only one bad card [probability $2p(1-p)$], the wing cannibalizes and sends only one box that contains two bad cards to the depot. If the second box contains two bad cards (probability p^2), the wing sends both boxes to the depot, and the Air Force incurs the costs of repairing both at the depot.

The Air Force prefers for the wing to have screening equipment and to cannibalize when

$$F_w + I2p(1-p) + s_w + \theta s_w < (1-p)^2 s_d + \theta(1-p)^2 s_d + \theta\left(2p(1-p)\right)^2 s_d .$$

The left-hand side of this expression is the costs associated with wing screening. The right-hand side of this expression is the depot costs avoided through wing screening. Depot costs are avoided because the wing sends fewer boxes to the depot when it screens and cannibalizes. Thus, the Air Force prefers for the wing to have its own screening capability when the costs avoided at the depot exceed those incurred at the wing.

Customer Decisionmaking Under Current DLR Price Structure

Suppose that the wing is charged a fixed price, P, each time it exchanges an unserviceable box for a serviceable one. If the wing does not have the capability to screen boxes, the command expects the wing to incur the following cost during the two day period: $P + \theta P$. This is the expected cost associated with the one unserviceable avionics box today and a possible box tomorrow.

If the command provides the screening capability to the wing, it anticipates that its costs combined with those of the wing will equal

$$F_w + (1-p)^2 \left(s_w + \theta\left(s_w + 2p(1-p)P + p^2 P\right)\right)$$
$$+ 2p(1-p)\begin{pmatrix} s_w + (1-\theta)P \\ + \theta\left(s_w + (1-p)^2 P + 2p(1-p)P + p^2\, 2P\right) \end{pmatrix}$$
$$+ p^2 \left(s_w + P + \theta\left(s_w + 2p(1-p)P + p^2 P\right)\right).$$

With this fixed price, the command will desire to provide the wing with its own screening capability when

$$F_w + s_w + \theta s_w < (1-p)^2 P + \theta(1-p)^2 P + \theta\left(2p(1-p)\right)^2 P \ ,$$

which occurs when the expected cost to the command of the local screening capability is less than the expected cost of replacing boxes that wing screening would identify as serviceable through the supply system.

Under the current DLR pricing scheme, $P > s_d$, and the command does not pay the increased pipeline inventory cost that the wing imposes upon the Air Force by holding a box for one day in an attempt to cannibalize. Hence, as in case 3, the command may provide screening capability to the wing even though it is not cost-effective from the Air Force's point of view.

Customer Decisionmaking Under Two-Part Pricing Structure

Now suppose that a two-part price system is put into place. The command is charged the wing's portion of the fixed cost of the repair capability at the depot, F_d. Also, the wing is charged exchange prices that depend on the state of repair of the item as well as the length of time between drawing a serviceable box from supply and turning in the unserviceable one. If the wing turns in a box when it requests a new one, the exchange price equals s_d if neither card is broken, $s_d + r_d$ if one card is broken, or $s_d + 2r_d$ if both cards are broken. If the wing requests a serviceable box today without simultaneously turning in an unserviceable one, the wing pays an additional cost, I, for holding the first avionics box.

Although the Air Force's view of costs has not changed, the command views the cost of level-of-repair decisions differently under this price scheme from that under the current one. When the wing sends all of its boxes to the depot, the command expects costs equal to

$$F_d + s_d + 2p(1-p)r_d + p^2(2r_d) + \theta s_d + \theta\left(2p(1-p)r_d + p^2(2r_d)\right). \quad (2)$$

When the wing has its own screening capability, the expected cost equals the cost in Expression (1) above. Expressions (1) and (2) reflect the exact expected cost to the Air Force of each level-of-repair alternative.

Through multipart pricing that varies according to the state of repair, the Air Force provides the command total visibility of costs. The command provides screening capability to the wing only if it is cost-effective for the Air Force. Alternatively, when there are true economies of scale associated with screening at the depot, the command will recognize those.

CASE 5

The reparable in case 5 is an item that is either repaired through a single repair process or condemned and replaced. (This analysis is generalizable to allow for varying degrees of repairs.) The wing cannot repair the item, but it can affect the probability that the item must be condemned through actions such as cannibalization and/or prolonged use that also reduce the total number of items that must be exchanged during the year. For example, the DLR might be a mechanical item that is repaired if not worn beyond a particular tolerance but must be replaced otherwise.

At the beginning of the fiscal year, the wing establishes maintenance policies that determine λ, the condemnation rate of the item. Assume that λ can take on only two values, $\lambda \in \{\lambda_L, \lambda_H\}$, where

$\lambda_L < \lambda_H$. Let $N(\lambda)$ be the expected number of items that the wing will have to remove from its equipment during the year. The function is decreasing in the condemnation rate λ, $N(\lambda_H) < N(\lambda_L)$.

Air Force View of Costs

Given a level of effort at the wing associated with condemnation rate λ, the expected total cost to the Air Force for the year is

$$F_d + N(\lambda)\left(\lambda FAC + (1-\lambda)r_d\right),$$

where F_d is the wing's share of the annual fixed cost associated with having depot-level repair;[6]

λ is the probability that the item must be condemned, which is a function of the wing's actions;

FAC is the expected cost of replacing a condemned item; and

r_d is the marginal cost of repairing the item at the depot.

