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Stockout Costs in Distribution Systems for Spare Parts

Arne Jensen

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Introduction

Stockout Costs in Theory

A stockout cost occurs when an item on a stocklist cannot be delivered directly from stock when required. Stockout costs are of significance in several fields within marketing and logistics.

A large number of mathematical decision models for inventory control have been developed within the field of inventory theory. The models normally include some form of stockout cost as a parameter. Empirical measurement of stockout costs with adequate precision is a prerequisite for the use of these models in specific applications. Decision models for inventory control have been dealt with in great detail in, for example, Hadley and Whitin[1], Naddor[2] and Silver and Peterson[3].

In the field of overall marketing theory, Kotler[4] and Lambert and Stock[5] use the concept of stockout cost to connect marketing's demand-stimulating activities with demand-fulfilling activities. When demand cannot be satisfied, stockout costs in a variety of forms, such as lost sales, are generally felt to arise as a result. In the context of vertical market systems, Baligh and Richartz[6] use stockout costs for deducing theoretical conclusions concerning vertical structures and price behaviour.

The past 20 years have witnessed increased interest in distribution costing (sometimes referred to as "logistics costing"), with resulting development and maturity of theory in this field. Reviews are provided by Schiff[7], Ray *et al.*[8], Christopher[9], and Stock and Lambert[10]. What is clear, however, is that the concept of stockout cost is not used as an operational concept within this theory.

Purpose

Stockout cost is an important theoretical concept, particularly within inventory control theory. At the same time, most authors of textbooks state that it is difficult to carry out empirical measurements of stockout costs and the concept is not used within the sphere of distribution cost control. For this reason, there is a distinct feeling of dissatisfaction with the fact that so few empirical studies have been devoted to this subject. Researchers have shown limited interest in steps which may contribute to the development of empirically founded theory and methodology regarding stockout costs and their measurement. This must be regarded as one of the reasons why many theoretically attractive inventory models have not been put into practice and why the concept is not used within distribution cost control.

The purpose of this study is to contribute to the development of the theory of stockout costs and their measurement in distribution systems. Within this framework, the study has focused on the following research issues:

- description of behaviour in stockout situations;
- structuring of stockout situations as a basis for the measurement of stockout costs;
- methods of measuring stockout costs;
- the effect of information about stockout costs on management attention and actions.

Only a few published studies include actual measurement of stockout costs. Some notable examples are Chang and Niland[11, pp. 427-47], Brandes[12] and Oral *et al.*[13, pp. 334-51].

Research has also been done in related fields. Miklas[14] proposes a method for researching customer response to stockout at the retail level. Ray and Millman[15] discuss stockout costs and how they are related to service levels.

Case Studies

Empirical research in this area is relatively limited. A case study approach has therefore been selected as the research method. There appears to be a need for a number of thorough case studies in different areas of application, in order to refine the theory of stockout costs and their measurement, and to establish the limits of the theory's practical relevance.

The case studies focus on the automobile trade's spare parts inventory system. Fieldwork was carried out in 1987 at three car workshops within the Catena Group. The Catena Group manages dealerships for Volvo in Sweden, Norway, Denmark, Germany and France via a network of subsidiaries. These subsidiaries sell cars and operate a large number of car workshops. Operations in Sweden dominate the picture, where Catena handles approximately 40 per cent of Volvo's sales. The spare parts warehouses surveyed supply adjacent workshops with parts and also sell parts directly to car owners and small, independent workshops (e.g. petrol stations). The workshops selected for the study differ as regards size and distance to Volvo's central spare parts warehouse. Two of the workshops are located in large cities (workshops A and B), while the third is situated in a small town (workshop C).

Theory Development

In the course of this study a theoretical framework was developed for the analysis of stockout costs. The first section defines the empirical situation for which the framework is relevant. This is followed by a general definition of the concept of stockout costs. Finally, a typology is presented which constitutes a tool for the classification of typical stockout cost situations. The typology is intended to facilitate the empirical measurement of stockout costs.

The Logistical System

The logistical system, which is the object of study, can be illustrated with the help of Figure 1. An independent economic unit (E) is part of a system created for the distribution of an assortment (Z) of m articles:

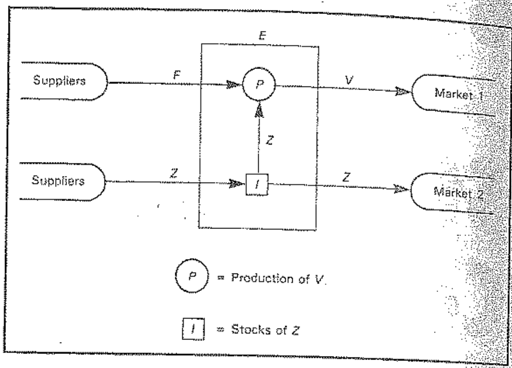
$$Z = (Z_1, Z_2, \ldots Z_m),$$

where Z_j denotes article number j.

Unit E stocks assortment Z and offers two outputs to external markets. The first output is the production of goods and/or services (V), with Z included as a production factor together with other production factors (F).

