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PACKAGING AS A CARRIER OF MATERIALS FLOW EFFECTIVENESS

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Abstract

The paper presents a methodology for evaluation and improvement of materials flow systems. The aim is to integrate subprocesses, for instance through packaging design, in order to eliminate materials handling activities not adding product value from the logistic point of view, and thereby increase the effectiveness of the system.

INTRODUCTION

The classical view of packaging is as a protector of goods during transport activities and as a means for transport and handling economy. The sales promotion function is also frequently mentioned, ie the design of the packaging unit should attract the potential customer of the product. This view of packaging has meant that it has primarily been designed to meet the demands from a sales market rather than from a specific transport network. Therefore, the packaging design has traditionally been adapted to the demands of the shipper and to the subsequent transport activity. This has in many cases resulted in packaging which is unsuitable for reuse, in low handling efficiency, especially at the receiver's end, or in extensive repacking.

In recent years, however, a new way of understanding the packaging unit as a vital component in the logistic chain has emerged. This is closely connected to the organisation of the transport system where products are transported in channels between companies working in long-term relations based on partnership. In such systems, the possibility of using returnable, "special-purpose" packaging increases, which in turn opens up new possibilities. However, to be able to exploit these possibilities fully, the packaging design process, or choice of packaging, must be a part of the design process of a wider system. This changed view of packaging has encouraged the design and use of packaging that meets the demands of all partners, increasing the effectiveness of the total system.

Nevertheless, many materials flow systems still suffer from lack of conformity between different positions in the systems. This lack of conformity appears in, for example, different demands on the packaging unit in different positions in the flow, these demands not being met in the same packaging unit. This often results in additional costs and delays, for example, a need for repacking, extra administrative costs and delays in the accessibility of the goods further on in the process, which leads to inefficiencies in the materials flow systems.

The main focus of this paper concerns the packaging configuration in relation to materials handling activities and performance in terms of, for example, handling efficiency and lead-time. Packaging configuration refers to the choice of packaging including load carriers, the number of packaging levels and the number of packaging units or items per packaging level, packaging pattern and orientation of the packaging units, product mix and identification. The aim of the paper is to present a methodology for evaluation and improvement of a materials flow system, starting from the packaging configuration and materials handling activities (Figure 1).

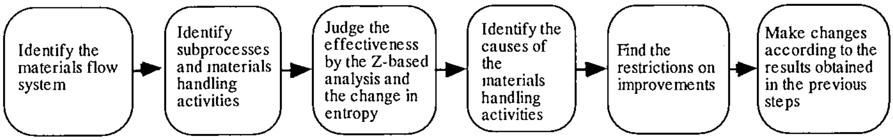

Figure 1 Methodology for evaluation and improvement of a materials flow system

The paper also includes a discussion regarding the ability of the packaging unit to compensate for the lack of conformity between positions in the materials flow by means of the packaging configuration and how this can affect the materials handling activities, and thereby the performance of the materials flow. This is done through focusing on the change in packaging configuration in the different positions in the materials flow system, where materials handling activities are performed, and relating this to the desired packaging configuration at the end of the materials flow.

MEASURING PERFORMANCE IN A MATERIALS FLOW

This section contains a short discussion regarding some performance measurements, including approaches used by the authors in previous work: measurement of entropy and zero-based analysis, which together have been used as the point of departure in the development of the conceptual model for judging effectiveness, presented in this paper.

Performance indicators

Performance can be measured in a number of different ways. A performance measurement can be seen as a tool for directing changes in an organisation. It is an instrument of control and it tells the organisation what efforts are rewarded, which makes it very important to choose the right measurement. In ten Broeke et al. (1989), it is stated that, despite the great interest shown in logistics during the last 25 years, few serious studies have attempted to analyse exactly how the logistics activity as a whole can be measured. Instead, component parts have been studied separately. This is also discussed by Mather (1988), who states that performance measurements do not emphasise logistics as a key objective. However, he also argues that improving the logistics performance can be of tremendous benefit to companies.

To be able to measure the performance of a materials flow system, some observable indicators of the performance have to be chosen. In the general transformation model (ten Broeke et al. 1989) in Figure 2, some examples of what is meant by performance indicators are illustrated. One output in this model is price, which is interpreted as the cost of producing the product.

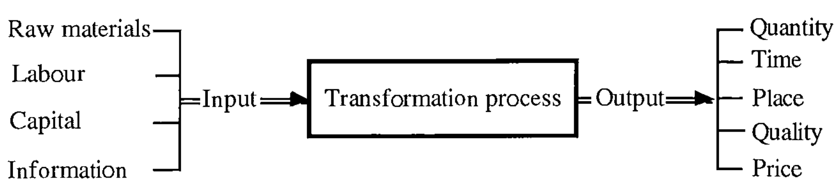

Figure 2 The transformation model (ten Broeke et al. 1989)

Some of the most common indicators of performance that ten Broeke et al. (1989) discuss are efficiency, effectiveness and productivity. Efficiency is explained as the effort, costs and reception of the inputs when employed in the process, in relation to the previously stated norms (ten Broeke et al.). Gattorna et al. (1991) define logistics efficiency as costs of, for example, transportation or warehousing. Effectiveness concerns the amount to which the process realises the previously stated norms (ten Broeke et al.). Gattorna et al. include in customer service effectiveness, for example, order cycle time and ability to adjust order quantities or requested delivery dates. According to ten Broeke et al., productivity reflects the relation between the result achieved and the means used to obtain the result.

