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Warehouse layout alternatives for varying demand situations

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Abstract
Many supply chains strive to shorten the time between a customer's order and the actual delivery of the ordered goods, i.e. the response time. However, a shorter response time may induce a higher volatility in goods flows. We present practical methods to determine layouts for the material handling facilities (warehouses, cross-docking centres and container terminals) which take these inherent variations into account. Advantages and disadvantages of the methods are treated. As an example, a comparative analysis of the methods is presented for the cross-docking centre of the "Royal Horticultural Company Lemkes" in The Netherlands.

1   Introduction
In various supply chains, with products ranging from mobile phones to groceries, efforts are being made to shorten the response time. We can divide total response time into three components: production time, handling time and waiting time. Production time includes, for example, the physical production of the goods, but also the time to enter an order into the computer system. Handling time includes all activities that involve movement of the products, such as road transportation and distribution activities within a warehouse. Finally, waiting time concerns all remaining time, where nothing happens with the product. Response time only includes the time spent on those activities that occur after the customer has placed an order.

The reduction of response times becomes more and more important from the perspective of cost reductions and customer service improvement (see, for example, De Treville *et al.*, 2004). Any attempt to reduce response times may be targeted towards any of the three components. In this paper, we will focus on handling and waiting times within the material handling facilities (warehouses, cross-docking centres and container terminals). It must be noticed that reducing the response time may increase fluctuations in workload. Consider, for example, a traditional warehousing operation. Customer orders are filled from storage, which means that arriving products are first stored and then wait in the warehouse until a customer orders them. This time lag between arrival and departure of the products, which may be days or weeks, gives possibilities for levelling the workload. Arrival and storage of products can be planned such that it occurs outside the demand peaks or can be spread evenly in time. If response time is decreased by reducing waiting time, i.e. the time that products are stored, less possibilities for levelling the workload remain.

The maximum reduction of waiting time in material handling facilities can be obtained if loads from incoming trucks are directed to departing trucks with as little time in between as possible; almost without storage. Loads can be stored on the floor between unloading and loading for a few hours to wait for a truck to arrive. This concept is generally called *cross docking* (see Schaffer, 1998). It must be noted, however, that the conceptual differences between cross docking, container handling, and unit-load handling in warehouses are minor. In all three situations, products (on pallets, in trolleys or in containers) arrive, are stored for a

short period of time, and leave. The typical storage area for all three situations consists of an open area (indoors or outdoors) where loads can be stored on the ground. Sometimes, loads may be stored on top of each other, or racks may be used. In any case, loads must be easily accessible, because the departure time of a load is always nearby. The definition of "a short period of time" may differ. For a typical cross-docking operation this may be a few hours, whereas for a container terminal this may still be several days.

Obvious candidates for cross docking are products that have already been ordered by the customer before transportation to the material handling facility has started. The shorter the duration of stay in the facility, the lower the response time to the customer. Other candidates suitable for successful cross docking are products with short delivery times, products with high demands and products with highly predictable demands (see Richardson, 1999). As can be derived from the product characteristics, successful cross docking depends on a reliable relationship between all partners in the supply chain, availability of information throughout the entire supply chain and a reliable handling of products (see Moore and Roy, 1998 and Schaffer, 1997).

The objective of this paper is to present practical methods which can be used to determine layouts for storage areas within warehouses, cross-docking centres and container terminals in quick-response supply chains. In Section 2 we present some background information in designing material handling facilities. Section 3 describes various layout models, varying from fixed layouts to flexible layouts on a daily basis. Furthermore, we treat advantages and disadvantages of these methods. In Section 4 we present a comparative analysis of the methods for the layout of the storage area of houseplants of the "Royal Horticultural Company Lemkes" in The Netherlands. Conclusions are given in Section 5.