The production factors $F = (F_1, F_2, \ldots F_n)$, where F_j denotes production factor number j, encompass raw materials, components, personnel, etc. Product V is sold in market 1. Economic unit E also sells its assortment of articles Z directly from stock to market 2, which is the second output.

Figure 1. *The Logistical System*



Since stock-point I in the distribution system in Figure 1 meets both internal and external demand, the two main categories of structuring and measurement problems, which can arise in practical applications, are covered.

It is assumed that it is relevant to take into account the payment stream to and from E for sales and purchases respectively. This is naturally relevant if E is an independent entity, that is to say a company, but could also be relevant if E is a profit centre within a company, on the condition that the company employs a correct internal accounts system.

A central problem in the development of a stockout cost theory is the selection of a suitable entity to which costs can be allocated. The cost unit which is selected must have a wide coverage, be decision-oriented and at the same time permit measurability and computation of cost parameters. The cost unit concept which has been found to be the most suitable on the basis of this study is that of the stockout event. A stockout event is defined here to occur when a set of units from assortment Z are being requested by a source of demand on one occasion and at least a subset of these units cannot be supplied directly from stock in accordance with normal procedures.

It should be noted that a stockout cost will occur only if a stockout situation turns into shortage (at least one unit is needed which is unavailable). A stockout event thus implies shortage. Therefore stockout and shortage are considered to be synonymous concepts in this article.

The term "demand" includes both external demand from market 2 and internal demand from production P. The source of demand in the external demand situation is normally a customer, while in the internal demand situation this may be a production order or similar source.

A stockout event may be defined either as assortment-based (as in this study), relating to units of Z, or article-based, relating to units of Z_j. The cost per stockout event can easily be specified in greater detail if necessary, for example as a function of the magnitude and/or duration of shortage. Furthermore, it is easy to convert the cost per stockout event into a total cost per period or to express this cost as a unit-based parameter such as per unit or an article.

Main Theoretical Model

A theoretical definition of a stockout cost should be based on the differences between the financial results from two different sequences for a firm. The first is a sequence which results if a stockout event occurs; the second is a sequence which the company would have experienced had the stockout event not occurred.

To define the concept of stockout cost more precisely, a cost model must be developed. Assume that t represents time and that time is measured in sufficiently short periods for the analysis ($t = 1,2,3, \ldots$). Assume furthermore that a stockout event occurs during period $t = T$. The stockout cost can be calculated on the basis of a comparison between the incoming payment stream $R_2(t)$ and the outgoing payment stream $C_2(t)$ which actually arose, on the one hand, and on the other hand the incoming payment stream $C_1(t)$ which would have arisen had the stockout event not taken place.

$R_1(t)$ and $R_2(t)$ are defined as net payments which arise by subtracting from incoming payments for sales of Z and V, all those outgoing payments which arise from direct factor consumption and which can be traced to Z and V. $C_1(t)$ and $C_2(t)$ are thus the remaining outgoing payments. If E has other lines of business than sales of V and Z, it is assumed that the effect of them can be summarized in the contribution margin stream $P_2(t)$, given the stockout event, and $P_1(t)$, if the stockout event had not occurred. If necessary, the payment stream can be discounted to period $t = T$ with the help of a relevant discount rate.

The stockout cost B is now defined as the following difference in profit contribution:

$$
\begin{aligned}
B &= \sum_{t=T}^{\infty} [R_1(t) - C_1(t) + P_1(t)] \\
&\quad - \sum_{t=T}^{\infty} [R_2(t) - C_2(t) + P_2(t)] \\
&= \sum_{t=T}^{\infty} [R_1(t) - R_2(t) + \sum_{t=T}^{\infty} [C_2(t) - C_1(t)] \\
&\quad + \sum_{t=T}^{\infty} [P_1(t) - P_2(t)] \\
&= \Delta R(T) + \sum_{t=T+1}^{\infty} \Delta R(t) + \Delta C(T) \\
&\quad + \sum_{t=T+1}^{\infty} \Delta C(t) + \sum_{t=T}^{\infty} \Delta P(t) \qquad (1)
\end{aligned}
$$

Cost B for the stockout event consists according to (1) of an immediately occurring contribution margin loss $\Delta R(T)$ plus all future contribution margin losses which arise as a result of the stockout event $\Sigma \Delta R(T)$ plus the immediately occurring incremental cost $\Delta C(T)$ plus all future incremental costs $\Sigma \Delta C(t)$ plus all the contribution margin losses from other lines of business $\Sigma \Delta P(t)$.

Three major categories of stockout events can be discerned

In practical applications the term "immediately" will be interpreted to mean those effects which arise in the short term as direct consequences of the shortages. All other effects are regarded as future effects. Future contribution margin losses — to the degree they are regarded as significant — will probably be estimated with less detailed data collection and calculation, occasionally on subjective grounds.