This can also be explained thus; efficiency measurements reflect the internal performance of a company and answer the question whether the process is performing the transformation correctly, for example, at low cost. In contrast to efficiency, the measurement of effectiveness is directed towards the external performance, ie achieving the right output from the transformation process, offering the customers what they demand. Another way of discriminating between the two concepts is to regard efficiency as connected to the process, while effectiveness is connected to the product. Here, the product includes not only the physical item, but also service aspects, such as the place, quantity and time utility.

Depending on the system boundaries chosen, performance can be measured on different levels in a company or materials flow system. For example, the lead-time which the materials flow system succeeds in attaining, in turn determining the time utility achieved, can be used as an indicator of effectiveness.

Entropy

The conceptual model for judging effectiveness in this paper is partly based on the concept of entropy introduced in Engström et al. (1989). The entropy measurement was originally used in thermodynamics as a measurement of the degree of disorder in a system. According to the second law of thermodynamics, dealing with entropy, the entropy of a system can only increase. However, according to Bertalanffy (1969), this law is not valid for open systems, only for closed systems. In open systems, the total change in entropy can be either positive or negative. The fact that it can decrease makes it possible to develop the system towards increased heterogeneity and complexity. To survive, an open system must move to stop the increasing entropy process (Katz and Kahn 1969). There is an ongoing input of energy from the environment as well as an ongoing output of products from the system.

The expression 'entropy' was, according to Kumar (1987), used in a new way in information theory by Shannon in 1948. Shannon used entropy as a measurement of uncertainty, information or randomness of a probabilistic system. Kumar claims that entropy is a convenient measurement of the uncertainty or unpredictability of a system or a process containing an element of contingency. It is applied in a number of fields with this information theory approach as the point of departure, for example, in transportation systems (for example, Erlander 1977) and manufacturing systems (for example, Karp and Ronen 1992; Moscato 1976; Yao 1985). However, Wilson (1970) states that there is considerable confusion due to the different possible definitions of the concept and he shows four ways of viewing the concept. The first three ways view entropy as a subjective concept, to be used as a tool to maximise the use of the information available. The fourth way is objective in character, where entropy is viewed as a measurable system property related either to order and disorder or to reversibility and irreversibility.

In Engström et al. (1989), the entropy measurement is used in a somewhat different way, which perhaps has more in common with the thermodynamics' definition than with the information theory definition. The concept of integration level is introduced as a measurement of the ability of a materials flow system to create orderly conditions. This concept is introduced via the use of 'entropy' as a metaphor of the degree of disorder in a certain position in the system. The degree of disorder is closely linked to the packaging configuration and could be seen as a measurement of how much the configuration at a certain position has to be changed in relation to the configuration to be attained at the end of the materials flow studied. This concept was in Engström et al. (1989) used in systems that supply assembly line production processes, but it is stated that it may also be applied to other materials flow systems.

The aim of Engström et al. (1989) was to offer a framework for contextual understanding of handling and transportation as value-adding activities and to show that the introduced terms are relevant when industrial materials flows are discussed. The question of value-adding activities is vital, since the purpose of a process is to transform an input into an output that in some respect has a higher value. Otherwise, it is a waste of resources. Value-adding in handling and transportation includes time, quantity and place utility as opposed to physical value-adding, which includes adding value to the form and function of the product. Time, quantity and place utility are focused upon in this paper in connection with the discussion on materials flow system effectiveness. Of interest is to what extent the system manages to decrease the entropy, thereby adding value to the product while utilising minimal resources.

Zero-based analysis

Another method for measuring the performance of a system being studied is the so-called Zero-based analysis, which is a mixture of the ideas in Wild (1975) and Engström and Karlsson (1981). It was applied in Engström et al. (1993) and it forms the basis for the work presented in this paper. This method relates the studied system to a reference system. The reference system is an ideal production system, including only necessary work and no losses of any kind, ie no non-value-adding activities. The method of analysis was developed by Wild, for comparison and selection of systems for mass production and has been further developed by, for example, Engström and Karlsson (1981).

In Engström et al. (1993), the resources used were divided into three main categories: necessary work, work inefficiencies, and system inefficiencies. The work inefficiencies include, for example, balance, division of labour and set-up losses. The system inefficiencies include, for example, tied-up capital, indirect personnel and tools. Furthermore, the product design is the basis when determining the necessary work in the reference system, while inefficiencies are considered to be induced by the production system.

