9-1-2010

Design of Cross-chain Internet Order Fulfillment Centres

Kees Jan Roodbergen
Erasmus University of Rotterdam, kroodbergen@rsm.nl

Iris F. A. Vis
VU University Amsterdam

Jaap Boter
VU University Amsterdam

DESIGN OF CROSS-CHAIN INTERNET ORDER FULFILLMENT CENTRES

Kees Jan Roodbergen
Rotterdam School of Management, Erasmus University, P.O. box 1738, 3000 DR Rotterdam, The Netherlands
kroodbergen@rsm.nl

Iris F.A. Vis
VU University Amsterdam, Faculty of Economics and Business Administration, Department of Information Systems and Logistics, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands

Jaap Boter
VU University Amsterdam, Faculty of Economics and Business Administration, Department of Marketing, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands
University of Amsterdam, Department of Book Studies, Oude Turfmarkt 141, 1012 GC Amsterdam, The Netherlands

Abstract

Many consumers have embraced the option of ordering via the Internet, which has resulted in an enormous increase in direct orders compared to the times when direct ordering was done by catalogue and phone. The fulfillment process in the supply chain is an important factor for these consumers impacting how long they must wait between ordering and delivery. This fact has significantly increased the importance of the back-end fulfillment process. We present a novel supply chain design to enable cross-chain coordination of order fulfillment operations for internet sales. Shared warehousing facilities are used more and more to achieve competitive advantage. This situation asks for new models to enable a smooth warehousing process for each web shop, but at the same time to ensure overall efficiency and effectiveness. This paper introduces a layout model for shared operations under one roof by simultaneously optimizing the overall facility layout and the area layout.

1 Introduction

The internet has completely changed the ways in which people communicate. Gradually, the internet is now also getting a firm grip on the physical goods flows. More and more consumers are ordering products via the web instead of buying them in a retail store. In 2009, internet sales in The Netherlands have shown a 17% growth compared to the year before, which is even more notable when compared to the 7.4% decrease in traditional retail sales over the same time period [1]. At least one product was purchased online by 8.6 million people in the country (on a total population of 16 million) in 2009. The average number of products purchased online was 6.2 products at an average value of 737 euro, which is an increase of respectively 15% and 13% compared to the previous year. Similar trends have been noticed for the rest of Europe by the research center Forrester [2].

From a logistics point of view, this sales channel switch has an enormous impact. Deliveries to traditional brick-and-mortar stores can be made in relatively large quantities at regular intervals. Consumers then buy the product in the store and provide an important logistics service: they transport their own products to their own homes for free. With the internet, products are ordered in small quantities by individual consumers and the web store has to arrange for transporting the products to the consumers' home address. It is almost needless to say that this significantly increases logistics efforts in the supply chain.

From the consumers' perspective, there seems to be a desire to increase online ordering, provided that some circumstances are improved. An important limiting factor for consumers is the delivery process. In many web stores, the consumer has no influence on the timing of delivery. As a result more than 30% of all orders cannot be delivered at the first delivery attempt. Besides planning, there is also the issue of speed. Information gathering and ordering is so fast on the web, that even a delivery time of 24 hours may feel like a lifetime. In the supply chain design, it must be decided which variability to accommodate and which variability to reduce. And, of course, to identify the means to achieve this. Given the pervasiveness of the internet as new channel and the new challenges it poses, it is surprising how little research to date has addressed the design of supply chains with online sales channels [3].