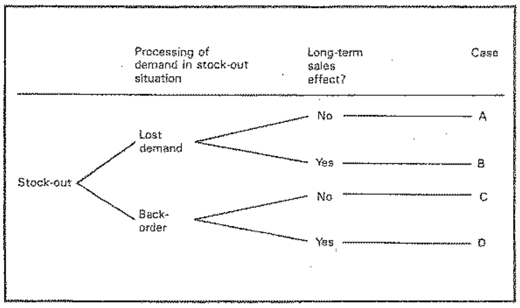
A Typology

Taking into account the composition of stockout costs and the prerequisites for measurement, three major categories of stockout events can be discerned. The first occurs in conjunction with external demand from market 2. The second category represents stockout events which occur in connection with internal demand. The third category, finally, consists of stockout events which can be rectified by adopting extraordinary measures. As a result, delivery can take place before negative consequences affect the demand sources.

Stockout in Conjunction with External Demand

In the event of external demand from stock, four cases can be discerned with due regard to the consequences of stockout (see Figure 2). In cases A and B, demand

Figure 2. *Stockout Consequences on External Demand*



which cannot be satisfied is lost. In case A, the stockout cost consists normally of the contribution margin which the company loses immediately as a result of the loss of demand. In case B, the stockout cost consists of the immediately lost contribution margin plus all future contribution margin losses which arise as a result of the stockout event. The long-term effects arise primarily from partial or total loss of future sales to the external demand units which are subjected to the stockout and also from possible consequential effects on other customers. No incremental costs normally arise owing to stockout in either case A or B.

In cases C and D, stockout leads to backorders, which means that there is no immediate loss of contribution margin which can be traced to stockout. In case C, the stockout cost therefore consists of all the incremental costs which the stockout causes compared with the normal supply situation (no stockout). Such incremental costs may arise as a result of additional work in conjunction with backorders, price rises or fees for special express order procedures, increased freight costs for express delivery, measures to prevent the loss of goodwill, etc.

Income loss is generated via mechanisms which differ

In addition to the incremental costs, stockout cost in case D consists of all future contribution margin losses which can be traced to the stockout event.

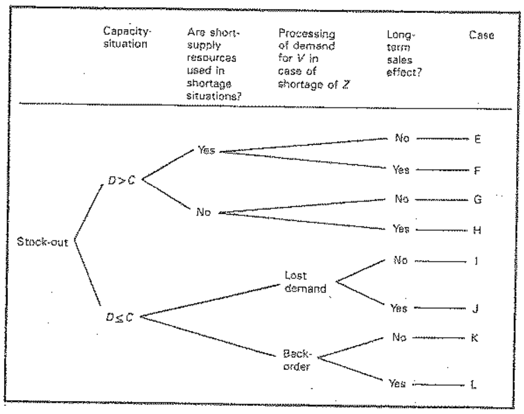
Stockout in Conjunction with Internal Demand

The internal demand situation assumes that articles from assortment Z are either included as components in V, i.e. in the output from the production system, or that they are used as spare parts in the production system. The typology which is constructed in this section covers both possibilities. The main assumption, however, is that Z is included as a component in V.

The empirical study reveals that the relationship between production capacity and demand for output from the production process is a variable which is central to the construction of a stockout cost typology. This is because immediate income loss as a result of stockout is generated via mechanisms which differ depending on whether demand (D) is greater than production capacity (C) or not. The typology which is constructed is shown in Figure 3.

In case E in Figure 3, demand is greater than production capacity ($D > C$). Among the production factors $F =$

Figure 3. *Stockout Consequences on Internal Demand*



($F_1, F_2, \ldots F_n$) there is a resource (let us say factor F_i) which is in short supply, which limits production of V and which is utilized if there is a shortage of Z. This results in an immediate reduction in sales of V which means loss of a value-added margin traceable to F_i. This may be defined as lost income minus cost savings caused by the stockout event. Cost savings resulting from stockout do not include costs for F_i, since they are not saved. Stockout cost in case E consists of the immediately lost value-added margin plus the incremental costs which accrue as a result of the stockout event. Since $D > C$, it is irrelevant if demand for V is lost or not owing to the shortage of Z. Lost demand can be immediately compensated by alternative demand which creates income (applies also to cases F, G and H).

Case F differs from case E only in that the stockout event is assumed to have a negative effect on future sales of V. The contribution margin lost in this context must therefore be included in the stockout cost for case F.

In case G, the stockout cost consists entirely of those incremental costs which accrue as a result of stockout, while in case H it is necessary to add to this the future contribution margin losses which result from a stockout.

When $D \leq C$, production capacity is assumed to be so much greater than demand that there is no production resource in short supply. If a shortfall of Z requires the use of production factor F_i, this on its own will not cause an immediate reduction in income. What is of significance, on the other hand, is whether a shortfall in Z causes lost demand or backorders (postponed production and delivery) for V. In cases I and J, the stockout cost consists of the immediately lost contribution margin from V (caused by Z stockout) plus those incremental costs which accrue as a result of the stockout. In addition, the stockout cost in case J also includes the contribution margin lost in the longer term.

Finally, cases K and L differ from cases I and J respectively only in that no immediate sales reduction is assumed to have taken place, since Z stockout results in backorders for V.

Adoption of Extraordinary Measures
This case (case M) implies that stockout is remedied by adopting extraordinary measures. The two sources of demand — market 2 and the internal production system — will not then feel the effects of any stockout. The extraordinary measure is generally specific to the situation at hand within the framework of the following three categories: supply from the normal supplier at very short lead time, acquisition from nearby supplier at very short lead time or acquisition from internal sources which are not normally intended to provide such a function. Stockout cost in case M consists of the incremental cost of implementing this extraordinary measure.