The time required to perform the necessary work is denoted Z. It is the time used in the reference system to perform the tasks included in the analysis. In manual assembly, the time for necessary work is the work time required for one ideal operator to carry out all the work. The components are materialising in the hand of the operator who then performs the work at the right quality level using the standard time for the work involved. The size of each loss is then expressed as a percentage of the necessary work. This measurement reveals the potentials for rationalisation in the production system compared to the reference system. Different production systems can also be compared.

This method of analysis allows comparison of different systems without using correction factors for the differences in product design. This is an advantage which increases the reliability of the results (Engström et al. 1993). According to Wild (1975), there is a restriction in that the procedure should be applied only to essentially manual systems. Instead of this restriction, Kjellström (1994) chooses the restriction on how to determine the necessary work as not only dependent upon the product, but also on the technology level. This enables the inclusion of both man and machine time and thereby the application of the method to different kinds of systems, as long as the systems compared have the same technology level.

The analysis method was initially applied to production systems. Therefore, the product has been the physical product. However, there should be no difference if also the immaterial part of the product is taken into account, such as place and time utility. The analysis has, for example, been applied to order picking systems (Brynzér et al. 1993), when the product was defined as a completed picking order.

A CONCEPTUAL MODEL FOR JUDGING EFFECTIVENESS IN MATERIALS FLOW SYSTEMS

In this paper, we try to further develop the entropy concept described by Engström et al. (1989) as one part of the methodology for evaluation and improvement of a materials flow system (Figure 1). Since the materials handling activities are the activities in the process that can change the packaging configuration, and thereby the entropy in a position in the system, they are studied in order to find out if they are value-adding or not. We focus on the changes in packaging configuration in the different positions where materials handling activities are performed, relating this to the desired packaging configuration in the last position of the materials flow so that the adding of value to the product can be measured.

The transportation can also be seen as value-adding, since it gradually adds place utility when moving the goods closer to the final destination, and time utility is added if it delivers the goods timely. This is discussed in Engström et al. (1989), but is so far disregarded in this model.

An important question is how to know whether an activity is value-adding or not. One way of analysing the adding of value is to use the zero-based analysing method as a point of departure. The zero-based analysis relates the studied system to a reference system that includes only necessary work, ie value-adding activities. The analysis divides the resource consumption into three parts: necessary work (Z); work inefficiencies; and system inefficiencies. We will, however, simplify the analysis by only dividing the resource consumption into necessary work, that include the value-adding activities, and inefficiencies, that includes the non-value-adding activities. What is included in the necessary work is not dependent on the design of the studied system; only the technology level of the system has to be considered when comparing different systems. It is the product to be produced that determines the necessary work.

When studying the materials flow, the product will be looked upon as the right quantity put in the right place, in the right packaging, together with the correct complementary goods, and having the right identification. Exactly what this includes depends on the system boundaries chosen and has to be defined in each case, just like every physical product being individually specified.

The model is applied in two stages. The first stage involves estimating the resource consumption of the different materials handling activities in the studied total process. This is done through classifying the materials handling activities in the materials flow system, through, for example, looking at the resources or the time needed to perform different handling activities and dividing the activities into categories. These categories can, for example, be; handling by an industrial truck, handling by handling devices, manual handling with two hands, and picking using one hand for each picking. These categories can then be used as a basis for easily determining the total consumption of resources, including both necessary work and inefficiencies. However, the purpose of the study must determine the relationship between the categories.

The second stage is to determine the correspondence with Z, ie the necessary work. First, the entropy in the input to the process, and the final entropy in the output of the process, which is the goal, have to be defined. They are both determined by the system boundary chosen. The difference between these two is an indicator of the necessary work that has to be performed to attain the desired entropy in the last position. A figure on this measurement is needed to enable a comparison of the reference system with different systems. In order to obtain this figure, the difference in entropy between the input and the output can be transformed into necessary handling activities, or resource consumption.

Besides being a measurement of value-adding and resource consumption for comparison of different systems, the entropy measurement is also useful for a more qualitative aim. This aim is to find out where in the materials flow system the non-value-adding activities, or the activities taking value away, are located. Therefore, the decrease in, and sometimes even in some positions in the flow, the increase in, entropy has to be documented for the studied materials flows. The way the entropy changes along the flow can differ between systems with the same ingoing and outgoing entropy, and this is one way of showing the different potentials in different systems and identifying what needs to be addressed in the change process to increase the materials flow effectiveness.

STRUCTURING CAUSES OF MATERIALS HANDLING

To be able to eliminate materials handling activities, an understanding of them, their causes and the restrictions in eliminating them, is necessary. A model to help structure and better understand their causes is therefore needed. In the following pages, a model is described for structuring the causes of materials handling, using the total process included in the system being studied as a point of departure.