2   Material handling facilities

Design of a material handling facility includes many aspects. Very roughly, we may distinguish three phases in designing these facilities. The first phase consists of determining the block layout, which places the various areas within the facility (for an overview see Meller and Gau, 1996). The second phase consists of determining the detailed layout of the areas. The third phase consists of finding operating procedures to control the processes both on a facility level as well as for separate areas. Although often presented as a top-down approach, it is important to acknowledge that the three phases could influence each other. Meller et al. (2004) aim for modelling constructs to include the area design (second phase) into the block layout design (first phase). It may, however, be equally important to take the operating procedures (third phase) into account while designing the areas and the facility as a whole. The latter issue will be explicitly taken into account in this paper.

What a good layout is for the storage area depends primarily on the reasons why this area exists. In our case, we are aiming at the design of an area that can operate within a quick-response supply chain. This means that the area must allow easy access to the loads and fast transportation of the loads to the loading dock. It seems, therefore, reasonable to focus on travel time minimisation. The travel distance depends on the layout, but also on the operating procedures. Many operating procedures for storage areas have been described in the literature. Routing policies determine the sequence in which various locations in the area must be visited (see, for example, Petersen 1997). Another operating procedure for storage areas concerns the determination of appropriate locations to store incoming products. For example, in traditional warehousing environments, one may wish to put the most-frequently requested products in the most accessible locations (see e.g. Petersen and Schmenner, 1999).

2

3　Layout models

Generally, the storage area of a material handling facility is rectangular with no unused space and consists of parallel aisles. Both sides of each aisle contain storage locations. The area can be divided into blocks, each of which contains a number of subaisles. A subaisle is that part of an aisle that is within one block. Cross aisles are positioned perpendicular to the aisles to allow travel between aisles. Cross aisles do not contain storage locations. An illustration is given in Figure 1.

XXXXXXXXXXXX
Insert figure 1
XXXXXXXXXXXX

In determining the layout of a storage area we need to decide on the values of the following variables:
- Number of aisles
- Aisle length
- Number of cross aisles

Each of these variables may be restricted by the available space, due to walls or other objects. To make decisions on the appropriate values for these variables a historical data set should be available for various input factors. The data set should preferable provide at least the following information:
- required storage capacity per day,
- number of routes per day,
- number of stops per route.

The required storage capacity, together with the space restrictions are needed to specify the set of feasible layouts. The amount of daily activity in the storage area is directly related to the number of routes per day and the number of locations to be visited (stops) per route. Different activity levels may require different layouts. Thus, from all feasible layouts, a layout must be chosen that best fits the pattern of routes and stops. The available data set needs to be split into two subsets. The first data subset can be used to create layouts. The second data subset can be used to test and compare the performances of the proposed layouts (see Section 3.4).

Bassan et al. (1980) provide a method for determining a layout for a storage area, under the conditions that loads are handled one-by-one ("single command") and that each load enters and leaves the area from opposite sides. Layout determination in warehouse order picking, restricted to a limited set of possible layouts and for skewed product demand (some storage locations generate more stops than other locations) is analysed in Caron *et al.* (2000).

In the following subsections we describe various general approaches to decide on a layout for quick-response situations. As a basic assumption we suppose that the layout of the storage area can be easily changed because no fixed constructions, such as racks or shelves, are used. This will typically be the case in many situations where loads are stored on the ground. Furthermore, we will assume that the process will have a natural cycle length of one day. This means that that arriving loads leave the facility the same day. Typically, such a facility will be (almost) empty at the start of each day. The presented approaches can also be applied to facilities with other cycle lengths; this assumption is only to facilitate ease of reading.

The resulting layout from each approach can be compared to the results of the other approaches. Furthermore, resulting layouts can be compared to an "optimal layout" scheme for benchmarking purposes (see Section 3.4). As described in Section 2, we measure the performance of a layout by its resulting travel distances. These travel distances can be obtained from, for example, statistical estimates (e.g. Hall, 1993) or from simulation.

3.1 Fixed layout

Our first proposed approach is to make a one-time decision on the layout. This means that the layout of the storage area will be fixed for a considerable time period, for example, one year. There is, however, a significant conceptual difference with the fixed layout of a traditional warehouse with racks or shelves. If, in a traditional warehouse, the storage requirements are lower than the storage capacity, then the layout does not change; only some rack locations remain empty. In our situation, less storage means that we can shrink the area by either reducing the number of aisles or the aisle length. Therefore, a fixed layout is to be expressed as either a fixed number of aisles or as a fixed aisle length. The other variable results directly from the required storage capacity for that period. The number of cross aisles can be determined independent of this.