We intend to study the design of supply chain networks where shipments in small quantities have to be made from many suppliers to individual consumers. Considering the small volumes involved, a service provider will typically accommodate the operations for multiple web stores in one network with shared facilities. As a result, cross-chain coordination is needed to fulfill the requirements of both consumers as well as suppliers. We propose that an important role will be played by the cross-chain control center (4C), which has a coordinating role, spanning across multiple supply chains [4]. To better explain the 4C concept in the context of internet orders, consider the following example: every web shop has its own "shopping cart", an electronic analogy of the supermarket shopping carts, to collect products from the web shop before proceeding to the checkout process. If a consumer wishes to buy products from three different web shops, (s)he will have to use three different electronic shopping carts, make three payments, and will have three separate home deliveries of the ordered products. A company that would offer one shopping cart that can be used to buy products at multiple web shops will make the ordering process much easier for the consumer. Implementation of such a concept is, however, far from straightforward, considering the potential consequences for information sharing, contract negotiations and software interfaces between all parties involved. Furthermore, the added value of the concept is only truly complete if all products from the electronic shopping cart are also delivered to the consumer's home in one single shipment.

Even though the above concept of a shared shopping cart is still a rarity, sharing of warehouse space is quite common. Even before the times of the internet, there were already public warehouses, that served multiple companies. With the emergence of the internet the facility sharing, is however become different in nature. Existing facilities tend to keep processes for different companies completely separated, essentially resulting in several operations just sharing the roof and a common pool of employees. This is partly done, because this makes it easier to maintain separate branding, i.e. to make sure that packaging, labeling and the invoice all contain the logo of the right web shop, not that of the 4C. The question arises whether a higher efficiency is obtainable by more integration of processes.

The goal of this paper is to show how to design 4C networks that efficiently coordinate and integrate fulfillment operations for delivery (and returns) of products from multiple web stores to individual consumers. Secondly, we derive a mathematical model to determine concurrently the facility layout and area layout for a warehouse serving multiple web stores such that the operational efficiency is optimized. In Section 2, we present a conceptual model how to design 4C networks for internet sales. In Section 3, we introduce the layout problem for shared warehouse facilities in more detail. Section 4 shows the layout model itself. In Section 5 we derive an estimate for the performance measure used in the model. Section 6 presents conclusions.

2 Conceptual model to design cross-chain internet order fulfillment

In this section, we propose how to design a supply chain in which online sales activities will be outsourced to a logistics service provider responsible for coordinating e-fulfillment operations of multiple web stores (i.e., an 4C) to increase competitive advantage. Figure 1 depicts the physical flows organized in such 4C networks for internet sales and distinguishes between the three main processes: replenishment, order fulfillment and delivery & return processes. The physical flows depicted in Figure 1 can be described as follows. Several companies (A-C in this example) share an 4C network for their internet sales. In such a network, one or more shared Internet Order Fulfillment Centers (IOFC) may be available (here: X and Y). The IOFC(s) may be owned/operated by one of the involved companies or may be a separate entity.

Products are stored at the IOFC until the arrival of a consumer's order. Order fulfillment operations make sure that the right product is delivered to the right consumer at the right moment in time. Either the product is transshipped directly to the home of the consumer or it is sent to a decentralized coordination point, where the product waits until the consumer picks it up (depicted with numbers 1, 2 and 3 in Figure 1). It is also possible that a decentralized coordination point holds an inventory of products, in which case only the order needs to be relayed if the product is locally in stock. The decentralized coordination points may have many different manifestations; from a consumer's perspective some may even look like a common retail outlet. In The Netherlands, consumers have the right by law to return products within 7 days and can either send it directly back to the IOFC or bring it to a decentralized coordination point. The products are, thereafter, sent back to an IOFC. For ease of reading we depict in Figure 1 only one delivery and return option per IOFC. Clearly, also a mix in delivery options can exist for each of the IOFCs. Basically, internet retailers compete in their front-office processes in attracting and servicing consumers and cooperate in their back-office processes with regards to e-fulfillment operations. In this way, economies of scale in handling flows of small orders can be obtained and the noted challenge of handling "thinner" flows of products can be tackled.

