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Study of the transferability of properties used for designing production systems layouts to distribution warehouse layout design

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Abstract: The performance of distribution warehouses plays an important role in the global performance of any Supply Chain. Logistic services providers need to plan the layout evolution of the physical system they manage to adapt to their customers' requests. A clear, global and detailed vision of logistic activities is therefore necessary. A considerable amount of research has been conducted on the design of production systems. This article proposes a study of the transferability of certain production system design properties to distribution warehouse design.

Keywords: graph theory, production systems, modeling, supply chain, warehousing,

1. INTRODUCTION

Distribution warehouses are key components of any Supply Chain [Gu et al., 2007]. The logistical activities carried out have a significant influence on the efficiency and effectiveness of distribution networks [Rouwenhorst et al., 2000]. This includes the handling of pallets (receiving and shipping) and storage, as well as other value added activities such as order picking, putting products in kits, product labelling or customisation [Gu et al., 2007]. These different logistical activities depend on the demand of the distribution warehouse's partners. These partners represent two other links of the Supply Chain: upstream production and downstream distribution. By extension, the entire design of the warehouse and its layout depends on the demand of these two entities.

Numerous issues are addressed when designing a warehouse [Gu et al., 2010]: (1) warehouse characterisation (determination of the storage capacity according to the seasonality of the activities, definitions of storage rules etc.); (2) warehouse dimensioning (translation of warehouse capacity into floor area, impact of the characterisation of activities on handling equipment etc.); (3) definition of the pallet stacking model (depth of traffic lanes, number of lanes for each depth, storage height, pallet movement angle in relation to the aisle, clearance between two stored pallets, aisle length and width etc.), storage layout (door locations, aisle orientation, aisle length and width, number of aisles etc.) and configuration of a potential automatic storage and supply system (determination of the number of lifting arms and aisles, design of storage racks etc.); (4) equipment selection (choice of storage systems, handling equipment, automation of activities etc.); (5) selection of operational strategies for storage (unspecified storage dedicated storage, class-based or time-based storage) and for picking (single order picking, sort-while-pick batching, sort-after-pick batching, sequential zoning with single order picking,

sequential zoning with batching, concurrent zoning without batching, concurrent zoning with batching). Designing a distribution warehouse is a complex task which determines to a large extent the logistical costs specific to the warehouse [Rouwenhorst et al., 2000], as well as its performance (construction and maintenance cost, handling cost, storage capacity, use of space, use of equipment) [Gu et al., 2010].

The demand evolves rapidly according to the market. This is why logistic services providers must rapidly adapt to their customers' demand in order to remain efficient. In order to provide a satisfactory response in terms of deadline and flexibility for their customers, distribution warehouse managers need to plan the layout evolution of the physical system they manage. Effective planning means anticipating the impact of the evolution of part or all of the physical system on all warehouse activities. Even if the activities carried out in a warehouse follow the same basic pattern, the flows generated are never exactly the same. They depend on their starting (storage location, unloading dock etc.) and arrival point (control point, loading dock etc.), which are not the same from one assignment to the next. According to Pierreval [Pierreval et al., 2007], if the components in circulation within a supply chain are complex and of many different types, it is difficult to comprehend their dynamic behaviour. This reasoning can be transposed to a distribution warehouse. Activities generate physical flows within the distribution warehouse, a global vision of these activities is required. The visualisation of the activities characteristics and links between these activities is also required.

Activities are essentially defined by physical and information flows. If the objective is to understand the global behaviour of the network of physical equipment, Pierreval [Pierreval et al., 2007] recommends the modelling of product flows. The characterisation of the physical flows due to pass through the warehouse is one of the most important decisions to be made during the (re)design of the physical system [Rouwenhorst et al., 2000]. Visualising the physical flows passing through the

