IMPLEMENTATION OF CROSS-DOCKS

J.J. Vogt*, W.J. Pienaar*

Abstract

The cross-dock-based supply chain is an integrated supply chain which uses the unique characteristics of a cross-dock to speed goods to downstream customers. A comparison is made with the warehouse process to demonstrate the improved efficiency of a cross-dock supply chain. There are three types of cross-docks and they all utilize the same design parameters to determine the shape and size of the facility. A method to determine these parameters is presented and practical design methods are illustrated. The relative advantages of manual and automated processes are discussed.

Key words: cross-dock, distribution centre, supply chain, warehouse

**Department of Logistics, Stellenbosch University, wpienaar@sun.ac.za*

1. Introduction

Like many simple methods, the cross-dock probably evolved in two industries concurrently. The cross-dock originated either in the railroads, where goods were moved across the platform from one rail car to another, or in the shipping industry, where the vessel was discharged across the dock and into a rail car, or vice versa. It is interesting to note that in the case of rail transport, the same mode was used inbound and outbound, while the ports utilized different modes. Irrespective of the origin, the intention in both industries was to move goods efficiently from one mode or medium of transport to the same or another mode of transport without storage. This remains the essence of the cross-dock operation today.

The cross-dock-based supply chain is compared to one that incorporates a warehouse with respect to the number of steps and hence the work involved. The warehouse is found to be the least efficient kind of supply chain. It is therefore necessary to investigate the use of the cross-dock and the applicable design principles. Two of the major issues related to the implementation of the cross-dock facility are then addressed in this paper: the layout and shape of the facility, and the choice of manual or automated operations.

2. Research Methodology

Considerable work has been done on the shape and size of the facility, predominantly for large, dedicated cross-docks in the retail distribution to end customers [1]. Transport problems are also mathematically treated for this situation [2]. There is some literature on the details of operations within the cross-dock [3, 4, 5, 6, 7]. But cross-docks are found in widely differing industries and situations remote from this large retail type of cross-dock, such as large-scale distribution of vehicles, ocean-port operations with containers and even perishable grocery products. Many of these situations are very different from the retail distribution scenario.

The types of cross-docking facilities have been recorded as Manufacturing, Distributor, Transportation, Retail [8]. There are also the pre- and post-distribution types based on where the barcode labels were added [9]. Other authors talk about 'opportunistic' types of cross-dock facilities and operations.

This literature search was complemented with detailed visits to multiple facilities on several continents. These explored both high- and lower-volume movements in:

- Port terminal operation (steel, paper and general cargo);
- Container depot operations;
- Apparel international movement centres;
- Grocery distribution centres;
- Home improvement equipment movement centres; and
- Consumer electronics movement centres.

The processes at these facilities were recorded in a flow chart, which reflected the work done in the total supply chain within which the cross-dock facility operated. These charts followed the three logistics aspects of:

- Physical movement;
- Information to generate movement; and
- Funds to enable the movement.

The flow charts created for the processes of these operations were analyzed. Touches and movements indicate the work done in the supply chain, while storage or stationary periods indicate inefficiencies, as the cross-dock-based supply chain has no storage component. A similar analysis was done for the standard distribution centre in a supply chain. Comparison of the metrics gave relative effectiveness for each supply chain. Each chain was ranked, and the factor or factors that made one chain more efficient was noted. Each factor that was identified was then referenced back to all the operational flow charts and a determination was made whether this factor changed the operation and type of cross-docking work in the supply chain. If there was a change that was common to multiple operations, then this factor underlined the type of supply chain and operation. Three factors were ultimately identified and are discussed later.

Some of the literature [9] recommends the use of Just in Time (JIT) practice for cross-docks. The primary application for JIT is continuous, full-volume operation where continual, small improvements can be made to achieve a balanced operation throughout the supply chain. This is rarely applicable to a cross-dock as the workload in the cross-dock varies with each transport receipt. It is true that the operation of a cross-dock is very similar to a manufacturing process. There is no buffer of stock to decouple the inbound and outbound processes other than staging. The operation takes place in a restricted area (the cross-dock), which is chosen to be no larger than required to improve efficiency through reduced travel distance and personnel. The work in the cross-dock for each received load alters with different orders and for different days. This is similar to a batch operation with variable workloads between batches [10].