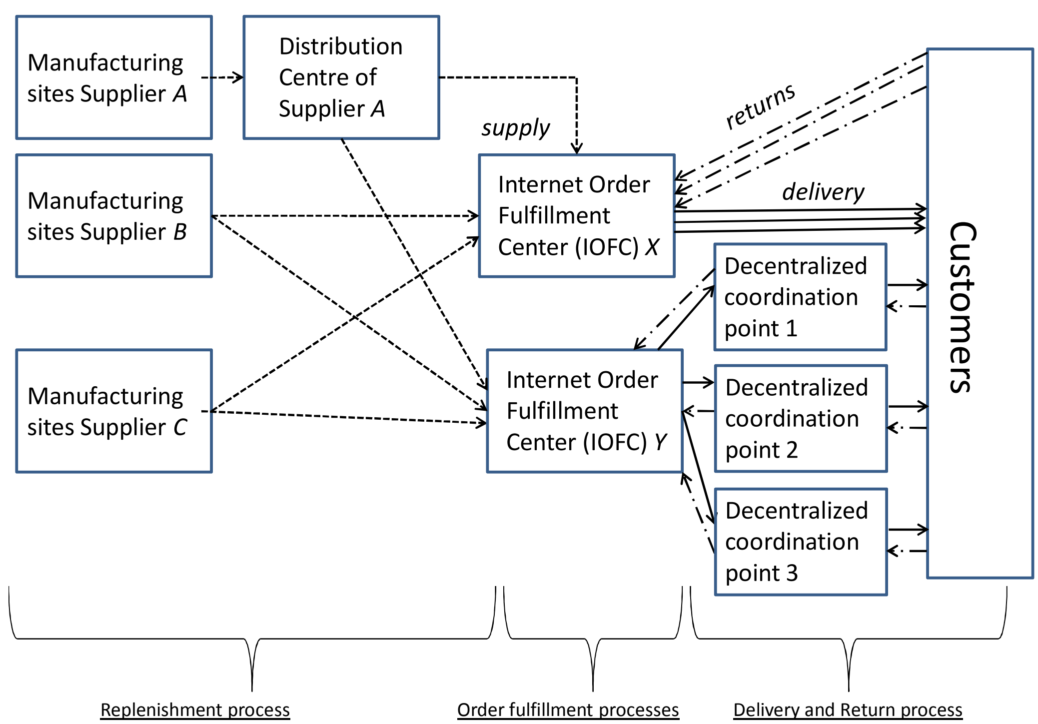

Figure 1: Physical flows in supply chains with cross-chain e-order fulfillment centers

The 4C is the coordinator in these supply chain networks and responsible for an efficient and effective organization of all forward and return shipments of products.

Figure 2 illustrates how information flows related to the replenishment, the order fulfillment and the delivery & return processes for each web store interact and need to be integrated to achieve this. The information flows can be described as follows. A consumer uses the website of a company to browse and/or purchase a product. The order is received at the 4C and the consumer is informed about the available delivery schedule. The 4C shares orders and forecasts of orders (based on information on e.g., promotions of companies) with the IOFC to make sure that the e-fulfillment process can be executed efficiently. Based on actual orders and forecasts of returns and transactions, the 4C determines replenishment orders such that space requirements are met. These replenishments orders are submitted to the manufacturers and/or distribution centers of the companies. Forecasts can, among others, be based on browsing activities of consumers. As can be noticed from Figures 1 and 2, there is a direct link between the flows of information available, the processes to be performed and the coordination of the 4C.