The Air Force wants the wing to behave in a way that minimizes the expected total cost, that is, choose $\lambda \in \left\{\lambda_L, \lambda_H\right\}$ to minimize

$$F_d + N(\lambda)\left(\lambda FAC + (1-\lambda)r_d\right).$$

The Air Force prefers λ_L (the lower condemnation rate) when

$$F_d + N(\lambda_L)\left(\lambda_L FAC + (1-\lambda_L)r_d\right) < F_d + N(\lambda_H)\left(\lambda_H FAC + (1-\lambda_H)r_d\right),$$

or

$$\frac{N(\lambda_L)}{N(\lambda_H)} < \frac{\lambda_H FAC + (1-\lambda_H)r_d}{\lambda_L FAC + (1-\lambda_L)r_d}.$$

[6]There are many ways to allocate fixed costs. We assume that the allocation here is unrelated to a wing's demand, $N(\lambda)$.

Loosely speaking, this expression is true when the increase in the weighted repair/replacement cost resulting from the higher condemnation rate outweighs the savings from sending fewer items to the depot. Similarly, the Air Force prefers λ_H (the higher condemnation rate) when

$$\frac{N(\lambda_L)}{N(\lambda_H)} > \frac{\lambda_H FAC + (1-\lambda_H)r_d}{\lambda_L FAC + (1-\lambda_L)r_d}.$$

Thus the optimal choice of λ from the Air Force's point of view depends on the functional form of $N(\lambda)$ and the values of FAC, r_d, λ_H, and λ_L.

As an example, suppose that

$$\begin{aligned} FAC &= 40 \\ r_d &= 4 \\ \lambda_L &= .25 \\ \lambda_H &= .75 \\ N\left(\lambda_L\right) &= 50 \\ N\left(\lambda_H\right) &= 25. \end{aligned}$$

Then,

$$\frac{N(\lambda_L)}{N(\lambda_H)} = 2$$

(i.e., items must be removed twice as often to achieve the lower condemnation rate) and

$$\frac{\lambda_H FAC + (1-\lambda_H)r_d}{\lambda_L FAC + (1-\lambda_L)r_d} = 31/13,$$

which is approximately equal to 2.4. Thus, total cost to the Air Force is minimized when $\lambda = \lambda_L$. However, if instead $N(\lambda_H) = 20$, then the inequality is reversed, and the Air Force prefers $\lambda = \lambda_H$.

Customer Decisionmaking Under Current DLR Price Structure

We now propose two pricing schemes and examine the effects of each on the wing's choice of condemnation rate λ. First, suppose that the wing is charged a fixed exchange price, P, each time it exchanges an unserviceable item for a serviceable one. The wing expects to incur costs during the year equal to $N(\lambda)P$. Because the exchange price it pays is independent of the condition of the unserviceable unit, choosing $\lambda = \lambda_H$ always minimizes the wing's costs because it exchanges fewer items. Each unserviceable unit that it exchanges has the higher probability of being condemned. Note that this choice of λ is independent of the fixed exchange price charged, P. This implies that when

$$\frac{N(\lambda_L)}{N(\lambda_H)} < \frac{\lambda_H FAC + (1-\lambda_H)r_d}{\lambda_L FAC + (1-\lambda_L)r_d}$$

(so that the Air Force prefers λ_L), total repair costs to the Air Force will not be minimized because the wing chooses the higher probability of condemnation. For the example above, total variable costs for the two choices of probabilities of condemnation are

$$\begin{aligned} N(\lambda_L)\left(\lambda_L FAC + (1-\lambda_L)r_d\right) &= 50(13) = 650; \text{ and} \\ N(\lambda_H)\left(\lambda_H FAC + (1-\lambda_H)r_d\right) &= 25(31) = 775. \end{aligned}$$

Thus, by choosing λ_H, the wing increases variable costs by over 19 percent.

Customer Decisionmaking Under Two-Part Pricing Structure

Now suppose that the Air Force adopts a two-part pricing scheme. The command is charged a fixed fee, F_d, to cover the wing's portion of the depot's annual fixed costs associated with repair and replacement of this item, and the wing is charged a price that depends on the condition of the carcass that it exchanges for a serviceable item. When the unserviceable item can be repaired, the wing is charged r_d, and when it must be condemned, the wing is charged the item's FAC.

The costs faced by the Air Force have not changed, but the command and wing now anticipate costs equal to

$$F_d + N(\lambda)\left(\lambda FAC + (1-\lambda)r_d\right),$$

which are equivalent to the Air Force's costs. Therefore, when

$$\frac{N(\lambda_L)}{N(\lambda_H)} < \frac{\lambda_H FAC + (1-\lambda_H)r_d}{\lambda_L FAC + (1-\lambda_L)r_d},$$

the wing will choose condemnation rate λ_L, which is the optimal condemnation rate from the Air Force's point of view. Similarly, when

$$\frac{N(\lambda_L)}{N(\lambda_H)} > \frac{\lambda_H FAC + (1-\lambda_H)r_d}{\lambda_L FAC + (1-\lambda_L)r_d},$$

the wing will choose condemnation rate λ_H, which is optimal from the Air Force's point of view.