A more appropriate method of process improvement is indicated in the Theory of Constraints (TOC) ([11]. This theory concerns itself with the identification of bottlenecks and their reduction or elimination. It utilizes visual identification of bottlenecks, which is more appropriate where the work changes each hour and each day, as in a cross-dock. In addition, the concepts of Lean Six Sigma are relevant here [12, 13].

In addition to the flow charts, structured interviews with two levels of management were recorded. These interviews focused on what management saw as the problems they encountered in making their operation successful, and what they saw as their success in implementing and operating a cross-dock facility in the supply chain. The interviews reflected common themes or issues in all the operations, irrespective of the industry or function.

3. Classification Of Cross-Docks

A definition that is valid for any cross-dock facility, whether in a retail chain, a port operation or in distributing industrial goods to sales points, is required and the most appropriate is the following:

A cross-dock is a facility in a supply chain, which receives goods from suppliers and sorts these goods into alternative groupings based on the downstream delivery point. No reserve storage of the goods occurs, and staging occurs only for the short periods required to assemble a consolidated, economical load for immediate onward carriage via the same mode as the receipt or a different mode [10].

It should be noted that the definition focuses on the downstream customer and takes goods from upstream. Its function is to offer a sortation of the goods into alternative groupings. This is the process where the goods are merged together or accumulated from multiple inbound suppliers to the outbound groupings of these products based on downstream customers. The facility will move the goods from the cross-dock to the downstream customers as soon as an economical load is achieved. This definition matches all cross-dock facilities reviewed in the literature and the research.

The flow chart comparison showed three primary features that identified the type of cross-dock and supply chain:

- Where in the supply chain the identification of specific items for a customer is done;
- Where the primary sort is done for the items to be delivered to a customer; and
- Whether the supplier is providing one product or multiple products to the sort.

When these features were tested against the researched facilities, it was found that there were only three types of cross-docks [10].

To define these three types of cross-dock, all three factors were required, thereby further validating the choice of these three factors. This is shown in summary in Table 1. They were tested against the existing operations and all were found to comply with these definitions. There are therefore only three types of cross-docks defined by these critical factors [10].

- Cross-Dock-Managed Load (CML);
- Joint-Managed Load (JML); and
- Supplier-Managed Load (SML).

4. Comparison Of The Types Of Cross-Docks And A Warehouse

While the above account answers the question of whether there is a common classification for the various cross-dock operations, a sub-question arises from the analysis: much as we can now classify the supply chain and its unique cross-dock type, what is the relative efficiency and value of these different types? The detailed research and analysis of the supply chains with cross-docks resulted in detailed understanding of the touches, the movements and the storage and/or staging of the goods. The warehouse and the different types of cross-dock-based supply chains are shown in a simplified summary of these analyses in Figure 1 [10].

Two operating conclusions can be drawn. The first is that the cross-dock is more efficient than the warehouse when total work in the supply chain is considered. The second is that, from these three classification factors for the supply chain, the choice for each factor for optimum efficiency is as follows:

- Identification of the products is done at the supply point for the use of the entire downstream supply chain;
- Supplier sorts the product(s) into uniquely identified consolidated units; and the
- One consolidated unit requires only a simple sort into alternative groupings for the downstream delivery.

This combination of the three factors results in the most efficient total supply chain. This is applicable to the SML-type of cross-dock-based supply chain operation. The greatest supply chain efficiency occurs progressively from the SML, then the JML and finally the CML types of cross-dock, followed lastly by the warehouse-based supply chain.