Empirical Measurement

Research Strategy

As we have seen, stockout cost is made up of a number of components. Data collection and costing were therefore organized by component. As expected, the cost accounting of the firms turned out to be unsuitable as a source of information for other than basic data.

The measurements have generally followed the method presented in Figure 4.

The "calculation model" component in Figure 4 varies with the cost component under review. One feature which it always includes is a rule for the calculation of the marginal cost per stockout event. In Figure 5, X_1 represents the number of stockout events per time unit at the time of measurement, while X_2 is the level which is assessed as attainable in the medium term, within three years, through management measures. K_1 and K_2 are total costs per time unit. X_2 has been estimated at half of X_1. The marginal cost is assessed as constant in the range between X_2 and $1.2X_1$.

Figure 4. *Cost Measurement Method*

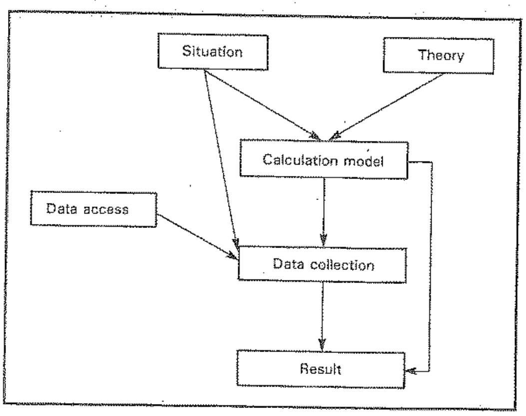
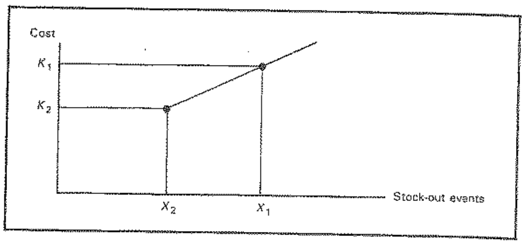


Figure 5. *Marginal Cost Model*



Measurement of the marginal cost within the framework outlined above has been based in most cases on either time and quantity studies, where the marginal resource requirement has been established directly, or on differential calculations where cost K_2 is calculated on the basis of specially collected data. With K_1 known (or easily calculated), marginal costs equal $(K_1 - K_2)/(X_1 - X_2)$.

The data collection methods which have been used are structured observation, quasi-experiments, interviews and internal secondary data.

Spare Parts Shortage in the Case of Internal Demand

In the workshops studied (and in other Catena workshops), spare parts shortage in the case of internal demand corresponds to case F in the typology. This means that demand for workshop services exceeds available production capacity, that the shortage of spare parts requires use of a resource in short supply and that shortage will have negative effects on future sales of workshop services. In the case of internal demand, a stockout event was defined to have occurred when a car could not be repaired according to the work order because of shortage of spare parts. The stockout event comprises those parts needed to execute the work order which cannot be delivered from stock according to normal procedures. A stockout event has been found to influence costs through the following effects:

(1) Lost value-added margin
(2) Increased resource consumption in the peripheral system, which consists of planners, customer reception staff, warehouse personnel and purchasers
(3) Special stockout-alleviation procedures
(4) Maintenance of goodwill through price reductions
(5) Maintenance of goodwill through provision of rental car
(6) Price rises owing to express order services
(7) Indirect effects
(8) Loss of workshop customers.

These effects therefore have been included as components in the stockout cost. In components (1) and (2) above, costs arise owing to the increased resource consumption which stockout causes in the workshop and the workshop's peripheral system. This increased resource consumption has been investigated in a comprehensive observation study.

For each workshop, measurements were taken during a representative three-week period of every work order featuring a spare parts stockout. A comparison was made of the amount of extra work time which was lost compared to a case in which there was no spare parts stockout. The study included both structured direct observation by a special observer as well as the personnel's own observation whereby the relevant staff members registered certain variables in accordance with given instructions. Relevant personnel groups were informed about the study during a preliminary investigation. This combined with the fact that no single group had any vested interest in obtaining specific results from the study, meant that the study could be carried out with a minimum of measurement bias[16, p. 503; 17, p. 397].

Value-added margin refers to sales minus costs

The data collection methods used in the assessment of other cost components will be described later.

Lost Value-added Margin

When a car is to be repaired, the mechanic receives a work order, drives the car into the workshop and begins the repair work. Spare parts, when needed, are fetched from the workshop's warehouse during the course of the repair. If there are no stocks of a certain spare part, the mechanic has to drive the car out of the workshop without having executed the work order. The missing spare parts are backordered. When the parts become available, the car is once again driven into the workshop and the repair is completed.

Spare part shortage entails a loss of mechanic's work time compared with a situation without shortage. During periods with insufficient availability of mechanics, the company's production capacity will be less than demand. In this situation the loss of a mechanic's time caused by spare part stockout will reduce the company's income. In periods with a shortage of mechanics, the lost value-added margin which is a result of spare part stockout is thus an important component in the stockout costs. The term value-added margin refers here to sales minus materials and energy costs.