A straightforward approach to determine a fixed layout is the following. We take the first data subset and use this, by means of calculations or simulation, to determine for each feasible layout the associated (average) travel distances. The layout with the shortest travel distances is then selected.

Several advantages of using a fixed layout can be noticed, such as ease of implementation and the possibility for employees to have a familiar, stable working environment. However, a fixed layout is static and not flexible. It does not adjust to fluctuations in daily activities and changes in workloads. Work efficiency may be good one day, but poor the next day. Furthermore, a fixed layout may become outdated if circumstances change. Therefore, it might be expected that the fixed layout needs to be checked and, if necessary, adjusted on a regular basis.

3.2 Category-based layouts

To incorporate more flexibility, we introduce the concept of category-based layouts. The basic idea is that we distinguish a limited number of different situations, based on the activity level within the facility. For example, one may distinguish busy, normal and quiet days. For each situation a fixed layout can be determined, following the approach of the previous subsection. If, for example, a busy day is expected, then the layout is composed according to the layout suitable for busy days.

To determine the appropriate set of layouts, an analysis must be made with the first data subset. One difficulty here is to select the factor(s) by which a decision for a layout can be made. One may think of distinguishing between activity levels by the required storage space, the number of customer orders, or the total number of stops. It may, however, be expected that these three factors are correlated. The total number of stops made on a day is, for example, likely to be higher on a day with many customer orders.

The second issue to be resolved is the best number of categories, i.e. the number of different layouts that are going to be used. The primary advantage of category-based layouts is the added flexibility compared to fixed layouts. However, employees now need to adapt to a set of different layouts. If familiarity with the layout for employees is an issue, there should be just a few categories. If familiarity with the layout is not an issue, or is outweighed by efficiency gains, then more categories may become attractive. However, in the latter case, the flexible layouts of the next section may be more appropriate.

3.3 Flexible layout

The concept of a flexible layout means that every day another layout is chosen, depending on the expected activity level. The possibilities for implementation depend strongly on the information that is available before the start of the day. If no information is available, it is not possible to use flexible layouts. However, often at least some information is known. For

example, the number of loads to be handled, or the number of customer orders for that day may be known. Since, we wish to obtain a method that can be used for practical purposes, it is not possible to determine each day the best layout according to the procedure for fixed layout. First of all there may not be enough information about the upcoming day to apply the model or to run a simulation. Secondly, these calculations are non-trivial and may thus require a considerable amount of computing time, for which there may not be an opportunity before the operation must be started.

We propose a simple, linear regression analysis to determine a rule of thumb for a flexible layout on a daily basis. The regression analysis should result in an equation that relates available information to layout. These flexible layouts may be suitable for situations with large fluctuations in the activity levels as well as for situations where long-run changes in customer demand are difficult to predict. The layout will adapt to the situation automatically, yielding a satisfactory solution on a daily basis. A disadvantage might be that employees need to adjust to a new working environment every day. Furthermore, the regression may give infeasible layouts that do not fit inside the building.

3.4 "Optimal layout" scheme
The "optimal layout" is not a method that can be used in practice. It is actually a benchmark, which can be used in the process of determining an appropriate layout. The "optimal layout" is nothing more than a layout based on an *ex post* evaluation of the data. This means that we determine for every day the best layout afterwards, so if all information is known. Now, it also becomes apparent why we defined two subsets from the original dataset. The first data subset can be used to determine layouts according to the three approaches, i.e. fixed layout, category-based layout and flexible layout. Next, we can use the second data subset to compare the performance of the various approaches mutually and with the benchmark. This ensures the independence of layout construction and performance evaluations.

4   Case study
We study a quick-response supply chain of houseplants. Royal Horticultural Company Lemkes functions in this supply chain as a logistics service provider for European retail chains dealing in houseplants. The core capability of Lemkes is to distribute houseplants from growers to retailers. Lemkes aims at minimising costs and maximising flexibility and customer service. In this supply chain, we can distinguish: growers, the cross-docking centre of Lemkes in the Netherlands and customers (i.e. retailers) all over Europe. Firstly, we will describe the most important material and information flows in this supply chain.

