OPERATIONAL CRITERIA FOR A SUCCESSFUL CROSS-DOCK-BASED SUPPLY CHAIN

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Abstract

There is a need for a common definition for cross-dock-based supply chains; and there is a need to understand the different types of cross-dock based supply chains. This paper offers encompassing definitions of 'cross-dock-based supply chain' and 'cross-dock facility'. The definitions are applicable to all types of cross-dock-based supply chains and cross-dock facilities. Comprehensive research on cross-docking in the context of the entire supply chain is lacking. The paper shows that cross-dock-based supply chains are of three different types, defined by three principal features. Empiric research was conducted in order to ascertain the operational criteria needed to maximise value from all three types of cross-docking operations.

Keywords: Cross-Dock, Goods, Operational Criteria, Supply Chain

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INTRODUCTION

Cross-docks are utilised in different types of supply chains. These include supply chains that send components to assembly and manufacturing plants; those that facilitate finished vehicle distribution using rail-based cross-docks; those involved in handling fast-moving consumer goods (FMCG) in retail distribution; and courier transhipment facilities. Cross-docks can add value to supply chains where potential exists to improve operational efficiency, to expedite the delivery of goods, to reduce inventory and to improve the reliability of goods delivery. However, making a value-added cross-dock operation possible requires a clear understanding of, firstly, the different types of cross-docks; secondly, the features that differentiate each type of cross-dock-based supply chain; and, thirdly, the operational criteria needed to maximise value from the different types of cross-docking operations.

There is a need for a common definition of cross-dock-based supply chains and to understand the different types of cross-dock based supply chains. This paper collates the empiric research conducted via questionnaires and interviews at cross-dock facilities in Africa, Europe and the US. In order to establish the key operational criteria for a successful cross-dock-based supply chain, field notes on eight facilities were analysed. The findings show in consensus that there are nine such operational criteria, discussed in detail in this paper.

RESEARCH

Research problem

A need exists for a common definition for cross-dock-based supply chains; and there is a need to understand the different types of cross-dock based supply chains. Once these have been established and understood, it is important to determine broadly applicable operational criteria for successful cross-dock operations. Without a commonly accepted definition of cross-docking and a clear classification of types of cross-docks, there can be no real agreement on such a set of criteria. Because many different categories of success factors exist in the literature, practitioners are left to pick and choose the design and operational elements that may or may not be critical for the success of a cross-dock-based supply chain. To ascertain the value of a cross-dock within a supply chain, it is important to consider the supply chain in its entirety when assessing optimisation potential, and not merely improvements in individual sections of the supply chain.

The research approach employed to resolve the research problem combined a literature survey and empiric investigation. These are discussed in the following sections.

Literature survey

Research publications and other pertinent literature on cross-dock-based supply chains were reviewed. It was found that comprehensive research on cross-docking in the context of the entire supply chain is lacking. Existing works concern themselves with individual aspects of cross-docking, such as physical layout or management approaches. For example, extensive research exists on cross-dock shape and size (Bartholdi et al. 2001; Bartholdi & Gue 2004). Similarly, there is a great deal of published material on the scheduling of trucks into the facility (Gue 1999; Tsui & Chang 1990, 1992). Other works focusing on single aspects examine location decisions (Gümüs & Bookbinder 2004) or the use of lean practices within the facility (Cook et al. 2005; Goldsby & Martichenko 2005). Almost no work examines cross-docking from the perspective of its role in the total supply chain. Cross-docking is often construed to be merely mean a method of packing and sorting goods items – as in, for example, 'the concept of packing products so they can easily be sorted at intermediate warehouses or for outgoing shipments' (APICS 2005). Cook et al. (2005) concur, but add the point that, therefore, cross-docking 'does not rely upon withdrawing stock from storage'.

Empiric research

To better understand the diversity of cross-dock applications in industry, on-site interviews and reviews of processes at different cross-dock facilities in a variety of industry segments were conducted. These included facilities with differences in throughput volumes, operational position in the supply chain and in inbound and outbound transport modes. The types of cross-docks studied included the following:

- Port terminal operations (steel, paper and general cargo) – Africa (four visited)
- Container depot operations – Europe (one visited); Africa (one visited)
- Clothing movement centres – Europe (two visited); Africa (three visited)
- Grocery distribution centres – US (one visited); Europe (two visited); Africa (three visited)
- Hardware equipment movement centres – US (one visited)
- Consumer electronics movement centres – Africa (three visited)

The research was conducted using the following three approaches:

- Interviews with structured questions
- Creation of detailed flow charts of an entire supply chain
- Process flow diagrams within the cross-dock facilities

To determine a set of operational criteria for a successful cross-dock-based supply chain, field notes on eight facilities (the three clothing companies in Africa, the three grocery companies in Africa, the grocery company in the US and the hardware company in the US) were analysed. There was significant agreement across all these supply chains about the factors that are critical to the successful operation of these facilities.