warehouse helps understand how the network of logistical activities is structured. The visual representation facilitates the familiarisation with and understanding of the data [Card et al., 1999]. One possible response to the need for a visual representation of the flows is graphs, commonly used to represent systems which include complex links between their components [Borenstein, 2000]. The use of graphs has been proposed in the Supply Chain domain, notably by Tzoreff [Tzoreff et al., 2002], who studied the vehicle routing issue using specific graphs, with one or two warehouses. Pishvaei [Pishvaei, 2001] used graphs to propose a heuristic solution for the design of a Supply Chain network to determine the network configuration with the lowest cost. Irani [Irani et al., 2000] proposed a list of different graphs used since the 1950s to describe the structures of the flows passing through physical facilities (production workshop, warehouse etc.): (1) the "Product-Quantity (P-Q) Analysis chart" makes it possible to select a significant sample of products to be used in order to design a layout based on production volumes; (2) the "Operation Process Chart", used to represent the production stages of one single product assembled at a time; (3) the "Multi-Product Process Chart", representing all the flows linking together the production equipment, for all the products manufactured in the workshop; (4) the "From-To Chart", a simple oriented chart combining the contributions of each product to the flows into a single flow linking every couple of machines; (5) the "Flow Diagram", a hypergraph representation of the "Multi-Product Process Chart" (which can only represent a limited number of manufacturing operation sequences).

A graphical representation of the actual physical flows within a distribution warehouse ("Flow Diagram") is proposed in figure 1 for two order picking assignments, the receiving and shipping of goods. Each assignment generates flows between steering station, storage locations and docks. More specifically, an order picking assignment is carried out as follows: the order picker starts from the steering station, where he/she picks up the assignment, after which he/she takes an empty pallet at the "empty pallets stock" location and moves to the first location where he/she must pick packages. Once the picking task is complete, he/she places the pallet in the control point, where the order is checked. The pallet is stretch wrapped at the "Wrapper" location before being placed on a dock.

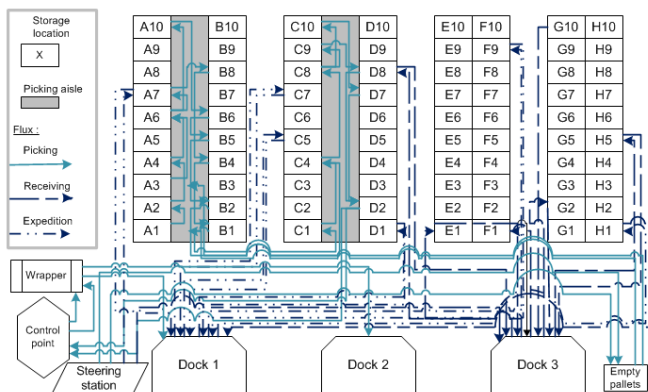


Fig. 1. : Flow representation within a warehouse

Figure 1 only represents a sample of tasks corresponding with a very short timeframe. However, the conclusions of a flow study are only valid if this study concerns a significant timeframe (several months to several years depending on the seasonality of the activities). Representing the assignment over a longer horizon leads to the appearance of a large number of arrows. The reader does not possess the cognitive skills to understand the structure of the flows based on this representation. Therefore the representation taking into account the actual physical layout does not respond to the need for a global and detailed understanding of the activities. It provides no clear insight into the structure of the flows and fails to draw conclusions on the ultimate efficiency of the flow management or equipment layout. This is why the flows must be redesigned without taking into account the actual physical layout of the material resources, to highlight the characteristics of the flows. This type of representation corresponds with what is known as conceptual graphs. Conceptual representation is one of the methods used to represent knowledge [Richard, 1983], the purpose of which is essentially to communicate and pass on information on reality.

The following questions arise: what should be represented in a conceptual graph and how?

Many studies have been conducted on the representation of production systems using conceptual graphs. The physical flows involved in warehousing are similar to those involved in production. The major difference between these two domains lies in the nature of the products stored. Unlike production warehouses, the sole purpose of which is to store the raw materials, goods being processed and finished products of a single company, distribution warehouses are used to store products from different production companies, intended for delivery to external customers [Rouwenhorst et al., 2000].

Flow structure analysis is facilitated by the definition of properties characterising the current physical flows between the different material resources of the physical production system [Dkhil et al., 2010]. According to Tompkins [Tompkins et al., 2003] and Zhou [Zhou et al., 2003], the relevant properties are those enabling the identification of specific links between all the material resources. Different analysis properties of manufacturing operation sequences are proposed in literature, such as clustering, ordering, source or sink properties [Zhou et al., 2003]. The question that arises is whether the properties defined for the production domain can be used for designing a physical system in the warehousing domain.