On a daily basis, retailers can electronically review the assortment and electronically place their orders. Plants can be ordered at Lemkes both in small quantities and in full trolleys. Demand for houseplants highly varies during the year. Huge demand peaks can be noticed just before Valentines Day, Mother's Day, Eastern and Christmas. In the winter and on Mondays demand is low. Currently, the annual demand equals 125,000 trolleys of houseplants. It is expected by Lemkes that the demand will double in the coming five years. Lemkes receives the orders of the customers and totals them for each of the 250 growers. The growers are notified by fax about the types of houseplants and the order size. The next morning, the growers deliver the houseplants in *grower trolleys* to the cross-docking centre of Lemkes. First, the houseplants are checked on quality and quantity. Thereafter, the houseplants are redistributed over the various *customer trolleys*. To this end, the empty customer trolleys are positioned in parallel aisles in the storage area. Each time an employee picks up a grower trolley, which is filled with houseplants, and the corresponding *distribution list*. The employee walks with the grower trolley through the storage area and puts houseplants from the grower trolley into customer trolleys in the sequence and quantity as

indicated on the distribution list. At the end of a day, the customer trolleys are loaded into trucks and transported to the customers. The total time between a customer's order and the delivery of the houseplant to the customer (the response time) is about 48 hours.

Summarising, this supply chain has to deal with a highly fluctuating demand, more or less predictable peaks in demand, expected demand growth and short response times. Clearly, the distribution of plants over the various customer trolleys in the storage area strongly impacts the response time in this supply chain. The objective of this case study is to illustrate the effect of layout optimisation for this storage area with respect to walking distances of the employees.

4.1 The storage area

The storage area of Lemkes is an indoor rectangular open area where, at the start of the daily process, empty customer trolleys are positioned in parallel aisles. Cross aisles can be inserted to divide each aisle into a number of subaisles. The minimum number of trolleys per customer equals 2, the average is 3.44, and the maximum equals 8. At the start of each day the empty customer trolleys are placed in the empty storage area, as follows: all trolleys of a certain customer are positioned at subsequent locations on one side of a subaisle. If the subaisle side under consideration has insufficient empty locations left, then all trolleys of that customer will be positioned at the other side of that subaisle or in the next subaisle. As a result, all trolleys of a customer are always on the same side of the same subaisle. Conversely, one side of a subaisle may contain trolleys for two or more customers. Some locations may remain empty at the end of a subaisle.

In optimising the layout of this storage area, we need to decide on the number of aisles, the aisle length and the number of cross aisles. We must take into account that the available area at Lemkes is 63 by 81 metres. The width of one trolley is 1.4 metres. A cross aisle must be 3.5 metres wide to allow for sufficient manoeuvring space. As a result the following restrictions can be derived:

- The maximum number of aisles equals 20
- The maximum aisle length equals 37 storage locations
- The minimum length of a subaisle equals 10 storage locations
- The maximum number of cross aisles is 3 or 4.

The maximum number of cross aisles depends on the number of locations per aisle. For example, in an aisle with 37 storage locations, at most 3 cross aisles can be used. Four cross aisles can be positioned in aisles with 34 or less locations. Adding a fifth cross aisle is not possible because of the fact that in that case the length of a sub aisle would be smaller than 10 locations.

4.2 Input data

As described in Section 3, we need historical data for various input factors. We obtained data from the information system for the period from January 1, 2002 until June 30, 2003. We divided this dataset into two subsets. One subset was used for developing the layouts and the other subset for the performance comparisons. The information in the system could be used to obtain the number of customer trolleys, the number of customers, and all distribution lists for each day in the dataset.