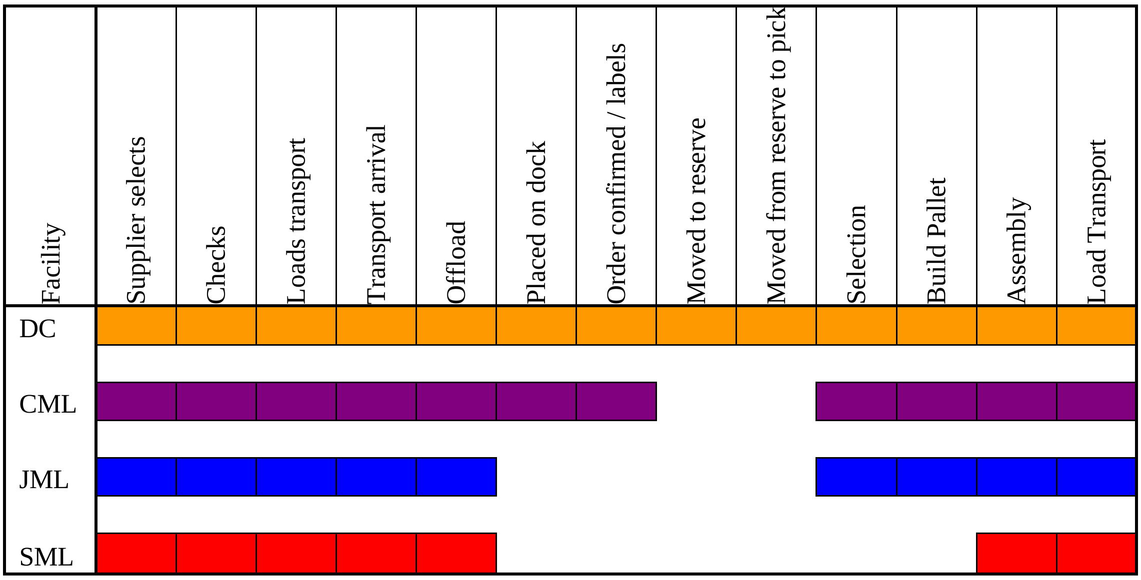


Figure 1. Comparison of supply chains containing a warehouse and the three different types of cross-docks

The cross dock has added advantages over the warehouse-based supply chain not shown in this figure. There is less inventory carried in the supply chain for the cross-dock operation, and the building is less costly as it is a simple, low-roofed facility when compared to a warehouse or distribution centre.

5. Physical Facility Layout - Requirements For Efficient Operation

5.1 Facility Shape and Size

Once the products, suppliers, systems, customers and cross-dock type have been determined, the only remaining issue is the design of the facility – its shape and size – to ensure maximum efficiency within these constraints. A large number of issues influence the width and length of the facility, and a significant number of these are closely interrelated [1, 10].

The efficiency of the cross-dock with regard to physical layout is determined by measuring the total travel distance with mass moved within the facility for all the goods. Thus the mass-distance moved is equivalent to the total work done in the facility and the design must try to minimize this value. This is nothing more complicated than the concept of centre of gravity calculations. The logical conclusion of this calculation is that the high-volume movement will be orientated to the middle of the facility. Inbound movement will have very low mass-movement values, if the high-volume outbound doors are placed near or adjacent to the high-volume inbound doors. Using the same logic, the lowest-volume doors must be furthest from the centre of the facility, as the lower volume multiplied by the longer distance will still minimize the mass-distance value in total.

The number of outbound doors is determined by a combination of the number of customers that must be served concurrently, and whether the outbound door is for a single customer or for a route servicing two or more customers. If every customer is allocated a door, then the goods for the customer can be moved into transport at the door immediately after sortation. No assembly or grouping of products needs to occur within the building. For smaller customers, it may be more economical for the delivery to be performed for two or more customers as a route. In this 'multi-stop' case, all the customers' goods for the route cannot be placed in a transport at a door at the same time, but must be assembled within the cross-dock. This immediately requires more space (increases the width), but it may be more economical than a larger number of doors with transport allocated to each door. There is obviously a complex trade-off between the choice of additional doors, which increases the perimeter of the facility (or length for a fixed width), as opposed to the increase in width when multiple customers are serviced on a route and staging within the cross-dock is required.

The number of inbound doors will be determined by the total movement through the facility and the time that trucks need to unload, as these factors determine the time that the door is occupied. The type of cross-dock will influence the time that the transport occupies the door and the space required to receive the goods. The SML requires no identification, only unloading. The JML will require more time, and the CML will require the most time and increased space for identification and labelling.

The perimeter is determined by the number of doors that are required for the receipt and dispatch of the goods, as they are generally placed on all sides of the perimeter. The width is chosen as discussed above. The determined width and the perimeter then result in a length and, therefore, the shape of the facility.

The overall capacity of the cross-dock is determined primarily by a combination of the capability of the personnel, the systems and the cross-dock design. Limitations in any of these three factors will reduce the efficiency of the cross-dock. The impact of the personnel, the correct facility design and systems capability is shown in Figure 2 [10]. The bottom left-hand matrix shows the comparison of operating personnel capability and the design of the facility with poor systems. The lack of systems, poor operating personnel capability and an inefficient facility design led to immediate failure, as is shown in the bottom left-hand block in this matrix. As personnel quality or facility design improves, so the potential to succeed increases. However, the facility will create problems and lead to inefficient operation. With the facility correctly designed and having good operating-staff capability, the results will be inadequate with poor systems. Even with improved systems as shown in the upper matrix, the potential for success increases, but the facility will be beset by errors if the people are not good, or by inefficient operation if the facility is poorly designed. Only with all three of the factors adding value will the operation have the potential to be highly efficient and effective.