Our contribution consists of studying the transferability of properties used for designing production system layouts to distribution warehouse design. The idea is to determine whether the use of these properties helps achieve a clear, global and detailed representation of the activities of a distribution warehouse, via conceptual representations highlighting the structure of the flows.

Section 2 presents the properties studied, the practical case and the method used for the study. The conceptual representations obtained and their operational implications

are developed in section 3. Section 4 presents the conclusions of the study as well as its limitations and research perspectives.

2. PROPERTIES STUDIED

The study was based on the flow data of a logistic services provider based in France. The properties applied to flow data were derived from a list of forty four properties found in literature on the production domain by Dkhil [Dkhil et al., 2010]. We focused on a sample of three properties. The choice of these properties was based on questions which arise in the warehousing domain.

The first property selected is the total ordering property. The definition of an order link between physical resources makes it possible to detect the four types of movement between physical resources [Dkhil et al., 2010], i.e.: in-sequence moves (sequential flow between stations), forward moves (jump in moving sequences), backtracking movements (product moves in the opposite direction of the main flow) and repetitive moves (repetitive operations at the same physical resource. Identifying these types of movement helps optimise the circulation of products through the physical resources by determining a predominant direction of product flow [Zhou et al., 1996], represented by a specific order of physical resources. The resulting minimisation of backtracking moves simplifies the circulation of products. A concrete application of the order property is the formation of production lines [Zhou et al., 1996]. The following question arises: is the total ordering concept pertinent in the warehousing domain? During picking tasks, items are chosen according to a predefined order. The question arises as to whether this order can be compared with a total order and whether a similar order notion exists for pallet receiving and shipping assignments. The next stage is to check that the application of the total ordering property to logistical flows improves these flows via the definition of specific routes.

The second property is clustering. This property relies on the similarity of manufacturing operation sequences to form groups of physical resources and product categories [Adil et al., 1996]. For example, it facilitates the formation of relatively autonomous groups of physical resources (manufacturing units or production cells), depending on the sequencing of operations, process times or production volumes [Mahesh et al., 2002]. The following question arises: does the application of this property to storage locations help decide on the pallet handling strategy in distribution warehouses? Two strategies can be adopted: (i) separately process receipts and shipments to optimise the treatment time of each assignment; (ii) combine receipt and shipment processing to optimise movements (minimise empty runs). To make an informed decision, one must determine whether the storage locations concerned by the tasks of each studied assignment belong to common areas. Figure 2 lists the storage locations defined in figure 1. It presents a possible zone clustering of storage locations, where each zone corresponds with a limited floor area. Therefore the movements made within each of these zones do not exceed a certain length.



Fig. 2.: Clustering of storage locations

The final property studied is the "ranking by level" property. Defining physical resource levels makes it possible to combine the physical resources with the same predecessor, by representing them within the same unit [Kahn, 1962]. Therefore the representation by level of the physical resources through which flows pass corresponds with the ordered list of these workstations, respecting the orders defined in the manufacturing operation sequences considered. This representation helps highlight a sequential order for all operations. A high number of levels means that adjacency relation is close to a total ordering property [Kahn, 1962]. Two types of physical resource can be easily and quickly visualised on a multi-level chart: sources and sinks, respectively positioned at the top and end of the multi-level chart. A source corresponds with a physical resource for the first operation of a manufacturing operation sequence, for all products or a limited number of products [Dkhil et al., 2010]. Conversely, a physical resource is a sink when it is used for the final operation of a manufacturing operation sequence [Dkhil et al., 2010]. The fact to highlight source and sink is used in the production domain to determine the best possible location of the stock of raw materials, goods being processed and finished products. The following question arises: is it possible to develop a ranking by level representation of picking tasks? Is it possible to identify sources and sinks in the picking stock? And does this help optimise the layout of workstations upstream and downstream of the picking activity?