The interviews were structured to discuss the following points:

- Why and how did the facility come to be created?
- What happened when the facility was commissioned and, in particular, what problems occurred? How long did it take to commission and to reach steady state? What was altered to achieve steady state and/or improve efficiency?
- Was this the first facility or did similar facilities precede it and, if so, what was different in the present facility?
- What systems were installed and were they altered during the first few months of operation?
- Where and how did the company recruit its staff, and which staff succeeded in operating the facility during and after commissioning?

An important objective of the research – namely, to identify clearly operational activities and their interrelationships – was accomplished by preparing a set of flow charts for each facility visited. Preparation of the flow charts required continual consultation with the various process experts to create a detailed understanding of the processes because none of the facilities had a comprehensive flow chart of the integrated processes. The flow charts provided a structured method of identifying and recording activities performed at the cross-dock facility. These included three components: physical movement, information needed to activate movement and expenditure needed to enable the movement.

DEFINITIONS OF CROSS-DOCK-BASED SUPPLY CHAINS

Confusion exists as to whether the term 'cross-dock' refers to a facility or an activity. Resolving the confusion requires clarification of what is meant by a 'cross-dock-based supply chain'. Given the need for visibility and coordination with upstream and downstream supply chain partners, then a cross-dock is not so much a physical facility as an activity shared by members of a particular supply chain, a common switch point where goods are sorted and redirected as quickly and accurately as possible within the supply chain. The efficiency of a cross-dock is premised on the cooperation of, and coordination with, upstream and downstream partners in a supply chain. Therefore, if a supply chain does not provide the required information flows and supply chain partners fail to coordinate among one another, then, although so-called cross-docking facilities may exist at points in the chain, the supply chain cannot be described as cross-dock-based.

A germane definition for 'cross-dock based supply chain' is as follows: *A cross-dock-based supply chain is one in which the integrated supply chain includes a cross-dock facility and in which the facilities and capabilities shared by members of the chain exist for the benefit of the chain as a whole, rather than of one downstream customer or another.* This definition focuses on the shared benefit derived from the cross-dock-based supply chain – an element that requires trust and a high degree of coordination and cooperation. A common definition of a 'cross-dock facility' applicable to all cross-docks is as follows: *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* (Vogt & Pienaar 2010).

A cross-dock facility holds goods to achieve the best possible balance of delivery speed and cost savings achieved by combining loads. Therefore, the process considerations of sorting and grouping are crucial to the economics of cross-docking. The definition provided above of a cross-docked-based supply chain can be applied to all cross-dock-based supply chains reviewed in the literature and the present research. Similarly, the definition supplied above of a cross-dock facility is applicable to all cross-dock classifications.

CLASSIFICATION OF CROSS-DOCK-BASED SUPPLY CHAINS

The analysis also identified the features used for the classification, i.e. those features that were present in all of the cross-dock-based supply chains, but in a different sequence or timing for different supply chains, and that were not due to factors such as different IT systems, but were inherent in the work performed by a cross-dock-based supply chain. The main differentiating features for cross-docked supply chains are three:

- Where in the supply chain the identification of specific items for a specific customer is done
- Where the primary identification and sorting for the items to be delivered to a customer is done
- Whether the supplier provides only one or different types of products

The first differentiating feature – product identification – is a factor with a direct impact on the supply chain in terms of the amount of work and personnel skill necessitated (Napolitano & Gross 2000). The earlier in the process the product is identified and the identification added (with a barcode, number or RFID tag, etc.), the simpler the downstream activities become. A cross-dock faced with a truckload of different items identified only with a paper manifest, and which need to be identified before being sorted, must do considerable detailed work and personnel must have knowledge of the products if apparently similar products with only subtle differences are included in the shipment. In addition, extra space and time will be required for the sorting, which will reduce the efficiency of the cross-dock-based supply chain.