It is not entirely straightforward to obtain the required storage space from the number of customer trolleys. First of all, Lemkes leaves one open position between trolleys of different customers to reduce errors. Thus, to obtain the required storage space, the space of one customer trolley must be added for each customer on that day. Furthermore, some locations remain empty when positioning the trolleys in the storage area. As we explained in section 4.1, all trolleys of one customer are kept together. Thus if, for example, three empty locations

remain in an aisle and the next customer needs four trolleys, then all four trolleys will be moved to the next aisle. Lemkes uses a simple look-ahead scheduling technique to do these assignments. The average number of empty locations due to this effect was estimated at 1.45 trolleys per side of an aisle. Summarising, the number of locations required equals:

number of customer trolleys + number of customers + 1.45*(number of aisles) (1)

This equation links the aisle length to the number of aisles, because the number of locations simply equals the product of the number of aisles and the number of locations per aisle ("aisle length").

The number of routes for each day is known directly from the information system, and equals the number of distribution lists. The number of stops per route is also known from the information system, and equals the so-called *order lines*. An order line is one printed line on the distribution list, which indicates the location where houseplants must be put into a customer trolley. In the evaluated period, the number of order lines per distribution list varied between 1 and 30. The total number of distribution lists varied between 523 and 2526. To allow for a larger number of replications than would be possible with the available empirical dataset itself, we created empirical probability distributions for the number of order lines for each day, from which we could sample in the simulations.

For all experiments considered in this case study, a replication size of 6000 orders has appeared to be sufficient to guarantee a relative error of at most 2% with a probability of 95% (see Law and Kelton, 2000).

4.3 Travel distances

To measure the performance of each of the layouts, we used the total travel distances per day. These travel distances also depend on the type of routing method chosen to route employees through the distribution area. The objective of routing methods is to sequence the locations of a single distribution list, such that an efficient route is obtained. Ratliff and Rosenthal (1983) propose a dynamic programming algorithm that solves the routing of order pickers in one block to optimality in polynomial time. Roodbergen and De Koster (2001a) extend this algorithm such that it is capable to find shortest routes in two blocks. In practice, the routing problem is mainly solved by applying heuristics. The *S-shape* heuristic is likely to be the most frequently used in practice. Order pickers handle block for block while completely traversing each aisle with at least one pick location (see e.g. Hall, 1993). The *largest gap* heuristic follows the perimeter of each block entering subaisles when needed. An aisle is entered up to the largest gap (i.e. largest part of aisle without pick locations). Vaughan and Petersen (1999) present the *aisle-by-aisle* heuristic. Aisles are visited sequentially and dynamic programming is used to determine the best cross aisle to go from one aisle to the next. Roodbergen and De Koster (2001b) propose the *combined* heuristic, which uses dynamic programming. Aisles are visited in the same order as with the S-shape heuristic. However, the combined heuristic looks one aisle ahead. An order picker can choose between traversing an aisle to the following cross aisle or returning to the cross aisle from which the aisle was entered, such that the shortest combination with the next aisle is found.

In this research we use this combined heuristic. From other research in practice, it is known that this heuristic has a near optimal performance and performs better than other heuristics (see, for example, De Koster et al., 1999, and Dekker et al., 2004). A comparison of routing methods specifically for Lemkes is described in Vis (2004).

4.4   Fixed layout

The first method we proposed in Section 3 was to make a one-time decision for the layout. We use the first data subset to find the best fixed layout from all feasible layouts by determining the total travel distances for all feasible layouts with simulation. We have varied the length of the aisles between 20 and 37 locations. The number of cross aisles varies between 2 and 4. The required number of aisles can be determined with equation (1). All results are represented in Table 1. From the results we conclude that a fixed layout with aisle length 32 and 3 cross aisles results in shortest total travel distances for all days in data subset 1. The difference in performance between this fixed layout and the optimal layout scheme (see Section 3.4) for the data from the second data subset is 1.65%.

XXXXXXXXXXXX
Insert table 1
XXXXXXXXXXXX

4.5   Category-based layouts

We use the method of Section 3.2 to determine a category-based layout. We distinguish between quiet, normal, busy and extremely busy periods, based on the number of order lines. We have decided to use just one of the input factors to determine a category-based layout. In Section 4.6 we will examine possible correlations between the three input factors while applying regression.