Through use of a multipart price scheme that depends on the state of repair, the wing chooses to exert effort to achieve the cost-minimizing condemnation rate from the Air Force's point of view, and total costs associated with repair and replacement of this item are recovered from both the wing and the command.

AN ITEM IN EXCESS SUPPLY

In this example, we derive the true cost imposed upon the supply system by a demand for a serviceable item that is in excess supply. Suppose that the Air Force desires to reduce its serviceable inventory of an NSN to k units because of factors such as increased efficiency in the repair shop, reduced transportation times, a reduction in the number of active aircraft, and so forth. There are currently m spares of this item in supply, with $m > k$. As a result of this new policy, the next $m-k$ unserviceables exchanged for the serviceable items will not be repaired and returned to the serviceable inventory. After the inventory is drawn down, unserviceables will be repaired and returned to the inventory. (The intention is that during peacetime the inventory will not be allowed to fall below k.) We assume that only one wing requires this NSN, and there is uncertainty about whether the wing will need a serviceable item each period.

Each time the wing draws a serviceable item from supply, it imposes a cost on the supply system by decreasing the time until the inventory of spares is depleted and repairs need to be resumed. Let $C(n)$ denote the discounted present value of all future repair costs (over an infinite horizon) given that there are currently n remaining spares. The function is decreasing in n for $n \geq k$ because additional spares extend the time until repairs are needed.

When $n = k$, the cost of drawing a serviceable item is r_d, the marginal cost of repairing one item at the depot. The discounted present value of costs when the k^{th} spare must be drawn (assuming the wing never needs more than one each period) is

$$r_d + \beta C(k).$$

β is the discount factor $1/(1+i)$, where i is the per-period interest rate. When $n = k$ and there is no demand during the period, no repair costs are incurred and the discounted present value of costs is

$$\beta C(k).$$

Letting θ denote the probability that the wing will need a serviceable item from stock this period, the expected cost associated with having k items in stock is

$$C(k) = \theta\left(r_d + \beta C(k)\right) + (1-\theta)\beta C(k)$$

or

$$C(k) = \theta r_d + \beta C(k),$$

which simplifies to

$$C(k) = \frac{\theta r_d}{1-\beta}.$$

For $n = k + 1$, no current repair costs are incurred when a spare must be drawn, but the stock of items in the next period is diminished by 1. Therefore, the cost of drawing the $k + 1^{st}$ item is the change in discounted present values

$$\beta\big(C(k) - C(k+1)\big).$$

If no spare is requested this period, $n = k + 1$ again next period. Thus, the expected cost associated with having $k + 1$ items in stock today is

$$C(k+1) = \theta\beta C(k) + (1-\theta)\beta C(k+1),$$

which can be rewritten as

$$C(k+1) = \frac{\theta\beta C(k)}{1-(1-\theta)\beta}.$$

More generally, when there are $n > k + 1$ spares, the cost of drawing a serviceable item from stock is

$$\beta\big(C(n-1) - C(n)\big).$$

Substituting

$$\theta\beta C(n-2) + (1-\theta)\beta C(n-1) \quad \text{for} \quad C(n-1)$$

and

$$\theta\beta C(n-1) + (1-\theta)\beta C(n) \quad \text{for} \quad C(n)$$

yields

$$\begin{aligned}\beta\big(C(n-1) - C(n)\big) = {} & \beta\big(\theta\beta C(n-2) + (1-\theta)\beta C(n-1)\big) \\ & - \beta\big(\theta\beta C(n-1) + (1-\theta)\beta C(n)\big).\end{aligned}$$

This can be rewritten as a function of θ, β, and r_d through the following simplifications:

$$C(n-1)-C(n)=\frac{\theta\beta\big(C(n-2)-C(n-1)\big)}{1-(1-\theta)\beta},$$

$$C(n-1)-C(n)=\frac{(\theta\beta)^{n-k-1}\big(C(k)-C(k+1)\big)}{\big(1-(1-\theta)\beta\big)^{n-k-1}},$$

and finally

$$C(n-1)-C(n)=\left[\frac{(\theta\beta)^{n-k-1}}{\big(1-(1-\theta)\beta\big)^{n-k-1}}\right]\left[\frac{\theta r_d}{1-(1-\theta)\beta}\right].$$

We draw on the lessons from cases 1 through 5 to derive exchange prices for the item that reflect the costs imposed upon the supply system when a wing draws a serviceable part. The appropriate exchange price charged for this item is

$$P(n)=\beta\big(C(n-1)-C(n)\big)\text{ for } n\geq k+1$$

$$P(n)=r_d \text{ for } n=k$$

where $P(n)$ is the price charged for a serviceable item when there are n spares.

Note that $P(n)$ is decreasing in n because $\theta\beta\big/\big(1-(1-\theta)\beta\big)<1$.