With the second differentiating feature – primary identification and sorting – again, the significant point is how the decision affects supply chain benefits as a whole. A number of sortation actions can be done elsewhere in the supply chain before products reach the cross-dock. The supplier may place items for a particular customer in a consolidated unit, such as a box or pallet. These shipments can be further sorted in a cross-dock by being added to other products destined for the same customer. The question of where sortation actions should best be performed in the supply chain (i.e. before or at the cross-dock) and the relative complexity of the sort required at any stage are both factors that help clarify the decision as to where the sort is best done. For example, the earlier a consolidation is done, the less work and time are required for sorting elsewhere in the supply chain, and, therefore, the greater the benefit to the entire chain.

The third differentiating feature identified was whether the supplier is providing a single product or multiple product types. One product, such as a pallet of soap destined to a single customer, requires the cross-dock to move the packaged item from an inbound truck to an outbound truck for delivery to the customer. Conversely, multiple products in different packages from one supplier destined to one or more customers, adds another dimension to the sortation work.

From the above, three distinct types of cross-docks can be identified. Firstly, there is the cross-dock-managed-load (CML); secondly, joint-managed-load (JML); and, thirdly, supplier-managed-load (SML). These three categories define the amount of work involved and speed in the cross-dock-based supply chain that can be achieved as the process moves from the least efficient type of process and supply chain (CML), through JML, to the most efficient type (SML) (Vogt 2010).

OPERATIONAL CRITERIA FOR CROSS-DOCK-BASED SUPPLY CHAINS

To establish a set of criteria for a successful cross-dock-based supply chain operation, field notes on eight facilities were analysed. There was consensus among all the cross-dock and chain managers about the factors that are critical for the successful operation of these facilities, and the responses to the five broad initial questions posed during the empiric research corresponded with the nine criteria for operational success eventually found. The nine criteria or norms were not disclosed during the early interviews. After the field visits, summaries of the formal interviews were provided to senior management to discuss and validate the conclusions. When the research conclusions were discussed, facility management was asked to comment on the validity of the proposed nine criteria. In all cases there was agreement that the nine proposed norms or criteria were valid. As a final confirmation, managers were asked whether there were any other criteria required in addition to these nine. No additional criteria were proposed. The managers all agreed that these norms constituted a complete set of critical criteria.

The various criteria are interrelated, as would be expected given the highly integrated nature of supply chains that can make best use of the cross-dock approach (Vogt 2010). The nine criteria for success are as follows:

1. Appropriate products
2. Understanding how cross-dock-based supply chains work
3. Effective computer systems
4. Efficient physical facility design and layout
5. Process improvement and problem-solving capability in the cross-dock
6. Reliable product suppliers
7. Specialist and reliable supply chain service providers
8. Uniquely skilled management and staff
9. Work balancing and minimisation

These are discussed in the following sections.

Criterion 1: Appropriate products

Cross-dock-based supply chains are not suitable for all products. Appropriate products are those that have similar handling characteristics so that only one handling channel is required for the cross-dock. For example, foodstuffs and machinery require different handling methods. If more than one handling method is needed, it necessitates increased space, personnel and handling equipment, all of which reduce efficiency.

The most suitable products for cross-docking entail, firstly, delivery to most, if not all, downstream customers; secondly, consistent movement of the products from a supplier to provide continual loading through the supply chain; thirdly, speed of movement is critical; and, fourthly, a single method of goods handling.

Products requiring work and/or additional space, such as kitting, should be sent to a warehouse operation first, where the work can be performed, and then to the cross-dock.

Because cross-docking services customers using only staging, downstream customers should require, and be able to receive continually, significant quantities of products at all times. If this is not the case, then loads are sent off too soon to be economical, or they are excessively delayed until an economical load is assembled, thereby eliminating the desired speed of movement.

Speed of movement benefits the supply chain as a whole by reducing inventory held by supply chain members. This benefit is significant especially where higher-value and higher-volumes of inventory are involved, because it reduces the amount of working capital needed. The one exception to this rule is products that have notable time-to-market restrictions, such as fresh produce. These products, while not of high inherent value by item, have a time restriction after which they have no value – which imparts a relatively high value to such items. Such products are best served by a faster supply chain with a cross-dock.