A process is in this paper defined as all the activities performed to transform an input to a system into an output of the system. The transformation does not necessarily include only the physical transformation, but can also include the addition of service to the product (Figure 2). In a materials flow system this can consist of adding value in the form of place, quantity and time utility. The transformation can take place on different levels, and can include, for example, the activities performed within the boundary of a company, the production process in a certain production area or department of a company. A process can be divided into subprocesses, where a subprocess has the same definition as a process. The only difference is the level focused upon in the system studied. In this paper, a process is divided into subprocesses when the transformation of the input is performed at different places and/or with slack time in between.

A spatial division of processes, which transform physical objects, generates the need for transportation of the goods. To connect the subprocesses obtained, there is also a need for materials handling activities. The other type of division is in time, where two subprocesses are performed with slack time in between. This frequently results in materials handling activities and sometimes also in transportation activities, for example, transportation to and from buffers. These activities take place in between the subprocesses to connect them. The way in which these divisions of a process are achieved influences the materials handling. If there could be less division of processes, the number of materials handling activities could be decreased, whereby the prerequisites for increased materials flow effectiveness would be improved.

A number of different causes of these divisions of a process into subprocesses are possible. We have divided them into two categories, including the principal causes; division due to the process design and due to the operation of the process. In the same materials flow system, both these principal causes can exist simultaneously, and sometimes the process design causes the operation of the process to induce division of a process. Furthermore, there are a number of underlying causes, some of which are more important for our purposes. These are discussed below (see Figure 3). In which category the underlying causes are included can sometimes differ between different cases. We have included them in the categories which, from our own experiences, are most frequent.

Process design includes the long-term planning of how the process is to be performed and by whom. This includes acquisition of equipment, buildings, etc. On the other hand, the operation of the process includes decisions that can be changed in the short term, without large investments. This includes how the equipment and information are used for operating the process but not which equipment should be chosen.

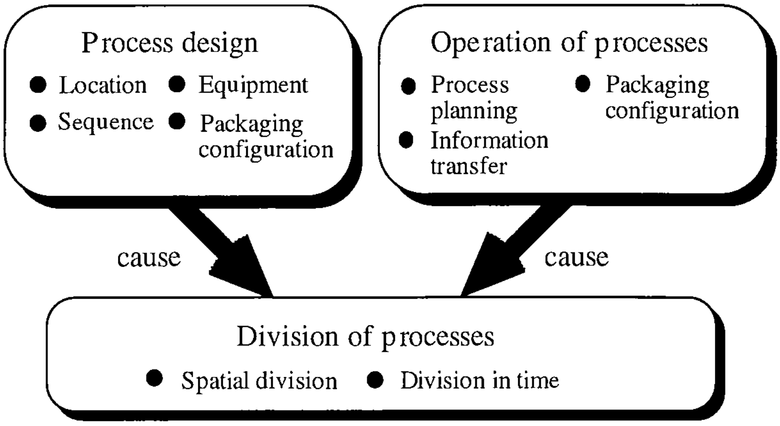

Figure 3 **Causes of division of processes**

Process design

In the design of a process, one of the first decisions to be made is how and where a process is to be divided into subprocesses. There has to be a decision about where the subprocesses are to be *located* and whether they should be in direct connection to each other or not. This includes whether they are to be performed at the same company, or if they should be bought from subcontractors, as well as whether or not they should be performed in the same line, or at different places in the same company.

Even if the starting and terminal points are known, there might be alternative *sequences* in which the process can be performed. It can be a question of choice of production system, for example, if a parallelised or a serial flow should be chosen, or the type of layout in a machining company. The chosen sequence can influence who is to perform the subprocess as well as how it should be performed and connected to the next subprocess. The number of necessary subprocesses can also be affected by this sequence.

When designing the process, the *equipment* to accomplish the transformation has to be chosen. This includes machines and tools as well as handling devices. Depending on the equipment selected, different solutions of how and where to divide a process into subprocesses can be chosen.

The last decision concerns the *packaging configuration*. Not all dimensions included in the definition of packaging configuration are affected, but mainly only the type of packaging and size which, among other things, are affected by the number of items per packaging level. The other dimensions are mainly affected during the operation of the process. Depending on the choice of packaging, including load carriers, the amount of goods that can be handled at a time differs, which affects the materials handling activities. The design of the packaging affects which handling devices can be used and possibly also if the orientation of the products coming from a machine can be kept so that there will be no need for complicated reorientation of the products before they are used in the next subprocess. In addition, the packaging configuration makes it possible to mitigate the consequences of lacking conformity between subprocesses. This can be done, for example, by combining, as one unit, a packaging unit that is suitable for one position in the flow with packaging units that are suitable for the next position, utilising the possibilities of combining different needs on different packaging levels. This means that the packaging configuration influences the results of the decisions concerning the other parts in the process design.

Operation of processes

As mentioned earlier, the operation of processes is dependent on the process design in that the process design sets the limits within which changes in the operation of the process can be made. There are, however, still some causes for the division of processes in the operation. Three causes are discussed here. The first is the *planning* of the operation of the process. The planning includes the scheduling of when different activities are to be performed and the planning of the sizes of batches that are to be transformed in succession. It also includes the planning of who or which machine is to perform which activities. If the planning is well performed, there might be less need to store and buffer goods in between subprocesses, leading to a reduction in the division in time and/or space.