Graphs have been designed with the help of a graphics editor to assess whether the application of these different properties makes it possible to visualise consistent flow characteristics, useful for organising physical flows within a distribution warehouse.

3. REPRESENTATIONS AND OPERATIONAL IMPLICATIONS

3.1 Total ordering

Figure 3 corresponds with the conceptual representation of a total order picking assignment. Figure 4 represents the existing order link between the locations where pallets are taken from or deposited during a receiving task. Figure 5 represents the same link for a shipping assignment.

The total ordering representation of logistical flows makes it possible to visualise the different types of movement allowing the linear flow analysis. The representations

proposed herewith include sequential and backtracking moves.

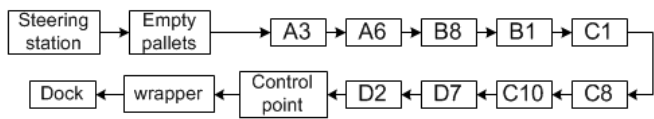


Fig. 3.: Conceptual graph of total order picking

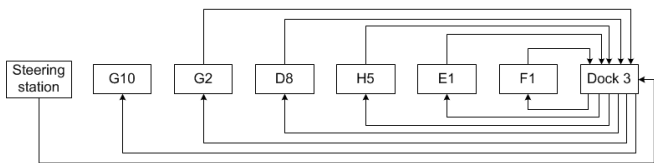


Fig 4.: Conceptual graph of a total order receipt

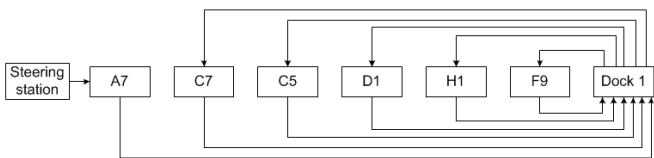


Fig 5.: Conceptual graph of a total order shipment

The application of the total ordering property to a picking assignment (figure 3) gives a linear chart with no backtracking. This shows that the picking activity is constructed according to the order concept: products are picked via a direct route, previously defined according to the picking strategy selected (in U, Z etc.) and the positioning of the different product references in stock. The application of the order concept facilitates the search for the required route and references to be picked to complete the order picking task.

Total ordering conceptual representations of receiving and shipping processes (figures 4 and 5) indicate that there are almost as many inward as outward displacements within each of these assignments. Half of the trips are therefore empty displacements, with no goods transported. This specific nature of the flows cannot be directly detected on the actual graph (figure 1). According to Irani [Irani, 1990], backtracking and crossing movements must be eliminated. Two solutions emerge from the conceptual representation of receiving and shipping flows: (i) insert docks after each location; (ii) modify the handling technology used so that the assignments can be performed in one displacement. For example, this could be achieved with supply trains used in the car industry.

The conceptual representation of flows according to the total ordering property raises the awareness of the characteristics of flows not directly visible on a layout plan (figure 1). The notion of distance travelled, important in the logistics domain, could be added to that of total ordering. This would help detect exceedingly long trip segments in relation to the overall displacements. For example, it would be possible to detect a poor choice of dock for an assignment.

3.2 Clustering

The application of the clustering property to a receiving and shipping assignment is represented conceptually in figure 6. It highlights three groups of locations which are in the same zone, based on the notion of zone clustering proposed in figure 2.

For the two tasks represented, the simultaneous processing of receipt and shipment makes it possible to reduce the overall distance travelled and therefore the total task processing time.

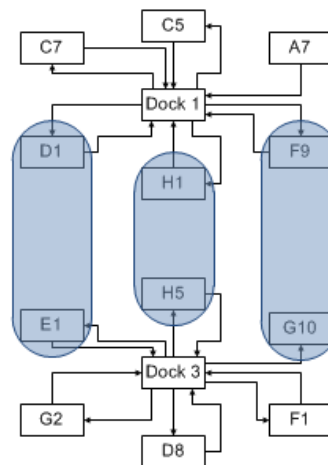


Fig 6.: Clustering conceptual chart

The clustering property is not only applicable to the flows of a distribution warehouse, it can also help steer logistical activities.