Criterion 2: Understanding how cross-dock-based supply chains work

It is important to understand the different types of product supply chains because each requires different processes to be used in the cross-dock (compare criterion 1). During the empiric stage of the study it was observed that supply chains whose cross-docks struggled or failed were those where the role and the limitations of the cross-dock were not well understood. It is easy to reduce the efficiency of a cross-dock-based supply chain; all it takes is a lack of understanding of supply chain requirements, and decisions will be made that are to the detriment of cross-dock efficiency. A clear comprehension of the operational imperatives to achieve efficient and effective product supply chain performance is needed to successfully deal with the remaining seven design and operational criteria. Each type will provide a different kind of supply chain efficiency and, therefore, understanding them is paramount when a cross-dock-based supply chain is designed or improved. At the same time, knowing the type of supply chain is important for understanding how the design and operational criteria apply in a given case. For example, cross-docks of different constructional shapes and sizes are required by the three different types of supply chain. Products for the SML-type chain need to be standardised so that the unitised load moves through the cross-dock facility without alteration. To achieve work balancing in the SML type of cross-dock is simpler than coping with the plethora of products that need to be identified and sorted in the CML type. In all cases, the SML requires the greatest focus on making no changes without a full understanding of the total operation (see the 9th criterion, below), whereas there is slightly more leeway in the CML, where physical identification and initial sort is done anyway. The type of cross-dock supply chain will also influence the time that unloading incoming goods occupies a given 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 space for identification and labelling. All these variants show that knowledge of the types is essential to ensure that the success factors are clearly understood in terms of the type of cross-dock-based supply chain. In other words, it is necessary to understand the factors in general, and to understand how, and to what degree, these factors are influenced by each type of cross-dock-based supply chain.

Appropriate products for the cross-dock from a reliable supplier, and delivered by a reliable logistics service provider are essential for the movement of the products. Suitable systems enable the orderly management of the flow through the cross-dock to downstream customers. Within the facility, management should focus on continuous improvement and utilising the facility to the maximum potential its design will allow. Senior management must support and endorse this focus on a highly efficient supply chain, and not lose sight of the fact that it is efficient because it is based on a cross-dock – an approach that requires the various criteria to be adhered to at all times. Cross-dock operations have failed not only because of poor operation in general, but also due to decisions that did not take into account one or more of the criteria discussed here.

There were occasions during the investigation when managers of failing operations were amazed to realise, as they reviewed the research findings, that a sequence of small changes that affected one or two criteria led to a near failure or total failure of their cross-dock-based supply chain. The best example observed during the course of the study was one where a company decided to merge its small-parcel (courier) movement division with a larger-size parcel movement division. This course of action was based on the assumption that the combined entity would achieve greater efficiency and more buying power, and benefit from common support structures. The apparently small change of introducing larger-sized parcels into a document express system was not seen as a potential problem. However, the larger parcels could not be handled on the courier type of automated sortation system, something which then necessitated two handling methods to be crammed into the restricted space of the courier sortation building. Efficiency decreased as the second handling method utilised space needed by both, and obstructed the movement of courier parcel-sized freight. As the service level dropped, the company lost customers, struggled to survive and was eventually sold.

Criterion 3: Effective computer systems

Cross-docks are focused on high-volume movement of products. The speed with which goods move through the facility precludes the use of manual systems. For example, one operation unloaded pallets of boxed fruit from refrigerated rail wagons, then moved them through a cool tunnel and onto a ship for export. The pallets all had an identification label with three tear-off portions. Each had the same pallet number on these tear-off portions. One was placed on a sheet to indicate it was placed into the rail wagon; one to indicate it had been unloaded from the rail wagon; and one when placed on the ship. Although this simple system worked, numerous clerical staff were required to effect reconciliation of the moves, and retrospective checking later was a major, if not impossible, task. Reconciling the previous year's work for one client took months and demanded several personnel.

The systems chosen must provide the information necessary to integrate and manage the entire supply chain. This demands a greater reach of information than is typically found in supply chains with warehouses.

The systems required must incorporate all the following functionalities:

- Order management (OM) with advanced shipping notice (ASN) capability
- Yard management system (YMS)
- Cross-dock management system (XDMS)
- Track and trace (T&T) across the supply chain

To ensure that suppliers and customers are integrated, OM and ASN capability is required. This capability also helps suppliers make sure they have the correct stock, increasing their reliability. In order to plan work at the cross-dock, products in the inbound transport need to be visible to the cross-dock, requiring OM/ASN and T&T capabilities. The XDMS will allocate the correct transport to the unloading door to minimise work at the cross-dock, with the aim of reducing the move distances for products in the load. To identify the transport in the yard, and to find it efficiently, requires a YMS. A receiving door with no transport unloading means inefficiency in a cross-dock, and YMS helps to reduce this open/waiting time. The cross-dock requires XDMS to efficiently receive the goods, sort them and load transport. The T&T adds value to the downstream customer by providing information as to expected delivery times. The T&T system also allows all of the service providers to be measured as to cycle times and variability, which affect the efficiency of the supply chain.