Another cause is the *information transfer*. If the information transfer is efficient, ie the right information is available at the right time, slack time and even subprocesses might be avoided. Otherwise, to compensate for the lack of information, it might be necessary to perform extra activities in order to accomplish a certain task.

The last cause is the *packaging configuration*, which, besides in the process design, may be affected in the process operation. Especially, the number of variants per packaging level, packaging pattern and identification of the goods can be affected in the operation of the process. With a little or no extra work in one position in the materials flow, much work with repacking or identification of the goods might be avoided in the next position, mitigating the effects of lacking conformity between different positions in the materials flow.

RESTRICTIONS AND POSSIBILITIES OF IMPROVEMENTS

It can sometimes be difficult to integrate subprocesses for the purpose of reducing the number of materials handling activities, since it might affect other parts of the system and the total effectiveness negatively. Finding the explanations for the causes of the present situation in the materials flow system would give a better understanding of the problem.

In trying to avoid as many of the undesired effects as possible when making changes that affect the number of materials handling activities, thus enabling the overall system to be optimised, it is useful to apply a systems view to solving problems, since these are often more complex than they first seem. A system is, according to Churchman (1979), a set of components that work together for the overall objective of the whole. Churchman states that one inefficiency has to be balanced against another in order to reach the best result possible and not to sub-optimise. When this view is related to the problem discussed in this paper, there are a number of factors that have to be taken into consideration when making decisions about the design and also about the operation of the process, or materials flow system. Some of the restrictions in making changes in the materials flow system in order to reduce the number of materials handling activities will be discussed in the following.

Process design

The process design is affected by a number of restrictions. Some of them can be seen in Figure 4. The first restriction is in the availability of *locality*. It might not be possible to have the entire process in the same locality, or the available locality is not suited for the intended purpose.

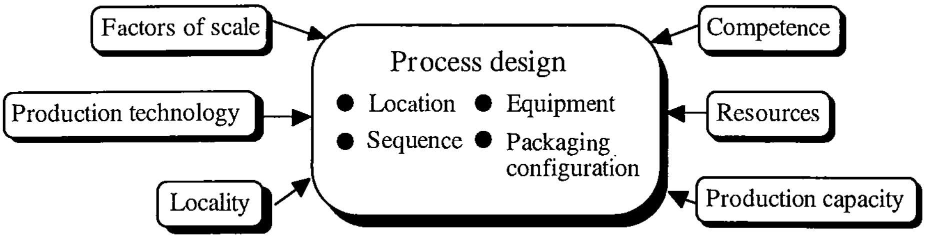

Figure 4 Restrictions in making changes in the process design

Another restriction is the *production technology*. It places restrictions on how the process can be performed, depending on both what is technically possible and costs. *Factors of scale* might also exist that make it impossible to manufacture all subcomponents in the same company, and it can therefore be necessary to use subcontractors to attain rational production. The reason for having to use subcontractors can also be that the necessary *competence* does not exist within the company or that the present *production capacity* is not high enough to perform the entire process.

The *resources* needed and available for performing the process are an important restriction which, to a large extent, influences decisions concerning the design of the process. It is a question of using the resources as efficiently as possible. This includes the importance of being competitive, and can be seen as a restriction which, to a large extent, overrules the other restrictions mentioned, since a business that is not competitive and profitable will not survive. When looking at an entire materials flow system, usually a number of companies contribute. An investment might be needed in one position of the materials flow, while the profit it generates is realised in another position. This leads to the question of how to share both the investment and the expected profit. Problems related to this can also mean restrictions related to resources in the design of the process.

Operation of processes

Restrictions concerning the operation of the process derive mainly from uncertainties in the environment and in the organisation within the materials flow system (Figure 5). One such restriction is *unforeseen incidents and disturbances*. It does not matter how few materials handling activities one can obtain in the normal, optimal case if the system cannot cope with any disturbances without producing difficulties in performing the transformation in the process. Therefore, it is necessary to have a process that can deal with these unforeseen incidents and disturbances in order to be able to compete on an uncertain market.

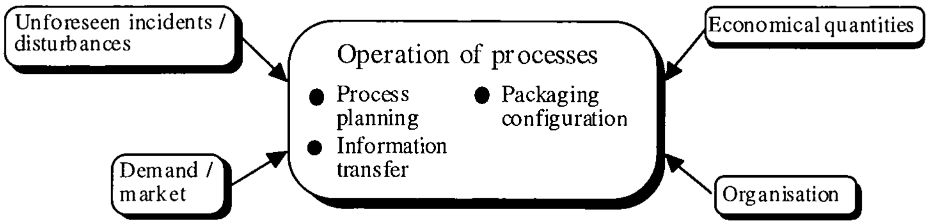

Figure 5 Restrictions in making changes in the operation of processes

The second restriction is the necessity of being able to operate and adjust the process when the *demand and market situation* vary. There can be seasonal variations as well as variations that are difficult to foresee. In order to accommodate variations in the demand and in the market situation, the process must be flexible and the work procedures should not have to be changed too much due to variations, with the consequent need for extra handling activities.