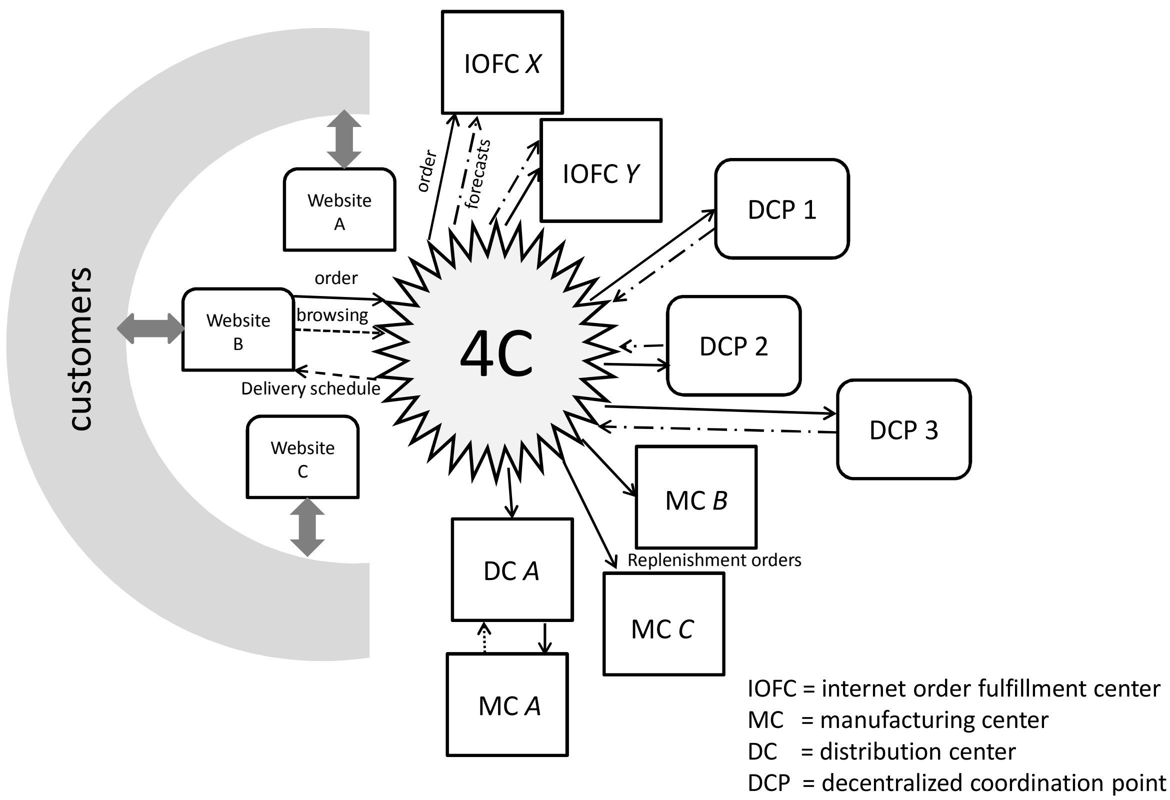

Figure 2: Information flows in supply chains with an 4C to coordinate cross-chain e-order fulfillment processes

An important challenge in this context is to design methods to efficiently merge flows of various web stores in IOFCs coordinated by the 4C. Closely related to this is the layout and organization of the IOFCs, which should be arranged in such a way that it ensures a smooth order fulfillment process for all involved companies. Despite the need for facilities to keep up with a service economy, the underlying design methods have not yet changed accordingly [5]. In the next section, we will present the layout problem for an IOFC in which multiple web stores share the facility and show the need for a new layout model in which overall and within-area efficiency is being optimized.

3 Problem description

The fulfillment process in the supply chain determines for consumers how long they must wait between ordering and delivery. This fact has significantly increased the importance of the back-end fulfillment process. As a consequence, the functional requirements for the IOFCs need to come to include capabilities to handle a higher frequency of shipments per consumer, a smaller number of items per order, increased responsiveness to changes in demand, and shorter delivery deadlines [6]. There is a need for additional research that helps to identify the magnitude of the impact of layout on total cost over the life of the order fulfillment centre [7,8]. Due to the labor intensity of the order fulfillment process, any future savings in labor may more than outweigh other design cost considerations, but this obviously needs to be investigated for each and every facility design anew.