Criterion 4: Efficient physical facility design and layout

One measure of the efficiency of the cross-dock is travel distance during the handling of goods within the facility. Once the products, suppliers, systems, customers and cross-dock type are determined, the design of the facility – i.e. its shape and size – should incorporate maximum efficiency in line with its goals. Many issues influence the width and length of the facility, and a significant number of these are closely interrelated (Bartholdi et al. 2001; Vogt & Pienaar 2010).

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 devoted to a single customer, or is a route servicing two or more customers. If every customer is allocated a door, then goods can be moved into transport at the door immediately after sortation. No assembly or grouping of products need occur. For smaller customers, it may be more economical for delivery to be performed for two or more customers as one route. In this 'multi-stop' case, all the customers' goods for the route cannot be placed in transport at a door at the same time, but must be assembled within the cross-dock, something which requires more space (width), but may be more economical than having more doors with transport allocated to each. There is clearly a complex trade-off between choosing additional doors, which increases the perimeter of the facility (or length for a fixed width), or fewer doors and more routes, which increases width required.

The number of inbound doors will be determined by the total movement through the facility and the time trucks need to unload, because these factors determine how long the door is occupied. The type of cross-dock will influence the time the incoming 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 space for identification and labelling.

The perimeter is determined by the number of doors required for receipt and dispatch of goods; doors are generally placed all along the perimeter. The width and the perimeter chosen determine the length, and also the general shape, of the facility. The capacity of the cross-dock is determined primarily by a combination of capability of the personnel, suitability of the systems and cross-dock design.

Criterion 5: Process improvement and problem-solving capability in the cross-dock

Successful cross-docks depend on continuous improvement (Goldratt & Cox 2004; Goldsby & Martichenko 2005). In every successful operation, the principles of theory of constraints (TOC) or lean six sigma logistics are applied. In some cases, this approach was not formal, but the principles were in actual use. However, in a large number of the operations, these approaches were formally applied. By contrast, it was found that failing operations were not applying these principles and techniques.

An operation reviewed during this research project was about to fail. A measurement had been introduced by the organisation – which had a few cross-docks and several warehouses – to minimise the time spent to unload a truck. Although this measure helped the warehouses, the cross-docks nearly went under. To meet the specified time limits, the focus was placed on unloading trucks in the minimum time. Additional people were allocated to unloading, and goods were left on the floor for later identification and sorting, which eventually caused a total bottleneck. The facility ran out of space. Goods were handled more than once just to create more space, and then handled again to find the right goods for the sort. All this occurred because the dock did not recognise the new bottleneck quickly enough, examine the causes and then eliminate them, which would have been the case had the organisation applied classic TOC methods.

Criterion 6: Reliable product suppliers

The suppliers of products to the cross-dock must consistently provide the required quantity of product ordered. As no inventory is carried by the cross-dock, the customer will only receive an order in timely fashion if the supplier moves it into the supply chain when required. Because of this interdependency among supply chain members, reliability must be extremely high to ensure the cross-dock approach is viable. At the same time, supplier reliability depends on customer behaviour to a large extent. A cross-dock approach should not lead to an increase in stock at suppliers, as long as other supply chain members make the correct product choices from the correct suppliers, and as long as the supply chain is tightly integrated by means of high visibility/transparency and information sharing. In addition, the supplier cannot deliver reliably if there are large, unplanned swings in quantities and frequencies of orders. The supplier must have access to sales information to plan the replacement of the products sold. This kind of feedback and/or planning will allow suppliers to be reliable without requiring them to carry additional inventory. Almost inevitably, this level of performance requires integrated systems with multiple suppliers, and customers who require the higher volumes that move through a cross-dock-based supply chain.

Criterion 7: Specialist and reliable supply chain service providers

Similarly, as product suppliers are obliged to move the right product in the right quantity into the supply chain at the right time, the logistics service providers – carriers and cross-dock operators alike – must also perform the tasks allocated to them to the same standards. All supply chain members must move and handle the products, both into the cross-dock, through the cross-dock and then to the customers, continually and efficiently. The choice of the most suitable logistics service providers ensures the fastest, most reliable and most effective supply chain. The overall integration of these service providers will influence the efficiency and effectiveness of the entire supply chain.