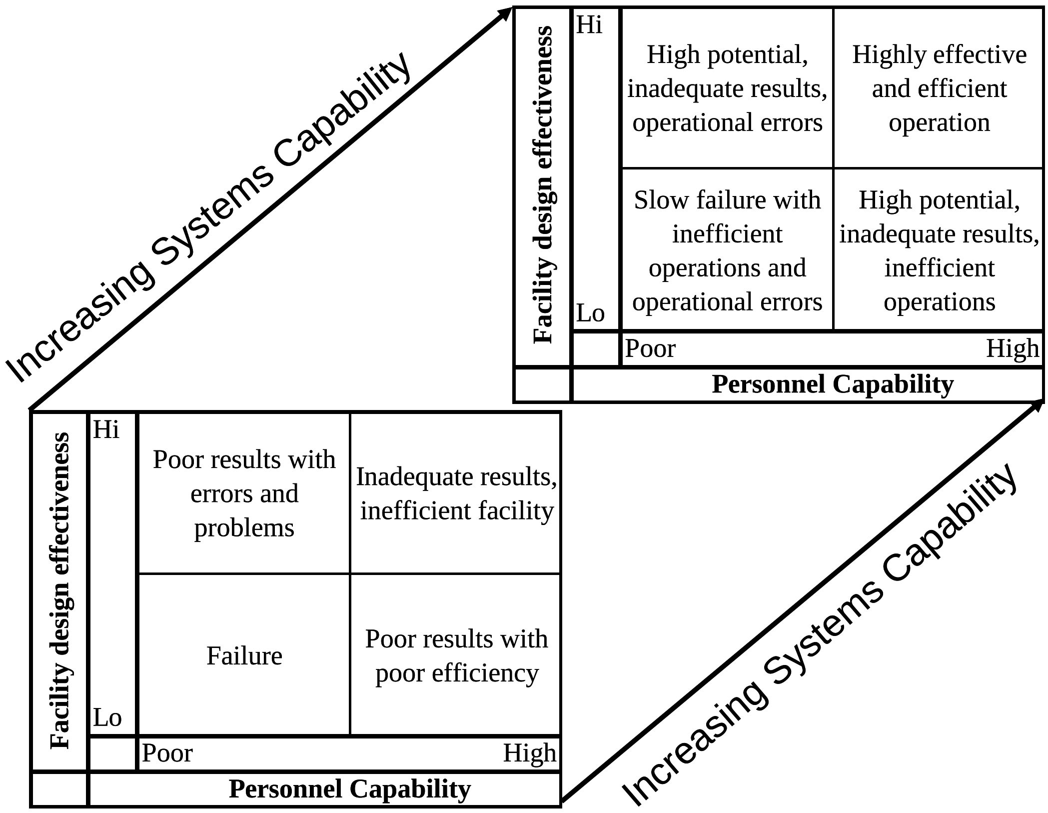


Figure 2. Inter-relationship of Personnel, Systems and Facility design

5.2 Facility Layout Options

If the above logic is analyzed, the facility can be designed in a number of physical shapes. In essence the above translates into the following [8, 14]:

- Determine the number of doors for unloading the transportation required to handle the goods inbound into the facility or Di;

- Determine the number of stores to be serviced, that is the maximum number of outbound doors or Do;
- Determine the space required for load identification inbound which is dependent on the type of cross-dock, whether it is classified as a CML, JML or SML. This is Si;
- Determine the number of routes that will be served, where the route implies one or more stores. If the routes are exactly equal to the stores, then there is one store per route. Each store is assigned to only one route. The routes are R;
- Determine the space required to assemble loads for the outbound economical loads or So.