Economical quantities are included in the third restriction. They concern both transportation and production quantities. The level of utilisation of space in trucks must be high and the batch sizes must not be too small to avoid long set-up times. There has to be a trade-off between space utilisation, set-up times and need for materials handling.

A fourth restriction on how to operate the process is how the *organisation* works. One example is the hierarchical structure of the organisation, and the responsibility given to the employees to make decisions on different matters and to perform certain activities. Another example is the competence of the employees. It is important to make it possible for one person to carry out a number of different activities, not just a fraction of the total process. This might be the easiest restriction of the four to affect, since it is decided upon by the company and not by the environment.

CASE STUDY—INCOMING GOODS AT A DISTRIBUTOR

The aim of this section is to show the significance of focusing on the packaging configuration and materials handling activities and that the factors used in the models described in the previous sections are relevant. In order to show this and to apply the models to a real problem, a case study concerning incoming goods at a distributor is described. The intention has not been to evaluate the situation in the case study, only to use it when evaluating the methodology presented in this paper.

The studied distributor has a central warehouse to which a number of companies deliver their products. From the central warehouse, the products are distributed to regional warehouses, from which they are delivered to shops. The goods are delivered to the central warehouse mainly on pallets. Goods are arriving daily, in amounts that can differ greatly from day to day. The suppliers rarely notify the distributor in advance when goods are delivered, and there is no delivery schedule.

When the goods reach the distributor, they are arranged in various ways depending on who the supplier is. To fit the system of the distributor, they should be delivered on EUR-pallets with a certain maximum height to enable them to be stored in the warehouse. Due to the risk of incorrect dispatching, storing products with different article numbers on the same pallet is usually not allowed, and storing products that have the same article number, but different batch numbers, on the same pallet is never allowed. The effect is that if the goods are mixed on the pallets or delivered on pallets not in accordance with the EUR-standard measures, they have to be repacked.

In order to examine in detail the effects of the way in which the process is designed and operated, a study of a number of suppliers was carried out. These suppliers were chosen based on a categorisation of incoming goods. Four different categories were identified:

1. EUR-pallets, to be stored without repacking;
2. EUR-pallets, must be repacked because of mixed goods;
3. Pallets, not in accordance with the EUR-standard, and thereby repacked, but otherwise according to the distributor's system;
4. Pallets, not in accordance with the EUR-standard, with mixed goods on the pallets.

In order to study the difference between these different categories in the work carried out at the distributor, suppliers with goods from the different categories were chosen. These suppliers' deliveries were studied by looking at the packaging configuration of the deliveries, information connected to them, and the throughput times before they are available in the central warehouse. The throughput time is seen as an important factor influencing the lead-time for the regional warehouses' orders to be fulfilled. The time consumption for the materials handling activities connected to the repacking was to some extent also studied. Some results from two suppliers will be presented. The first supplier, supplier 1, delivers goods according to category 1 and is considered to arrange the goods in a way that is easy to receive. The second supplier, supplier 2, delivers goods according to category 2 and the delivered goods are considered to be among the most time-consuming to prepare for warehousing.

The study was performed by direct observation of the work in the central warehouse on a number of occasions over a period of approximately seven months. Open-ended interviews were conducted with employees at the purchasing department and in the central warehouse regarding work procedures, information, goods flows, etc. Video recordings and analyses of the handling of incoming goods were performed to compare the time-consumption for different categories of goods. Archival data on throughput times up to availability in the warehouse, number of articles, pallets, etc., for the deliveries from the suppliers were studied during a period of one year.

The materials handling activities

The process is in this case defined as the delivery of goods, from arrival at the central warehouse, to making them available for ordering by the regional warehouses. The physical input to the process is here the same as the output, ie the goods. Instead of transforming the physical input, the process adds value in the form of place, quantity and time utility of the products, to use the terms in Figure 2. The place utility is, however, associated with transportation. This part is therefore not considered since transportation so far is delimited in our model.

Focusing on the handling in the warehouse at the distributor, a number of materials handling activities are performed, aiming at preparing incoming goods for warehousing (Figure 6).

The worst case, similar to deliveries from supplier 2, is when the goods arrive without any information being available about the content. Therefore, the goods are stored on the floor until the documents are received. Sometimes, large amounts of goods have been placed on the floor, leading to the need for rearranging the goods to make the goods needed accessible. If the goods are mixed on the pallets, they have to be repacked with only one article number and batch number on each pallet. If they are delivered on pallets that are not in accordance with the EUR-standard, all the goods have to be moved to other pallets, leading to more handling. Then, the goods are moved to an area for goods ready to be stored in the warehouse. The next step is to move the pallets to the warehouse using an industrial truck. Furthermore, another industrial truck brings them to their final places in the warehouse.