An additional challenge arises when operations for multiple web stores need to be taken into account. Namely, next to efficiency and costs considerations, avoidance of errors is a vital aspect. Operations of various web stores should not be mixed up (e.g., a promotion leaflet of one company should not be added to the package of another company) to prevent effects on image and branding of the web stores. It is in this space that we aim to make a contribution, by defining a method that optimizes the layout of IOFCs while simultaneously considering within-area operational efficiency. Very roughly, we may distinguish three phases in designing facilities. The first phase consists of placing the various areas related to the various companies within the facility (e.g., [9]). The second phase consists of determining the detailed layout of each of the areas. The third phase consists of finding control policies that organize the processes both on a facility level as well as for separate areas.

The approach we take herein is not the usual, myopic, analysis-based approach, but in fact ventures into developing an integrated methodology that considers several aspects simultaneously. The goal of the shared facility layout model presented in Section 4 is to simultaneously design the overall layout of the facility and the layout of each of the areas designated for each of the web stores to optimize operational efficiency. Namely, we formulate a linear programming model to determine the layout of each of the storage areas in an IOFC such that the total layout fits in the total warehouse. We assume that each area consists of a single block with a front and back cross aisle and that random storage is being applied. The objective is to minimize the total time required to pick orders and replenish the items related to these orders in all areas. We will show in Section 5 how to derive an estimate within each area for travel times as part of this objective for several well known routing policies such as the S-Shape policy. We relate travel times to the number of items to be picked in each area. Calculations are performed on a daily base to distinguish between the workloads in each of the areas. Furthermore, we take into account in this objective, distances to be travelled for both replenishments and order picking from the areas to the dock doors.

4 Shared facility layout model

In this section, we derive a shared facility layout model to simultaneously determine the facility layout and area layouts. First, we define the required parameters and variables. Important input consists of facility specific information (e.g., total available space, width and depth of facility, products being stored and number of web stores), specific information for each area i in the facility (e.g., aisle width, cross aisle width, required capacity) and web store customers' information (e.g., size of orders). Travel times for both replenishments and picking within and between areas, which depend on the layout of the specific area and the number of picks, are being considered.

Parameters:

- Z set of areas for Z companies
- E maximum number of empty areas used to fill up total area
- A total available space (i.e. storage area) in warehouse (meters ^{2}) . Clearly, $A = W*D$
- W width of the storage area
- D depth of the storage area
- N maximum number of aisles to be used for each of the areas
- M maximum number of picks in a single order picking route
- J total number of products to be stored
- u_{im} probability that a pick list in area i ($1 \le i \le Z$) contains m items ($1 \le m \le M$)
- λ_i number of orders per day in area i ($1 \le i \le Z$)
- α_i average number of orders that can be collected of a pallet in area i ($1 \le i \le Z$)
- w_i aisle width in area i ($1 \le i \le Z$)
- v_i cross aisle width in area i ($1 \le i \le Z$)
- T_i total travel time required to perform picking (given a certain routing policy) for a single route in area i ($1 \le i \le Z$)
- R_i total travel time required to perform replenishments (given single command) for orders in a single route in area i ($1 \le i \le Z$)
- g'_{ikm} average travel distance within aisles for area i ($1 \le i \le Z$) with k ($1 \le k \le N$) aisles, 2 cross aisles and m ($1 \le m \le M$) picks in an order.
- h'_{ikm} average travel distance within cross-aisles for area i ($1 \le i \le Z$) with k ($1 \le k \le N$) aisles, 2 cross aisles and m ($1 \le m \le M$) picks in an order.
- S_i total length of area i ($1 \le i \le Z$) expressed in meters. This total length needs to be chosen such that there is sufficient space to store all products in this area.
- K large integer value

The values of g'_{ikm} and h'_{ikm} can be determined upfront for each combination (i,k,m) and a routing policy. We will show in Section 5 how these values can be obtained and used for the S-shape routing policy. We distinguish between two categories of decision variables. On one hand, we have common facility layout variables to assign areas to specific positions in the warehouse. Empty areas are also set to make sure that the total area is being used. In defining X and Y coordinates to represent the location of a department, we assume that the dock doors are located at the lower end of the area (i.e., y-coordinate equals zero). The other group of variables presents the size and layout of each area.