One can write this mathematically as follows:

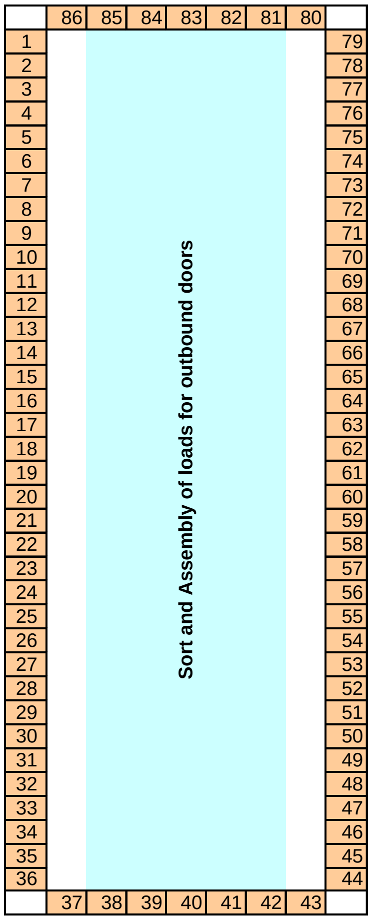
- Width = f(Si, So)
- Perimeter = f(Di, Do or R if R < Do)
- Di = Throughput / Rate of unloading per door.

As the ultimate requirement is to have the shortest distance to move the goods to achieve the cross-dock work, the concept is to minimize the total movement distance multiplied by the mass moved [15].

Bearing in mind that facilities and conditions vary widely and that a generic design is not sensible, the types of facilities can be shown by the juxtaposition of a high-volume and a potential low-volume facility with all the loads assembled in the facility. The low-volume storage facility allows lanes of various depths to be utilized to store the products. Each downstream customer will be allocated one or more lanes, depending on the volume of goods to be sent to the store. This allows the products to be assembled into these lanes and, when transport is available, to choose the best combination of downstream customers to deliver to from these lanes. The lanes are orientated to allow a sortation area, the movement left to 3-deep or 6-deep lanes, or right into the 4-deep lanes. Obviously the lane depth can be designed to allow for different numbers of pallets, but this is the principle of the design and layout.

Typical facilities for the higher- and lower-volume movement are shown in Figures 3(a) and 3(b) respectively.

What is interesting to note is the substantially different shape and size of a facility that evolves based on high- or low-volume movement.



lower case "a" for "assembly"

Figure 3(a). High-Volume Design Concept

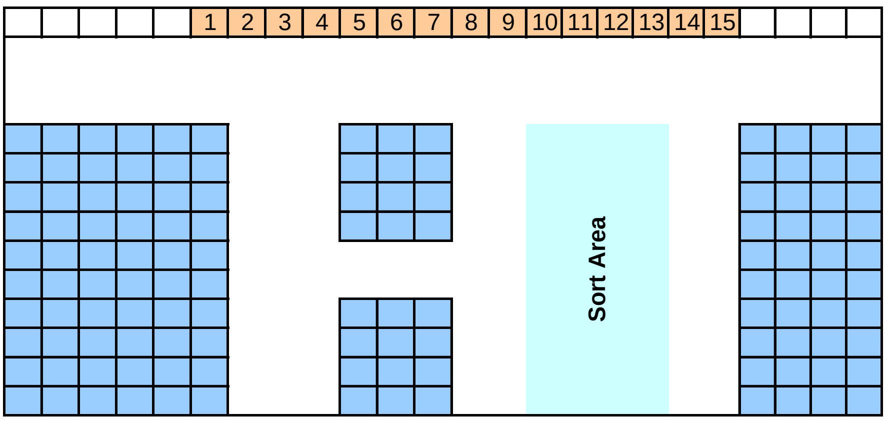


Figure 3(b). Lower-Volume Design Concept with Storage

6. Automated Or Manual Operations

6.1 Choice Of Manual Or Automated Processes

A choice of manual, partially automated or fully automated movement systems can be made for:

- the induction area, and/or
- the assembly areas and/or
- the sortation area.

The choice of a manual or automatic process is dependent on a number of factors. This section will review the most pertinent factors in deciding between manual and automatic systems.

Automated equipment is capital intensive. For any given facility area, it is difficult to justify the high capital cost for automated equipment for very low volumes. As the volume rises, obviously automation becomes economically feasible. It is therefore simple logic that leads us to understand that volume will be one of the primary issues in choosing between manual, partial automation or full automation.