On the other hand, when goods with only one article number and batch number on each pallet arrive with a packaging configuration that fits the system at the distributor, including that all information needed to take care of the goods is available, ie with goods most similar to supplier 1, only a few materials handling activities are needed. When the pallets are brought in from the truck, they can be prepared for warehousing without being moved. They can then be moved to the area for goods ready to store in the warehouse. The following handling activities are the same in the two cases studied.

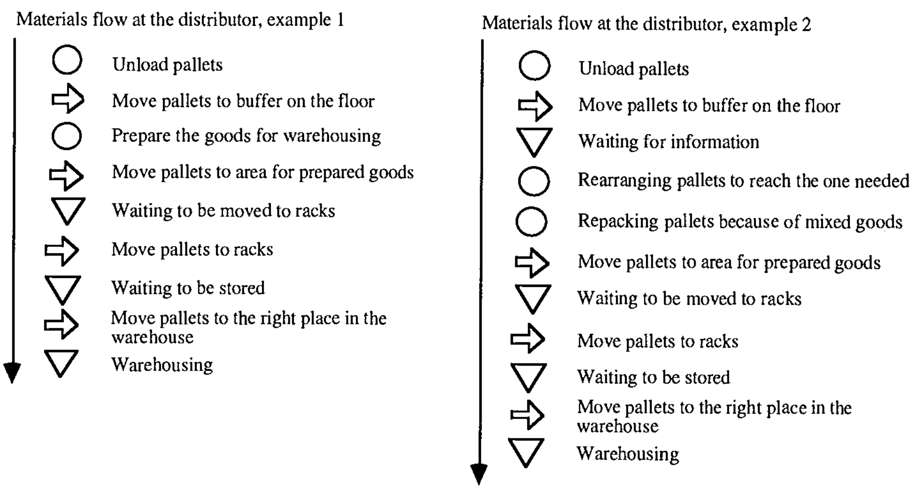

Figure 6 **Two different examples of how the materials flow at the distributor can vary, depending on the packaging configuration. Example 1 is most similar to deliveries from supplier 1, and example 2 is most similar to deliveries from supplier 2.**

Effectiveness

Not even in the case when everything works smoothly are all materials handling activities adding value to the product. In fact, no materials handling activities at the distributor add value to the products in this case in terms of the variable quantity. Only the palletising at the manufacturer adds value. In the worst case, there is an increased entropy at the palletising since we go from a condition where the goods are not mixed to a condition where they are mixed. This has to be offset by decreased entropy at the distributor, when repacking the pallets due to mixed goods. Some of this is value-adding. An example of how the change in entropy can be illustrated for the worst case respectively the best case when everything works smoothly, is shown in Figure 7. The necessary activities, which are marked as added value in the Figure, are the ones that should be included in Z in the zero-based-analysis. The remaining resources used in the materials handling activities are inefficiencies.

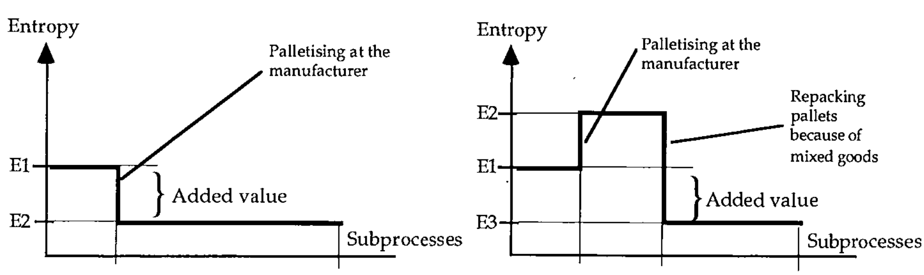

Figure 7 **Change in entropy for examples 1 and 2, according to Figure 6**

The results from the studies of the two suppliers were in accordance with the expected results. The time it took for one person to prepare the deliveries differed a great deal between the two suppliers studied, depending on the packaging configuration. The mean time for each pallet was 3.5 minutes for supplier 1 and 10.7 minutes for supplier 2, ie the mean time to prepare the goods was three times as long for pallets with mixed goods compared to pallets with only one article number per pallet.

The study of throughput time, ie from the time the goods arrive at the distributor until they are available for ordering, also showed a difference between the two suppliers. Rather often, one or more out-of-stock products are among the received goods, which gives them priority, especially if it is out-of-stock not only at the central warehouse, but also at the regional warehouses. Therefore, it can be difficult to compare different suppliers. However, comparing supplier 1 and supplier 2, almost the same number of deliveries included products that are out-of-stock at the regional warehouses, 17.5 % and 19% respectively. During the one-year study, the throughput time was on average 3.4 days/delivery for supplier 1 and 6.4 days/delivery for supplier 2. This is despite the formal work procedures where the goods are prepared first that arrive first at the distributor, besides when there are prioritised out-of-stock products, which means that there are more factors influencing the work than these work procedures.