Variable:

A_i	size of area i ($1 \le i \le Z$) in meters ^{2}
E_c	size of empty area c ($1 \le c \le E$) in meters ^{2}
n_i	number of aisles in area i ($1 \le i \le Z$)
q_i^k	= 1 if the value of k (k = 1 .. n_i) is equal to the number of aisles n_i in area i for i $(1 \le i \le Z)$. Else, $q_i^k = 0$
l_i	length of each aisle in area i ($1 \le i \le Z$)
x_i	horizontal position of the upper left corner of area i ($1 \le i \le Z$)
y_i	vertical position of the upper left corner of area i ($1 \le i \le Z$)
p_{ij}^x	= 1 if area j right of area i. Else, $p_{ij}^x = 0$
p_{ij}^y	= 1 if area j right of area i. Else, $p_{ij}^y = 0$

The objective of the model is to minimize the total time required to pick orders and replenish the items related to these orders in all areas and consists of within and between area travel times. These travel times can be estimated based on the values of the variables obtained in the model. We will explain how to derive travel time estimates for T_i and R_i for a certain routing policy within-areas in Section 5. The shared facility model can now be formulated as follows:

Model:

$$\text{Min } \sum_{i=1}^{Z} \sum_{m=1}^{M} [u_{im} * \lambda_i * \{R_i + T_i\}] + \sum_{i=1}^{Z} [(y_i - l_i) * \lambda_i * (1 + \tfrac{1}{\alpha_i})]$$

Constraints:

(1) $\sum_{k=1}^{N} q_i^k = 1 \quad \forall i \in Z$

(2) $k * q_i^k = n_i, \quad \forall i \in Z, k = 1..N$

(3) $\sum_{i=1}^{Z} A_i + \sum_{c=1}^{E} E_c = A$

(4) $n_i * l_i = S_i \ \ \forall i \in Z$

(5) $A_i = w_i * S_i + 2 * n_i * w_i * v_i \ \ \forall i \in Z$

(6) $x_i \geq 0 \ \ \forall i \in Z$

(7) $x_i \leq W - (n_i * w_i) \ \ \forall i \in Z$

(8) $y_i \leq D \ \ \forall i \in Z$

(9) $y_i - (l_i + 2 * v_i) \geq 0 \ \ \forall i \in Z$

(10) $p_{ij}^x + p_{ji}^x = 1 \forall i, j \in Z$

(11) $p_{ij}^y + p_{ji}^y = 1 \ \ \forall i, j \in Z$

(12) $(x_i + n_i * w_i) - x_j \leq K(1 - p_{ij}^x) \ \ \forall i, j \in Z$

(13) $(x_j + n_j * w_j) - x_i \leq K(1 - p_{ji}^x) \ \ \forall i, j \in Z$

(14) $(y_i + l_j + 2v_j) - y_j \leq K(1 - p_{ij}^y) \ \ \forall i, j \in Z$

(15) $(y_j + l_i + 2v_i) - y_i \leq K(1 - p_{ji}^y) \ \ \forall i, j \in Z$

(16) $A_i \geq 0 \ \ \forall i \in Z$

(17) $E_j \geq 0 \ \ \ j = 1..E$

(18) $n_i \geq 0 \ \ \forall i \in Z$

(19) $l_i \geq 0 \ \ \forall i \in Z$

(20) $x_i, y_i \geq 0 \ \ \forall i \in Z$

(21) $p_{ij}^x, p_{ij}^y \in \{0,1\} \ \ \forall i, j \in Z$

(22) $p_i^k \in \{0,1\} \ \ \forall i \in Z, k = 1..N$

Constraints (1) and (2) ensure that q_i^k is set to one for all $k = n_i$ and otherwise $q_i^k = 0$. These constraints are required to calculate the values of T_i and R_i and will be explained in more detail in the next section. Equation (3) indicates that the complete storage space available is filled by areas for Z companies and further E remaining areas with empty space. Not necessarily all empty areas E are required and as a result for some of these areas the solution $E_c = 0$ might be obtained. No additional constraints are required for these empty areas where as they are directly created from the empty space between the various areas. Equation (4) indicates that the total length of area i equals the product of the number of aisles in that area and their respective lengths. Clearly, each aisle has the same length within a area. With Equation (5) we calculate the surface of each of the areas. This surface consists of space required for the aisles and the cross aisles. Combining constraints (3) and (5) makes sure that no more than the available space will be used.