The overall efficiency of any manual operation is critically dependent upon the distance that the goods must be moved by manual means. The further the distance to be travelled in the facility, the greater the inefficiencies that become inherent in the system. This determines the shape and size of a facility, and accounts for the findings which recommend that the shape of a cross-dock should change progressively from the initial rectangular shape, to a T shape and then an H (or I) shape of building. These shapes minimize the total distance travelled and thereby improve efficiency. Extending this logic, the manual movement of goods across the floor and in the sortation area cannot be done in increasingly larger areas and with longer distances as the throughput volume increases without an adverse effect on efficiency. The efficiency from the longer distance is in proportion to the distance travelled. If the width does not increase, which it should not in a cross-dock, then this is in direct proportion to the increase in length of the facility.

As the volume increases, so the number of operating personnel will increase. As the length of the facility, and hence the length of travel of the items, increases with volume, the number of personnel will increase even further than the pure length increase would require, as this length influences the productivity of these personnel and the efficiency of the operation. Personnel would need to traverse this longer distance to carry out this manual process. As more personnel are introduced to overcome the distance problem and the inefficiency that results from it, so more interference would occur in the process flows as the personnel move goods between the receiving and the dispatch doors. This interference will progressively add to a reduction in the efficiency of the operation. The efficiency is then dependent on two major factors –distance, and the interference that results from increased personnel operating in a defined space. These two factors working in combination would ensure a continuous decrease in efficiency as the volume handled increases. One could postulate that ultimately the efficiency would decrease at such a rate as to make the introduction of additional personnel of no added value. This is the point of marginal value for the manual operation. This will be at the point at which the interference factor is so high that the error rate becomes significant. The system is at the point where it cannot handle any increase in the volume and the volume has to be curtailed if it is to continue to offer a service of value. This is a natural limit for any manual operation. Space in the manual cross-dock cannot be infinitely increased, as it requires personnel to operate and these additional personnel, with the volume increase, result in progressively increased inefficiency as the size increases, and hence the distance items have to be moved.

For the automated option the logic is somewhat different. An automated system is designed with a specific maximum speed of movement, for which the motors and mechanisms are specified. Once chosen, this speed cannot be altered without significant cost. Thus the automated movement and sortation system is designed for the maximum throughput required at any given period of operation. This equipment can only run at this design speed, unless more expensive motor control systems are introduced, which add cost and limited value to the operation in terms of cost reductions.

6.2 Movement and sortation

Movement and sortation can be done by manual methods, where personnel manually move and sort the items without the use of automated equipment. Where items are being handled in a partly or fully automated process, the goods can be placed on a conveyor, moved to the sort area and sorted on the conveyor either manually (partly automated), or by automated (fully automated) sortation equipment. These systems all have high capital costs. As the speed of movement and sort increases, so the cost increases even further. Technology also has to change to accommodate the higher speeds. As the speed increases, so the change in impact on the item to change its momentum from the current path to the new diverted path increases. Automated sort equipment ranges from a soft move to a more serious impact, where fragile items are easily damaged in this diversion process. There are a number of different sort technologies. The more gentle diversion of the item is done by some form of arm that pushes the item into a new direction. Harsher sortation methods have wheels that pop-up and accelerate the items in the new direction. To utilise these automated movement and sortation systems, the range and size of products need to be restricted within limits that suit these sortation methods and the conveyers that feed them.

It is evident that the use of automation in the sortation area is dependent upon the physical characteristics of the goods as well as the speed of the sortation. The faster the speed, the higher the impact that the diversion facility will have on the product and the more restrictions the design will place on the physical characteristics of the product. When automated sortation is introduced, the premise to make it cost effective is that all products must be handled, otherwise two processes exist in parallel, additional space is required as well as additional staff, all of which adds complexity and costs. This would defeat the potential benefits of automation. Fragile products and extreme size or mass items cannot be handled on an automated system for standard items. It is therefore evident that only a restricted range of physical characteristics within clear limits can be handled by the sortation equipment, and that fragile products in particular cannot be handled in an automated sortation system.

6.3 Characteristics of manual and automated processes

There is a continuum of operating capabilities between the manual, partially automated and fully automated systems.