The lost value-added margin per stockout event is equal to the number of lost mechanic hours multiplied by the value-added margin per mechanic hour. The latter was calculated directly from the company's accounting system as an average based on totals from a one-year period, while the lost mechanic hours have been quantified in the three-week observation study described earlier (average per stockout event based on total enumeration).

Increased Resource Consumption in the Peripheral System

Spare parts stockout also results in increased resource consumption in the workshop's peripheral system, in the form of changes in production plans, communication with customers about delivery postponements, backorder administration, extra supplier contacts, etc.

When mechanic availability constitutes a bottleneck, the marginal effect of a stockout event — for example by a reduction by one unit — is that resources consumption is reduced in the peripheral system. There are two opposing effects: "Stockout administration" is reduced at the same time as resource consumption increases as a result of the fact that freed mechanic work time is used for income-earning production. The stockout cost B is the marginal net change in the peripheral system's resource consumption valued at cost price. Measurement of B expressed per stockout event has been structured with the help of the following model:

$$B = X_1 - X_2 \cdot X_3 \quad (2)$$

where X_1 is the monetary value of the freed resources in the peripheral system per stockout event, X_2 is the freed mechanic time (minutes per stockout event) and X_3 is the incremental cost in the peripheral system of increased work flow through the workshop (monetary value per invested mechanic minute).

Average time requirements for personnel and computers were measured

X_1 has been calculated from the three-week observation study described earlier and from accounting data. Average time requirements for personnel and computers in the peripheral system per stockout event were measured in the observation study. Summing the time spent, valued at cost price (average from one year's accounting totals), yielded X_1. The measurement of X_2 has been described in the previous section.

An increased flow of cars through the workshop affects, first and foremost, the direct wage costs of personnel in the peripheral system as well as the cost of computer time and power. The sum total of all incremental costs for these items based on one year's accounting data and expressed per invested mechanic minute, gave X_3.

Special Stockout-alleviation Procedures
The companies have developed systems for internal transfer of spare parts between different warehouses within the same company and, in one case, a system of rapid special transport from Volvo's central spare parts warehouse in Gothenburg. Use of these systems may in certain cases help alleviate spare parts shortage more quickly than waiting for replenishment from the ordinary source.

Total stockout incremental cost was found to be linear

The calculation of the incremental cost per stockout event for special stockout-alleviation procedures is based on the assessment of the average cost reduction per stockout event at a 50 per cent reduction in the number of events. Within this reduction range, the total stockout incremental cost was found to be approximately linear, since the personnel and vehicle resources used were divisible and could be put to alternative uses. The cost calculation is based partly on direct personnel costs from the companies' internal accounts covering one year and partly on special vehicle calculations.

Maintenance of Goodwill through Price Reductions
Spare part shortage is generally inconvenient for customers since it often results in postponement of delivery times and/or a return to the workshop. It is therefore natural that customer reception staff in such cases sometimes compensate customers with a price bonus, particularly if a customer has been caused considerable inconvenience or the customer in question is a skilful negotiator. The fact that such compensation is offered is confirmed in interviews with customer reception staff at the three workshops surveyed. Price reductions are regarded as a tool for avoiding or at least limiting the loss of customer goodwill. The cost of such price reductions is not known. The price reduction is specified on the invoice, but the reason for offering it is not stated. Since there are several other reasons for price reductions as well, it is not possible to determine the extent of stockout-induced reductions only through a survey of invoice.

It was, however, possible to use a quasi-experimental design to estimate the approximate cost of price reductions per stockout event. The term quasi-experiment is used to denote a research design which simulates the true experiment but which lacks two crucial criteria: control over the experimental treatment (spare part shortage) and control over group formation[18, p. 128]. However, the terminology does vary. Green *et al.*[19, p. 120] use the term "natural experiment" to denote this research design.

Of the cars which were in workshop A for repairs during autumn 1985 (the reference visit) and which had been exposed to spare part shortage, 48 cars were selected at random to form an "experimental group". Every car in the experimental group was matched by an "identical" car which had been repaired by the workshop at roughly the same time but which was not affected by shortage (matched control group). The term "identical car" is used to denote a car which matched its counterpart in the experimental group as regards model, mileage, age, number of doors, finance arrangement (leased/non-leased) and ownership (private/company).

After selection and measurement, the two groups were compared with regard to mean values for 13 important variables and they were found to be virtually identical. The groups differ in that the experimental group was subjected to a shortage of spare parts at the time of the reference visit. The difference between the average price reduction per car in the experimental and control groups is therefore used as a measure of price reduction directly traceable per stockout event. The results were considered representative for the other workshops after a minor adjustment based on production structure.

Maintenance of Goodwill through Provision of Rental Car
In cases in which a car is brought in for repairs and cannot be returned to the customer at the promised time in driveable condition, a rental car is sometimes provided for the customer. In such a case, the customer only pays the actual operating cost for driving the car. All the companies operated car rental schemes in parallel with their other operations, or had access to cars for rental.