So far, we have ensured that in total no more square meters are used than available. However, we do not test if it is possible to fit all areas within the area such that length and wide constraints are met. Therefore, we need to perform a feasibility check by deriving the location of the system within the area. Equations (6) and (7) check that horizontal coordinate of the upper left corner is chosen such that total area fits within the given width of the area. Namely, with equation (7) we make sure that the distance from the upper left corner to the outer boundary of the total area is smaller than the total width of the area. In equation (8) we indicate that the upper left corner can never be located outside the vertical boundary D of the total area. Furthermore, the distance, including aisle length and the width of both cross aisles, from the upper left corner to the lower left corner needs to be larger than 0 as expressed in equation (9). Finally, we need to make sure that the areas do not overlap. First, we use equation (10) to ensure that either area j is located at the right of area i or the other way round. Similar, this holds in equation (11) for the vertical positioning. Secondly, if area j is positioned right of area i , the following constraint should hold: $x_i + n_i*w_i \leq x_j$. We can use the logical expressions of equations (12) and (13) to incorporate both if-conditions for the horizontal positioning. Similar conditions (14) and (15) can be derived for the vertical positioning. The remaining constraints define the non-negative and binary constraints.

Thus, we try to find values for n_i, l_i and A_i for each of the areas i ($1 \leq i \leq Z$) such that both replenishment and order picking distances and handling times are being minimized. The method can be used for any routing method. In the next section, we will show how a linear estimate can be derived for one commonly used routing policy, namely S-shape. In a similar way, estimates can be derived for other routing policies, as largest gap, combined and aisle-by-aisle. We refer to [10] for a detailed description of these routing policies.

5 Linear estimates travel distances

In this section, we will show how to derive linear estimates for the average order picking and replenishment travel distances. Both the terms R_i and T_i in the objective require some additional information. Namely, we need linear estimates to determine these travel times. First, we will derive a linear estimate for T_i .Based on the results in Roodbergen and Vis [11] we use the property that the travel time within an area exist of traveling within aisles and traveling within cross aisles and depends on the number of aisles and the number of picks per route. The values for g'_{ikm} and h'_{ikm} for S-shape routing can be derived similar to the procedure described in [12].

The number of aisles, however, is a variable in the model. As a result, we need the binary variable q_i^k that can be used in combination with constraints (3) and (4) to indicate the number of aisles as found in the solution. We now can express T_i as follows:

(23) $T_i = \sum_{k=1}^{N} q_i^k (g'_{ikm} * l_i) + \sum_{k=1}^{N} (h'_{ikm} * w_i).$

The first part of equation (23) is however not linear, due to the fact that both q_i^k and l_i are variables in the model. Therefore, we need to reformulate this part of equation (23). First of all, we know that $l_i = \frac{S_i}{n_i}$. As a result, equation (23) becomes:

(23') $T_i = S_i * \sum_{k=1}^{N} q_i^k (g'_{ikm}) * \frac{1}{n_i} + \sum_{k=1}^{N} (h'_{ikm} * w_i).$

As explained the values for g'_{ikm} are known and depend on the number of aisles. Therefore, we can use the term $\frac{1}{n_i}$ to adjust the values of g'_{ikm} to g_{ikm} before we solve the model. Clearly, $g_{i1m} = g'_{i1m}$. The values of the g_{ikm} $(2 \le k \le N)$ then become respectively $g_{i2m} = \frac{g'_{i2m}}{2}$, $g_{i3m} = \frac{g'_{i3m}}{3}, .., g_{iNm} = \frac{g'_{iNm}}{N}$. As a result, we get a linear estimate for T_i with equation (23).