Manual sortation can operate up to medium volumes. Beyond that point the number of people and the rate of sort action required by the operator are too high to make the process feasible. To sort a single parcel the operator must identify the parcel as being necessary for the sort, push or pick up the parcel and move it to the diversion and push it onto the diversion conveyor. Above a certain speed the parcels will just travel too fast for the person to perform this sensibly and automation is required. Once automation is introduced, the products must be identified and barcodes have to be present on the items so that they can be read automatically. Automatic barcode scanners not only have to read a barcode, they must read the barcode on the face of the item while it is in motion. This makes the use of an in-line barcode scanner a prerequisite, but it is considerably more expensive than the hand-held unit. The installation of this equipment means that it becomes a permanent fixture. It is a large capital investment and cannot be altered to incorporate a slight change in the process or one additional customer without time and effort and cost.

The automated operation requires a process that is defined prior to the installation of the equipment. The process cannot subsequently be changed, as the automated equipment requires a specific set of steps to be completed before and after the automated system is utilized. For example, the design must indicate where in the supply chain the barcode label will be fixed to the item. If the decision is to place the barcode label at the cross-dock, then a sufficient area will have to be set aside to allow this operation. If the labelling operation is later moved upstream, the area in the cross-dock is under-utilized, as the automated equipment cannot be moved to incorporate this area. The automation also requires that the process is done in a specific sequence and at a specific minimum rate. This sequential requirement can be illustrated with the requirement that the barcode must be added prior to the item entering the automated sort equipment. The face of the item showing the barcode must be orientated in a specific direction to be read correctly by the in-line barcode reader. The rate of induction must be sufficient so that the system is able to handle the full throughput volume in the day. The system has a maximum speed determined by its design. It must run at this speed whether one or a thousand parcels per hour are being sorted. This holds up to the point where the maximum design level is being sorted. The impact of this is the same as if this were a manufacturing capability. The sortation acts as a bottleneck and any time lost on the automation is lost capacity. Thus if the trucks are not scheduled correctly and there are no items to sort for an hour, the system will have lost an hour. If five hours of the day are left to complete the sortation and dispatch, the system must now operate at 20% above the previous average (6/5) to complete the sort in time. If the system is designed to work to less than this 20%, then the sort completion will be delayed and problems will occur. Thus the automated process has far less flexibility than the manual process and is far more rigid in its demands for space and the steps in the operating sequence.

Obviously the manual operation, even with utilizing forklift trucks for the movement of the goods, requires a lower capital investment than the automated. As the volumes grow, additional equipment and personnel can be added without significant impact on either capital cost or the actual operating needs. This adaptability and agility mean that manual operations are suitable for a business that has a variable throughput or requires special operations such as value-added services (VAS). Automation cannot be altered with ease. Automated equipment, and changes to existing equipment, cannot be introduced as quickly and simply as can be done in the manual system.

The introduction of automation reduces the flexibility inherent in the manual operation, and in exchange offers a continual flow of items without the requirement for people and machines moving along the cross-dock. The speed that items can be moved and sorted is higher than in a manual process. The problem of interference between personnel as they move goods from one place to another place in the cross-dock also disappears, as automation replaces these people and machines. The multiple steps in the manual process of taking items from the truck, placing them on a consolidation unit, moving the consolidation unit to the required sortation area, placing it in a holding area, and doing the sort and moving the items to the assembly area are replaced by the automated operation. The automated sortation is designed for a specific throughput, with a specific number of induction points (receiving) and sort chutes to dispatch assembly points. This does make it extremely difficult to change any of the induction points, the sort points or the speed in the future. The automated sort must also be sized for the maximum throughput required in any one period and must run constantly at this high rate. The manual equivalent would achieve this change of throughput with additional personnel and pallet jacks or fork lifts which can be acquired in a day.

Where value-added services are to be provided, the automated system is less advantageous than a manual system. The automated system delivers items and a separate VAS area would then have to be created adjacent to the automated dispatch points from the sort chutes. Each item would then have to be handled and moved into the new area and only then consolidated for dispatch. These additional steps and touches of the goods negate the advantages of automation to a large extent. The one exception to this is VAS done to segregate products as they are taken from the sort chutes. For example, the perishable products that are handled in an automation operation are taken from the sort chutes and placed in 6 different containers, depending on the product type, by the operator. This is done by a simple visual check and label information so that the chilled items and the frozen items are segregated and placed in consolidation units or, in this case, containers. The perishable items are placed in up to four separate containers. The perishable products are segregated, as some products require different temperatures, some products are not compatible with others and some influence the shelf life of the other perishable products. For example, bananas and cauliflower must not be near one another as the cauliflower produces ethylene, which speeds up the – undesirable – ripening of bananas. The operator does this sortation, because the automated equipment would have to become far too complex to sort the product to six chutes for each store. The sortation equipment would have been six times more complex and the capital cost would have increased commensurately. Thus manual sort at the end of the process complements the high throughput that can be achieved with automated sortation.