The express order has a very short lead time

The companies' avoidable costs for the use of rental cars as customer compensation in the event of spare part shortage, primarily costs of depreciation and personnel, have been traced from accounting information over a one-year period. The costs are averaged per stockout event.

Table I. *Cost (SEK) per Stockout Event in the Case of Internal Demand. Mechanics in Short Supply (Case F)*

Cost component		Workshop A	Workshop B	Workshop C
1.	Lost value-added margin	174.50	116.91	76.36
2.	Increased resource consumption in peripheral system	19.60	71.54	51.29
3.	Special stockout-alleviating procedures	39.60	21.51	88.61
4.	Maintenance of goodwill through price reduction	51.00	48.00	48.00
5.	Maintenance of goodwill through provision of rental cars	16.68	6.80	8.16
6.	Price increases owing to express order services	4.49	7.04	3.23
7.	Indirect effects	4.59	2.60	3.36
8.	Loss of workshop customers	50.00	50.00	50.00
	Total	360.00	324.00	329.00

Price Rises Owing to Express Order Services
In the event of shortage, an express order is normally issued to the supplier to cover a portion of the normal order which will already have been placed when the reorder point was passed. The express order has a very short lead time, maximum one day compared to the eight to 11 days for processing a normal order. The net effect of express orders is that the supplier demands a higher unit price. The internal incremental costs for express order handling are included in the cost component previously dealt with under the heading "Increased resource consumption in the peripheral system".

Indirect Effects
Spare part shortage also brings with it indirect effects which are not represented in the cost components already dealt with. These effects may arise as second-line, third-line or fourth-line effects and they influence managers and their administrative support staff at different levels.

Personnel influenced by indirect effects were identified. During a three-week observation period they were estimated to lose as large a proportion of their total work time owing to spare part shortage as do the company's mechanics. The incremental cost of this loss of work time is expressed per stockout event.

Loss of Workshop Customers
The companies try to reduce the impact on customer lead time from spare part shortage by adopting various special procedures which alleviate shortage situations. In addition, the companies attempt to counter the loss of customer goodwill resulting from shortage through a number of measures. The impact of shortage on future loss of workshop customers is felt to be fairly limited, given the current management procedures. In order to assess the monetary value of loss of workshop customers owing to spare part shortage, customer receptionists were asked to estimate the proportion of "stockout-affected" customers lost. This proportion together with an estimate of the size of contribution margin which the average car brings to the workshop during its service life, result in an estimate of the expected future loss of contribution margin resulting from spare part shortage.

The relationship between spare part shortage and new car sales has been estimated as insignificant, given current service levels and goodwill-maintenance measures. The conclusion is based on interviews with customer reception staff and car salespersons as well as on existing market surveys. The term $\Sigma\Delta P(t)$ in definition (1), "contribution margin losses in other lines of business", is thus considered insignificant.

Summary
Table I shows the empirical results obtained from cost measurements relating to spare part stockout in the case of internal demand. The costs are expressed in Swedish crowns which are abbreviated SEK. The results apply to the current situation which corresponds to case F in the typology.

Table II. *Cost (SEK) per Stockout Event in the Case of Internal Demand. Mechanics not in Short Supply (Case L)*

Cost component		Workshop A	Workshop B	Workshop C
1.	Mechanics' wages	59.38	45.03	24.45
2.	Increased resource consumption in peripheral system	50.15	94.64	67.92
3.-8.	(See Table I)			
	Total	276.00	276.00	294.00

The cost components in Table I are computed as average per stockout event according to methods described in the foregoing sections. The averages are based on data from either a representative three-week period (components 1, 2, and 7) or one year of operation (components 3, 5, and 6) or special estimates (components 4 and 8).

The table shows that there are considerable variations between workshops in individual cost components but that the total costs are relatively similar. This reflects the fact that the workshops adapt to their specific conditions in different ways.

Criticality was not found to be a cost-differentiating factor

In some textbooks, the criticality of the article is mentioned as one of several factors which can explain variability in stockout costs. It may therefore be interesting to note that in this study the criticality of the article was not found to be a cost-differentiating factor. The reason is that the stockout cost depends on the actions taken in response to the stockout event and that these actions are independent of the types of articles constituting the shortage.

In the current situation, the availability of mechanics is a bottleneck which reduces the company's income-earning capability. The relationship between the availability of mechanics and demand for workshop services may however change in the future so that the availability of mechanics no longer limits a company's earnings. With all other conditions remaining unchanged, case L, as portrayed in the typology, would be present. In this case, a reduction in stockout frequency would release additional mechanic hours as well as personnel and other resources in the peripheral system. All the indicated production resources should in such a case be valued at direct cost prices, since they will be either released or put to alternative uses where they are assessed as having this value. Hence the difference between cases F and L lies in the valuation, and it only affects the first two cost components in Table I. The costs in case L are shown in Table II.

Table II indicates that the stockout costs in this case are lower than when mechanic availability constitutes a bottleneck. When the study was carried out, mechanics were in short supply. The relationship between the availability of mechanics and demand for workshop services can, however, change to a situation in which the stockout cost is represented by Table II. A general model for the prediction of the cost A per stockout event for a planning period, during which there is uncertainty as to which of two cases (F and L) in the typology would apply, may be as follows:

$$A = pB_F + (1 - p)B_L \quad (3)$$

where

p = proportion of workshop visits or time where case one (F) applies

B_F = cost per stockout event in case one (F)

B_L = cost per stockout event in case two (L).