Causes of materials handling

If the model of causes of materials handling is applied, the many handling activities in the worst case can be caused by a number of different factors. One major problem is that the system boundary is very narrow, only focusing on the central warehouse and not on the manufacturer, where the goods are loaded onto the pallets. Of course, some of the causes of materials handling are found within the central warehouse, but the limits within which the process can be operated are to a large extent set by the preceding positions in the materials flow system.

If the study of the system is extended to also include the manufacturer palletising the goods, the causes would become clearer. The division of the processes between the manufacturer and the distributor is in this case spatial, which is caused by the *process design* and in this design the *location* is the cause. It might be easier to affect the *packaging configuration*, and to some extent the *equipment* used in the defined process. The part of the packaging configuration included here is the type of packaging, if pallets not in accordance with the EUR-standard measure are used. This results in the need for repacking to EUR-pallets at the distributor. Concerning the equipment, it is difficult to know anything about the causes of materials handling related to the manufacturer. At the distributor, one cause is the use of different industrial truck types for moving the pallets when preparing them for warehousing, when bringing the pallets to the racks waiting for final warehousing and when bringing them to their places in the warehouse.

If the *operation of the process* is focused upon, the *packaging configuration* is probably the most important cause of materials handling. Product mix on the pallets and identification are problems frequently occurring. The problem with mixed goods on the pallets results in extensive handling. Sometimes, the identification on the pallets and on the single packaging units on the pallets is scarce when delivered to the distributor, which leads to the need to look inside each packaging unit to identify the content. In addition, the *planning* and *information transfer* cause some extra handling. Also in this case, the preceding position to a large extent influences and sets the limits within which the process can be operated. Since the documents are sometimes late, the goods have to wait on the floor until they arrive and by then there might be new goods in front of the pallets. To reach them, the goods have to be rearranged. In addition, the fact that there is no delivery schedule causes irregular deliveries, with a mean of 43 pallets a day and a standard deviation of 29. The work load therefore varies, and sometimes many pallets are waiting on the floor to be prepared, with the same effects concerning the materials handling as when the documents are missing, at the same time prolonging the throughput time before the goods are available in the warehouse.

Restrictions

Looking at the prerequisites for improvements, the restrictions have to be considered. Since the case study was only performed at the distributor, the restrictions discussed here only concern the distributor's and not the manufacturers' restrictions. In the design of the process, one example of a restriction is the *production technology*. One type of industrial truck is not suited to performing all kinds of materials handling activities that cannot be performed manually, resulting in goods having to be buffered in between handling using the different types of industrial trucks. A restriction in the operation of the process, concerning improvements in the process planning, ie attaining a more uniform work load, is the *demand* of the products. At certain times of the year, the demand increases, which the distributor must be able to accommodate. *Disturbances*, such as deliveries including products that are out-of-stock and that have to be prepared immediately, are another restriction.

DISCUSSION AND CONCLUSIONS

The aim of this paper was to present a methodology for evaluating and improving a materials flow system. It is one step in our long-term objective, which is to be able to decide where a process is best performed in the materials flow, how to utilise the packaging configuration to obtain a high degree of effectiveness in the total materials flow system, and to identify the most important factors on which improvement efforts should be concentrated.

If a change process is to be performed in a system including a large number of materials handling activities and transportation, the materials flow can be used as a point of departure. An argument for this is that the materials flow can be seen as the main process of the system, and if it works well, the prerequisites for an effective total system are good. On the other hand, if the materials flow does not work very well, there will be great problems for the other subprocesses of the system, as well as for the system as a whole. When having evaluated the materials flow effectiveness, and the causes of materials handling activities have been identified, the next step is organisational or technical development in parts of the system.

However, the methodology in this paper is so far not sufficiently developed to be fully utilised in evaluation and improvements of materials flow systems. It needs to be further developed, especially regarding the zero-based analysis for judging effectiveness in the materials flow systems. The main problem concerns the definition of necessary work (Z), and a set of rules has to be formed that in a reliable way discriminates necessary work from inefficiencies. The concept of entropy, however, seems to be a fruitful base for such rules, combining the value-adding aspect of Z and the logic of the materials flow being a process creating orderly conditions. Also, the models concerning the causes of materials handling, ie causes of division of processes, and restrictions on changes, need to be studied in more detail, adding factors at lower levels to be used as more reliable check lists when looking for possibilities of improvement.

Besides being a measurement of value-adding for comparison of different systems, the entropy measurement is also useful in a more qualitative sense for finding out at which positions in the materials flow system the non-value-adding, or even value-subtracting activities are located. Thus, the positions which need to be addressed in the change process in order to achieve increased effectiveness of the materials flow can be identified. One reason for using the entropy measurement is that it can be measured early in a planning process for a new or changed materials flow, before all details are known, and that it is more stable over time than, for example, monetary measurements. It also provides more information regarding prerequisites and potential for improvements than measurement of the actual outcome at a certain time. Therefore, in order to determine whether an activity is really adding value to the product, or whether it could be carried out more effectively, the entropy measurement can be helpful.

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