This comparison is summarized in Figure 4, recording the differences and benefits of the manual and automated systems.

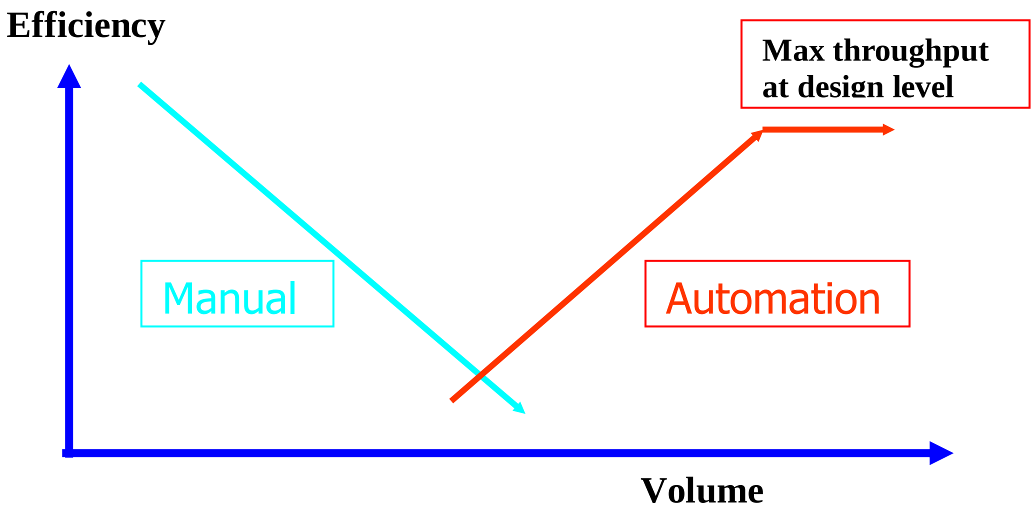


Figure 4. Comparison of manual and automated systems

Manual
•To match throughput fluctuations:
•Hours worked can fluctuate
•Staff levels can fluctuate
•High flexibility
•Low capital cost - high operating cost
•Supports VAS

Automation
•To match throughput fluctuations, the rate of induction is altered to match the throughput •Maximum speed set by automation
•Fluctuations increase the capital cost of equipment
•Limited flexibility
•High capital cost - low operating cost
•Difficult to introduce VAS

7. Conclusions

The most efficient type of operation is the supply chains with the SML type of cross-dock, while the warehouse is the least efficient, based on the number of steps in the process and the work done in the facility.

The layout of the cross-dock facility will be determined by a combination of the throughput, the number of downstream customers, the type of the cross-dock (be it CML, JML or SML) and whether the processes are to be automated or manual. These factors, excluding the manual or automated processes, are taken into account in order to minimize the total distance-mass movement. This is the concept of the centre of gravity calculation and the minimization of this value optimizes the facility for its role in the supply chain. There are defined relationships between all these factors regarding the shape and size of the facility, as discussed and shown mathematically.

When the benefits of manual and automated sortation systems are compared, it is evident that as the throughput increases and as the work done within the facility increases, so it becomes more and more difficult for a manual operation to maintain the efficiency required for a cost-effective operation. The first move to automation may well be the automated movement of the product to a sortation area, with the automated sort and its high capital cost delayed for future consideration.

The sort is the highest capital cost in the process and the automation speed sets the upper limit of the throughput. These can only be altered by means of physical changes to the automation system and software changes, which will be both expensive and time-consuming. Automation has its place to cater for higher volumes, but it needs to be chosen carefully and for the appropriate operation.

The choice of automation requires that all – or if not all, only a very small quantum – of the products are suitable for automation. Once this is established, then and only then should automation be considered. Operations with high fluctuation in throughput and with incompatible products are not suited to automation. Automation also demands more rigorous operational practices, where specific steps must be completed before induction into the automated system and, unless specifically designed, downstream processes are significantly curtailed in the cross-dock as a result of lack of space and the throughput rate.

Designed correctly, implemented with knowledge and understanding, operated with the right systems and resources, and utilized for the correct products, the supply chain with a cross-dock is a uniquely and highly valuable type of supply chain.

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