(23') $T_i = S_i * \sum_{k=1}^{N} q_i^k (g_{ikm}) + \sum_{k=1}^{N} (h'_{ikm} * w_i).$

Similar, we can formulate an expression for R_i . Single command operations are being performed to replenish products at a certain location. For each location to be visited in an order, a replenishment needs to be performed. Therefore, we need to include the order size *m* in this estimate. With a single pallet multiple orders can be replenished. As a result, we need to divide the replenishment time by the number of orders that can be replenished to get a replenishment time per order. Furthermore, we follow the same procedure as introduced for T_i . Except this time, we only need to use the values g_{ik1} and h'_{ik1} to get the order picking and replenishment travel time related to performing a single command operation. Thus,

(24) $R_i = [\{S_i * \sum_{k=1}^{N} q_i^k (g_{ik1})\} + \{\sum_{k=1}^{N} (h'_{ik1} * w_i)\}] * \{\frac{m}{\alpha_i}\}$

6 Conclusions

Consumers have adopted internet as a valuable sales channel and it is reasonable to expect a further significant growth of the online retail sales, which emphasizes the need for improved ways of handling the product flows efficiently and effectively. In this paper, we presented a new concept to design supply chains for online shopping and proposed a new model to derive the layout of shared internet order fulfillment centers for multiple web stores. We showed in Section 2 that an important role in this type of supply chains can be played by a cross-chain control center (4C), which has a coordinating role, spanning across multiple supply chains. In Section 3-5 we derive a mathematical model to concurrently design the facility layout and area layout for each web store while minimizing travel times.

Acknowledgements

This work was supported by Dutch Institute for Advanced Logistics (DINALOG), Grant 2 0101 013R.

References

[1] www.thuiswinkel.org (visited April 5, 2010)
[2] Keuning, W., De online shop groeit, crisis of niet, *De Volkskrant* (29 maart 2010).
[3] Hill, A., Collier, D., Froehle, C., Goodale, J., Metters, R. and Verma, R., "Research opportunities in service process design," *Journal of Operations Management,* 20, 189-202 (2002).
[4] Commissie Van Laarhoven, Logistiek en Supply Chains: Innovatieprogramma, The Netherlands.
[5] Cross, C.S., "Warehouse design eliminates slim pickings," *Industrial Engineer* 38, 10, 48-49 (2006).
[6] Olson, D.R. (1994*), Designing and implementing order picking systems*. In: Perspectives on Material Handling Practice, Material Handling Institute, Charlotte, North Carolina, 1-24
[7] Gu, J., Goetschalckx, M. and McGinnis, L.F. "Research on warehouse operation: A comprehensive review," *European Journal of Operational Research* 177, 1-21 (2007).
[8] Gu, J., Goetschalckx, M. and McGinnis, L.F. "Research on Warehouse Design and Performance Evaluation: A Comprehensive Review," *European Journal of Operational Research* 203(3), 539-549 (2010).
[9] Meller, R.D. and Gau, K.Y. "The facility layout problem: recent and emerging trends and perspectives," *Journal of Manufacturing Systems* 15(5), 351-366 (1996).
[10] Roodbergen, K.J. and De Koster, R. "Routing methods for warehouses with multiple cross aisles," *International Journal of Production Research,* 39 (9), 1865–1883 (2001).
[11] Roodbergen, K.J. and Vis, I.F.A. "A model for warehouse layout,", *IIE Transactions* 38, 799-811 (2006).
[12] Vis, I.F.A. and Roodbergen, K.J. "Simple procedures for warehouse layout optimization," *Progress in material handling research: 2006*, R Meller et al. (eds), Material Handling Institute, Charlotte, North Carolina, 525-538 (2006).