From the data collected we can conclude that the largest number of observations (approximately 54%) is concentrated between the 3000 and 5500 order lines. We conclude that this is a normal workday for employees. A second but smaller peak (27%) can be found between the 5500 and 8500 order lines. This amount of order lines corresponds to a busy day for employees. Quiet and extremely busy days have respectively a probability of 9% and 10%. The characteristics of each type of category are represented in Table 2. For each of the categories we have determined an appropriate layout. These layouts are presented in Table 3.

XXXXXXXXXXXX
Insert tables 2 and 3
XXXXXXXXXXXX

The data in Table 2 suggest the following relation between the number of order lines (categories), aisle length and the number of cross aisles: the aisle length increases and the number of cross aisles decrease if the number of order lines increase. This can be explained as follows: cross aisles can be used to change easily between aisles. Cross aisles become more useful if an employee needs to visit fewer locations in an aisle. On normal days fewer locations need to be visited in an aisle compared to busy days.

The performance of this category-based layout is measured with the days in the second data subset and the results are compared with the optimal layout scheme. The total travel distances with this category-based layout are 1.13% higher than the total travel distances with the optimal layout scheme.

4.6   Flexible layout

At the start of each day all information is known at Lemkes concerning the required storage capacity (i.e. the number of customers and the number of customer trolleys), and the number of routes (i.e. distribution lists). Based on this information, we follow the suggestion from Section 3.3 to determine a rule-of-thumb for the number of aisles on a daily basis.

A regression analysis is performed on the first dataset to obtain a regression equation which

relates the available information (number of customers, number of customer trolleys, number of distribution lists) to the value of the variable aisle length. Based on the results for fixed layouts (see Table 1), we choose not to alter the number of cross aisles on a daily basis, but to keep the value constant at 3 cross aisles. Equation (1) can be used to derive the corresponding aisle length. Clearly, the measure of goodness of fit, R^2, has the highest value if all three input factors are used in the regression equation. However, R^2 is only marginally (R^2=0.804) smaller if just the two factor "number of customers" and "number of distribution lists" are used. This can be explained by the fact that the average number of trolleys per customers is fairly constant, and therefore does not add much information to the regression analysis. The rule of thumb for the aisle length equals:

$$\textit{Aisle length} = \tag{2}$$
$$(0.066 * \textit{total number of customers} + 0.003 * \textit{number of distribution lists} + 18.38)$$
$$\textit{locations}$$

We have used equation (2) for the second data subset and we have compared the results with the optimal layout scheme. The total travel distances for a flexible layout on a daily basis differ only 0.98% from the optimal scheme.

5   Conclusions

In this paper we have presented three practical approaches to determine layouts for storage areas in various material handling facilities that experience strongly fluctuation demands due to quick-response practices. The first – and most traditional – approach is to introduce a fixed layout for the storage area. "Fixed" means that we fix either the number of aisles or the aisle length. The other variable depends on the storage requirements for the day. A fixed layout will generally be chosen for a considerable period of time. From the case study at Royal Horticultural Company Lemkes, it appears that this option can give very satisfactory results. It must be noted, however, that unnecessary efficiency losses can occur if the layout is not updated on a regular basis.

Category-based layouts create more flexibility to deal with varying demand. In this type of layout, daily activity can be categorised based on information available before the start of the day. For each of the categories an appropriate layout can be determined beforehand. Flexible layouts automatically adapt to changes in the daily activity. For each decision variable a regression equation can be determined. For our case study at Lemkes, we found that a simple regression equation to determine the layout can achieve a performance that differs less than 1% from the optimal solution. It must be noted that the optimal solution is calculated with full information, which is only available *after* the day is over. A disadvantage of a flexible layout might be that employees need to adjust to a new working environment each day.

All three presented methods seem to be potentially useful in the considered environments. The more rigid methods need to be monitored more closely so they can be updated if the activity patterns have changed. The flexible layout adapts itself, but is more demanding for the employees because they are faced with a slightly different layout every day.