Criterion 8: Uniquely skilled management and staff

Management: Management must be detail-oriented and disciplined. This means that managers need to follow standardised methods of operation and receive a high degree of training to integrate the entire supply chain to ensure that it operates at the most efficient level, under the constraint of having no control over the ordering process in the member firms. The cross-dock is, therefore, liable to become the bottleneck in the supply chain because it is designed to use limited space and be efficient, with little or no margin for error. Any potential bottleneck must be quickly identified and then eliminated before it becomes a problem. For example, one operation visited during the present research had a long queue of trucks waiting to unload in the afternoon because all operations closed for an hour at lunch. The goal – i.e. supply-chain integration through continuous flow – was ignored, resulting in inefficient use of transport (i.e. trucks and drivers sitting idle) and pressure on the staff to perform faster after lunch, thereby increasing the potential for errors.

Staff: Special types of personnel are needed to operate a cross-dock. They must be able to continuously operate at very low error rates. In a warehouse, although an error is a problem, it is a routine part of normal practice. However, in the cross-dock, there is neither the time nor the space to correct significant numbers of errors. This is exacerbated by the problem of identifying errors in a cross-dock. Goods usually move so rapidly through the facility that an error will often be detected only when it has already reached the customer. When that occurs, all that can be done is to correct processes to reduce the potential for future errors – damage caused by an error missed often cannot be rectified.

Criterion 9: Work balancing and minimisation

There are three requisites for efficient cross-dock operation. Firstly, workflow remains consistent throughout the day. Secondly, specific doors are allocated to inbound and outbound goods movement to minimise the overall travel distance (and hence the total work done). Thirdly, the location of the inbound door at which each shipment is unloaded is chosen to minimise the distance for product movement.

Keeping a continuous level of work allows the correct resources to be planned and allocated to the known work. Within the operation, it allows the identification and elimination of bottlenecks before they become major restrictions. In a complex operation such as a cross-dock-based supply chain, it is almost impossible to allow significant changes in the throughput of the facility hour by hour and still be efficient; this is counter-intuitive. One facility refused to plan inbound deliveries because of concerns that the suppliers would not accept delivery slots. An experiment was done to part level the workload and the facility discovered it finished its work with the same loading of goods some 15 per cent more quickly.

Choosing doors for inbound and outbound freight can minimise the average travel distance. The door location applies the centre-of-gravity rule: the highest volume doors are placed in the centre and progressively lower volume doors are further from the centre. The highest volume doors in a cross-dock are the receiving doors, followed by the doors allocated to the higher volume customers. To minimise the travel distance within the facility, the doors for receiving should be adjacent to the higher volume outbound doors. Doors should be allocated from high volume in the centre outwards as the volume decreases. One further efficiency refinement can be made by using the correct systems. An individual transport vehicle can be unloaded at the door most likely to require the least total cross-dock work. A number of techniques exist to allocate transport to the most appropriate door to minimise travel distance. This allocation will vary depending on which outbound doors must be serviced with the received items. Advanced theory for allocating transport to doors has been presented (Gue 1999; Tsui & Chang 1992). The most practical method is to allocate the transport to the door that will minimise the travel distance, subject to the door's becoming available within a limited period that allows reasonable turnaround of the transport. This balancing of work ensures that the cross-dock is operated as close to level loads and as near to the maximum throughput possible, but without exceeding it.

CONCLUSION

Three key features drive the classification scheme of cross-docks: where the product is identified; where the primary sortation is performed; and whether the supplier provides one or different product types. From these three features there result three different types of cross-dock based supply chains: the cross-dock-managed load (CML); the joint-managed load (JML); and the supplier-managed load (SML). Distinguishing these is valuable for understanding how to choose a cross-dock: one type is more efficient than the others depending on how early products moving through the supply chain can be identified. The greatest supply-chain efficiency possible is, in order of decreasing efficiency, the SML, then the JML and finally the CML type. Although ideally the choice will be the most efficient – i.e. the SML type of operation – practical considerations will dictate which type is used.

This research has offered a set of nine criteria for value-maximising the operation of cross-dock-based supply chains. Understanding these criteria is valuable both for establishing new cross-docks and for operating existing cross-dock facilities. However, not all types of supply chains can effectively utilise a cross-dock-based operation.

Designed appropriately for the type of products to be distributed, implemented with knowledge and understanding, and operated with suitable systems and resources, the cross-dock-based supply chain offers the prospect to maximise flexibility, reliability and throughput productivity, which are imperative for improving order fulfilment, and it is, therefore, a highly valuable system.

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