Spare Part Shortage in the Case of External Demand

Spare part shortage in the case of external demand can be classified as a combination of cases A and C according to the typology (see Figure 2). In the event of sales to external customers, demand in a stockout situation will be backordered or lost immediately. It appears, however, that a portion of the backordered demand will also be lost. The reason is that certain customers do not actually take delivery of spare parts which have been backordered on their behalf.

The cost structure of shortage caused by external demand is such that it is suitable to express the stockout cost per unit of each article. This can easily be converted into a cost per stockout event with the help of information relating to the stockout event's composition. In a large proportion of cases, the stockout event comprises one unit of one article. The stockout cost B_i per unit for article number i will be a weighted average which is based on the possible outcomes. It can be expressed as:

$$B_i = r(C + F_i) + D_i(1 - r + pr) \quad (4)$$

where

r = proportion of all shortage registered as backorders

p = proportion of shortage registered as backorder, which ends up as lost demand

C = incremental cost per unit for backorders

D_i = contribution margin per unit for article number i (= sales price minus purchase price minus any variable cost per unit)

F_i = price rise incurred by express order service for article number i.

Table III. *Parameter Values and Stockout Costs (External Demand)*

Group	r	p	C(SEK)	B_i(SEK)
1	1.00	0.00	11.91	$11.91+F_i$
2	0.80	0.25	11.91	$9.53+0.8F_i+0.4D_i$
3	0.67	0.49	11.91	$7.98+0.67F_i+0.66D_i$

An intensive survey revealed that the proportion of shortage cases which result in backorders varies with the degree of competition. In order to reflect these differences, the articles have been allocated into three groups: articles not subject to competition (group 1), articles partly subject to competition (group 2) and articles entirely subject to competition (group 3). The allocation has been implemented in such a way that an article can be accurately assigned to the appropriate group on the basis of its part number.

The parameters r, p, and C were estimated in the survey and the estimates are shown in Table III together with the stockout costs B_i computed according to (4).

Table III shows that the backorder proportion r increases with decreasing competition and that p, the proportion of this which ends up as lost demand, decreases. The table also shows how the grouping, together with F_i and D_i, differentiates the stockout costs B_i among articles.

Total Stockout Cost

Total stockout cost per time unit may be a measure which can be used as a basis for decisions about prioritization. A total stockout cost cannot, however, be calculated as (number of stockout events per time period) × (marginal cost per stockout event), since the marginal cost cannot be assumed to be constant across the entire range from zero stockout events and upwards. A more appropriate measure is the cost saving at X per cent reduction in shortage frequency, where X is selected so that it represents a realistic maximum reduction in the medium term and at the same time brings about a change which lies within the range where the marginal cost can still be considered constant. This measure can be referred to as a savings potential.

The savings potential per year in this sense has been calculated at workshop, company and group level for both internal and external demand, where the costs are based on surveyed workshops and where the approximate raising factors are known for the various populations. A stratified estimate at group level of the total savings potential for all the group's car workshops assuming 50 per cent reduction in shortage frequency, which has been estimated as a realistic goal, indicates an appropriate potential of 0.8 per cent of total sales for internal demand and 0.9 per cent of total sales for external demand. Total sales in both cases include the sales of workshop services plus the sales of parts.

Table IV. *Example of Stockout Costs (SEK)*

Competition group	Proportion of internal demand (α)	Stockout cost (E_i) Sales price = 40	Sales price = 2,000
1	1.00	260	652
1	0.75	200	592
1	0.50	140	532
1	0.25	80	472
1	0.00	20	412
3	1.00	260	652
3	0.75	200	657
3	0.50	140	662
3	0.25	81	667
3	0.00	21	672

Variable Cost per Unit of an Article

Another use for the stockout cost measure is as a cost parameter in decision models for inventory control and for differentiated control measures which aim to reduce stockout frequency. The decision situation here is such that the parameter should be defined as a variable cost per unit of an article. The variable cost E_i per unit of article i can be expressed approximately as:

$$E_i = \alpha\,[(A_f/X) + V_i\,] + (1 - \alpha)B_i \qquad (5)$$

where

- V_i = variable incremental cost per unit of article i in the case of internal demand
- A_f = fixed cost per stockout event in the case of internal demand
- X = average number of units short per stockout event in the case of internal demand
- α = proportion of shortages caused by internal demand
- B_i = stockout cost per unit of article i in the case of external demand (defined according to (4)).

In (5), A_f is the fixed portion of the cost per stockout event which is independent of the magnitude of the shortage. In relation to Table I, A_f encompasses all the components excluding "price increase owing to express order service", which is genuinely variable and therefore restructured to V_i in (5).

The method is able to contribute to differential economic inventory control

The approximation (5) can be regarded as sound since X is close to one. A study revealed that X is equal to 1.1 in workshop A, 1.3 in workshop B and 1.1. in workshop C. Furthermore, a control based on stockout cost information will cause a further reduction in X.