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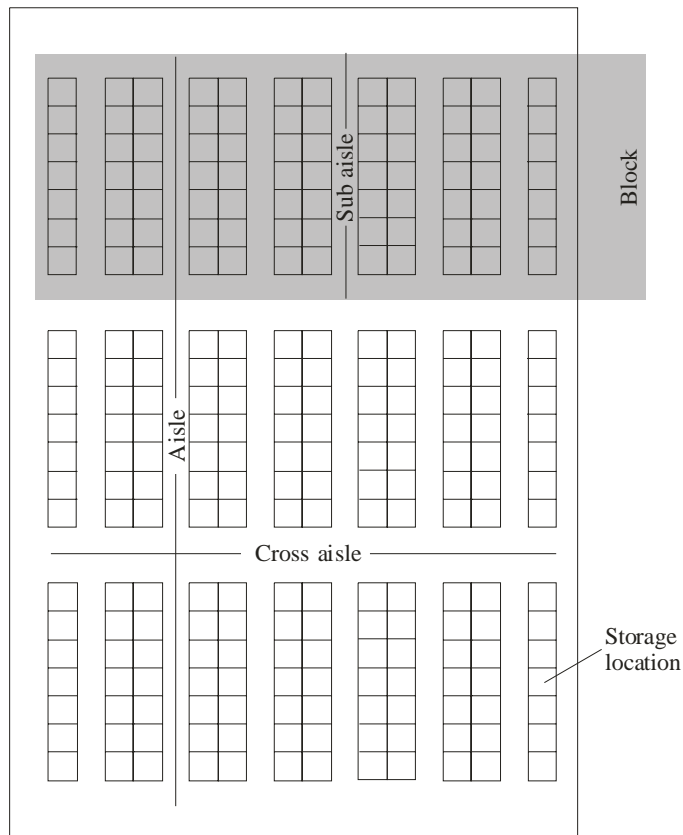
Figure 1: example layout of a storage area in a material handling facility. Each square indicates a storage location. Such a storage location may, for example, indicate the space to store a single pallet in a warehousing operation, or the space to store multiple containers in a container terminal.

Aisle length	Number of cross aisles	Length in meters	Number adjusted	Aisle length	Number of cross aisles	Length in meters	Number adjusted
10	2	25663718	97	28	2	24194366	8
11	2	25588891	88	28	3	18515195	8
12	2	25482761	76	29	2	24261529	5
13	2	25298910	66	29	3	18544025	5
14	2	25081482	49	30	2	24331289	4
15	2	24885183	40	30	3	18458117	4
16	2	24691234	35	30	4	18724249	4
17	2	24510691	33	31	2	24414567	3
18	2	24372774	30	31	3	18488623	3
19	2	24250271	26	31	4	18618279	3
20	2	24097737	25	32	2	24547123	3
20	3	19439081	25	32	3	18446241	3
21	2	24094389	21	32	4	18523216	3
21	3	19297666	21	33	2	24694019	3
22	2	24030132	14	33	3	18475933	3
22	3	19100517	14	33	4	18530974	3
23	2	24003117	11	34	2	24799694	2
23	3	19001714	11	34	3	18509283	2
24	2	23947054	11	34	4	18524838	2
24	3	18893185	11	35	2	24967520	2
25	2	24029230	11	35	3	18548621	2
25	3	18771678	11	36	2	25132199	2
26	2	24073441	10	36	3	18572630	2
26	3	18647008	10	37	2	25330827	2
27	2	24106947	9	37	3	18646852	2
27	3	18611666	9				

Table 1: This tabel represent the total travel distance of the 115 days in dataset 1 by varying aisle length and number of cross aisles. The fourth column indicates the number of days for which the fixed layout needed to be adjusted to fit in the building. A high number indicates a layout which is not very useful.

Category	Number of order lines	% of observations	Average number of Distribution lists
Quiet	0 – 3000	9.01 %	808
Normal	3000 – 5500	54.08 %	1007
Busy	5500 – 8500	26.61 %	1299
Extremely busy	8500 – 16500	10.30 %	1841

Table 2: Categories with specifications

Category	Aisle length	Number of cross aisles	Route length in metres
Quiet	28	3	60610
Normal	32	4	109866
Busy	32	3	192226
Extremely Busy	36	3	360449

Table 3: category-based layout