The clustering property can also be applied to order picking assignments and provide valuable assistance in the choice of the strategy to be adopted. The two strategies presented for receiving and shipping activities can be transposed to the order picking activity. It would be possible to optimise this activity by implementing a multi-order picking system, which would reduce the overall preparation cycle. This preparation method is called "sort-while-pick" batching. The following question arises: how to combine customer orders to create picking orders which include several orders to be processed simultaneously? The clustering property applied to several traditional order picking tasks makes it possible to detect order batches which require the picking of items within the same zones. The formation of these batches is based on the similarity of the lists of goods ordered and the actual position of these goods within the picking stock.

3.3 Ranking by level

Figure 7 is a conceptual representation of two "ranking by level" picking tasks. Only the locations of the picking stock are represented.

The "ranking by level" representation of picking tasks helps visualise forward moves. Sources and sinks can be determined based on this multi-level chart. According to this chart, the A1 and A3 locations are sources within the picking stock. The physical location visited before these locations

during a complete picking task is the stock of empty pallets. Figure 1 indicates that the stock of empty pallets is far from storage locations A1 and A3. This warehouse layout results in long trips, which could be made shorter. Moving the stock of empty pallets nearer to the sources or creating a new stock would minimise the distances travelled. This flow visualisation can also highlight the best possible location of the control point, the optimal position being near the sinks. According to figure 7, location D2 is a sink for both tasks. For the picking tasks represented, the control points' optimal location is as near as possible to D2. Identifying sources and sinks within the picking stock makes it possible to optimise the distances travelled by redefining the position of the workstations used upstream and downstream of the picking stock. These different modifications made to the layout of the physical facilities can reduce the picking time and therefore the costs incurred by the activity. As this activity is generally deemed the most expensive [DeKoster et al., 2007], this gain is significant.

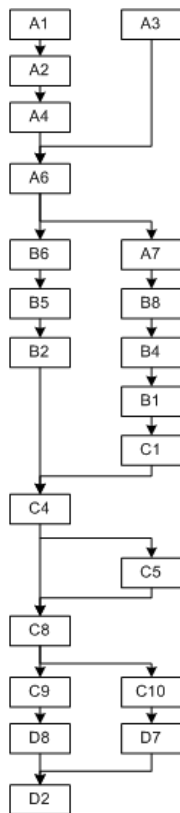


Fig. 7.: Conceptual "ranking by level" picking chart

4. LIMITATIONS AND RESEARCH PERSPECTIVES

The few properties studied have made it possible to verify that the properties defined for the defined for designing systems layouts in the production domain make sense in the warehousing domain. Furthermore, the different applications indicate that these properties can be useful when (re)designing the equipment of a distribution warehouse.

This study shows that knowledge developed for production systems design can be transferred to distribution warehouse design. This is partly explained by the fact that the four basic

activities, i.e. moving, storing, processing and controlling, are the same in the production and warehousing domains. However, these activities are not of equal importance in both domains: the processing activity is far more important in the production domain than in warehousing, which essentially consists of the moving activity. Warehousing needs are therefore not exactly the same as production needs. In a production workshop, product flows must be monitored and steered as a priority. In the warehousing domain, the analysis of product flows (pallets, packages etc.) helps identify potential improvements in the design of the physical facilities. For example, it helps detect unnecessary moves (use of a buffer stock, move from one storage location to another with no added value between the two etc.) or visualise the storage time of each reference. However, the movements of people (forklift truck operators, order pickers etc.) are the most important physical flows in terms of distances travelled and therefore cost. In addition, a significant portion of these movements are "empty" displacements, with no goods transported. The flow of people presents considerable optimisation possibilities.

Examining the transferability of the forty four properties listed by Dkhil [Dkhil et al., 2010] would make it possible to establish a repository of properties for the analysis of flows in the warehousing domain. This repository should be completed by other properties to be identified in literature on distribution warehouse issues. As orders in the warehousing domain correspond with the notion of goods in production, the clustering of orders is a pertinent example of the property. The repository developed could ultimately be used as a foundation for the development of a benchmark, providing a global and detailed representation of the physical flows within a distribution warehouse.

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