The proportion of shortage α arising from internal demand is article-dependent. An analysis shows that a form of grouping already used in the article register, so-called "function groups", accounts for a considerable portion of the variation.

Table IV shows an example calculated according to (5). The example relates to one of the warehouses and two alternative sales prices, SEK 40 and SEK 2,000 respectively. The stockout cost is calculated for both competition group 1 and competition group 3. The figures in Table IV show how the stockout cost varies with article attributes, which can assume a number of different outcomes. This example thus illustrates the ability of the stockout cost method to contribute to differentiated economic inventory control.

Management Effects of Stockout Cost Measurements

In the companies reviewed here, the magnitude of the stockout costs was unknown before the study was carried out. The presentation of this study to the group offered an opportunity to observe over a three-year period the response of the companies to information regarding the size and character of stockout costs. The response contains two components. One is an increased attention to stockout problems from an organizational and costing perspective and the other specific measures, both internal and external, designed to reduce stockout costs. Three categories of measure were observed.

In the first place, Catena's executive management initiated meetings with the supplier regarding changes in the distribution system. These changes aimed at bringing about shorter lead times and increased order flexibility for dealers, together with the development of local systems for inventory control, offering the possibility of using decision models with stockout cost parameters.

In the second place, a system was developed at company level, in the case of internal demand, for periodic monitoring of stockout frequency, structure, causes and cost. This system functions as a logistics control system [20, p. 549].

Stockout costs are no more difficult to measure than other costs

In the third place, several projects were initiated at company level aimed at dealing with the actual causes of stockout. One such project dealt with improved forecasting of demand based on early diagnosis of spare parts requirements, with parts requirements registered when customers booked times for service or repairs.

The effect of the measures at company level was followed up at one of the companies being surveyed. Over a two-year period, stockout costs traced to internal demand were reduced by approximately 40 per cent, measured in fixed monetary value.

Managers at different organization levels appeared to find no difficulty in understanding or interpreting the concept of stockout costs, nor did they find it difficult to relate it to other important control parameters which have a monetary basis. The same cannot, however, be said of probability-based control parameters. An existing formal system for inventory control used control parameters and key figures based on stockout probability. Interviews revealed that administrators in positions of responsibility found it difficult to interpret the implications of the probability indexes and to relate them to economic goals. They were therefore not used as control parameters. The system showed several signs of sub-optimization.

Conclusions

Stockout Costs and Distribution Cost Analysis

This study has shown that stockout costs are measurable and that, in this case, they were not any more difficult to measure than other decision-adapted costs. The cost concepts were easy to communicate to decision makers, and information about stockout costs led to corrective measures. In a formal sense, the results only apply to the system under review, but they should also be applicable to other similar systems. A few authors, cited in the introductory section, have carried out field studies in other areas and have shown there how stockout costs can be measured empirically.

Our empirical knowledge of measurement and use of stockout costs is still fragmentary. However, together with the role of the stockout cost conception in the basic theory, this knowledge supports the inclusion of stockout costs in the theory of distribution cost analysis.

Distribution cost analysis has hitherto primarily discussed the allocation of costs to products, customers, facilities, functions and organizational responsibility. An increased interest in event-related cost allocation would contribute to continued progress in this subject. One means of making distribution processes more efficient is to use cost-control principles to regulate the frequency of both desirable and undesirable resource-intensive events towards optimal levels. Customer orders, placing orders with suppliers, etc. are examples of desirable events, while stockout, faulty order processing, transit damage, etc. can be classified as undesirable. Event-orientated allocation of opportunity costs is entirely in accordance with the economy control system's task, which is profit optimization and not cost minimization.

General Measurability of Stockout Cost

Let us conclude with a few comments about the general measurability of stockout costs, based on the experiences derived from this study.

The components in formula (1) which represent costs and immediate contribution margin losses should be generally measurable with an error margin which is no larger than that of other distribution cost measurements. The main difference is that a larger and more varied arsenal of data collection methods may have to be used for measurement of stockout costs.

When it comes to future contribution margin losses, the problems are greater, since there is usually a lack of reliable data. For stockout cost measurement to be recommended generally, it is necessary that future contribution margin losses are either limited in relation to other components in the stockout cost, which permits a larger margin of relative error, and/or that certain information is available regarding customer behaviour in the event of shortage. These two conditions have been fulfilled throughout this study.

Design of special stockout information systems would be able to create entirely different general conditions for the measurement of future contribution margin losses resulting from stockout. This system should be based on the registration of central variables associated with the stockout event, such as:

- stockout event composition (article number, units short of each article, value, etc.);
- customer identity (if the customer is identifiable);
- information about the customer ordering framework within which the stockout event occurs (order code or full information);
- stockout handling (backorders or lost sales);
- other articles used as substitutes for the shortage (if any).

Ongoing registration and storing of this information in a stockout information system would make it possible to use causal methods such as multivariate techniques, quasi-experiments, true experiments and interviews with interrogating questions, to estimate future earnings losses induced by stockouts, and thereby contribution margin losses such as $\Sigma \Delta R(t)$ in (1). On the other hand, even with this method it will probably be very difficult indeed to measure contribution margin losses in other lines of business.

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