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More efficient urban freight consignment preparation and transportation

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Abstract

Two alternatives of consignment preparation in an urban distribution centre serving a network of hypermarkets are analysed. The first alternative looks at orders from retailers being prepared simultaneously. The selection criterion for consignment preparation is the type of product. After identification and pick-up from the storage areas simultaneously for all destinations, products are then sorted per destination. Quasi-simultaneously all the consignments are prepared for loading onto the delivery vehicles. The second alternative is looking at identification and pick-up from storage depending on the consignment destination. For each destination consignments are successively prepared.
The comparison described in the paper between the two technologies (simultaneous and successive consignment preparation) highlights the advantages of the simultaneous consignment preparation. These technologies impact on delivery, with potential to be adapted to the retailers' requirements and avoid congested traffic conditions on urban arterial roads.

Keywords: Consignment preparation; delivery; urban distribution

1. Introduction

Warehousing plays an important role in the logistics of the distribution system. In correlation with other activities it determines the level of service offered to customers. Besides its main role, storage, warehousing contributes to the sorting, consolidation and transfer of products. It also provides a series of financial and information transactions. All these activities generate material, informational and financial flows which attract costs higher than the actual storage costs (Lambert et al., 1998).

The fast and efficient movement of goods throughout the warehouse, complemented by prompt and precise information on the incoming/outgoing/stored products represents the objective of any logistic distribution system. Hence, the three main functions of the warehousing, handling, storage and transfer of information are high on the list of priorities for the management of many companies (Tompkins et al., 1996).

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The handling function includes activities like: reception of incoming products, moving products into storage, preparing consignments according to customer requirements, direct product moving between the incoming and outgoing ramps (cross-docking), consignment delivery to customers using available transport resources. This paper focuses on the selection of products for consignment preparation according to customer requirements. The rationale for this investigation can be found in all the examples of inefficient activity of warehouses (Power, 2005; Colin, 2005; Fable-Costes et al., 2006; Filser, 1989; Pappadakis, 2006) caused by excessive or double handling, poor use of the storage space/volume, maintenance and idling costs of equipment and staff, uncoordinated receiving, distribution and cross-docking activities. All these have a negative impact on the performance of a distribution system.

2. Technologies for Consignment Preparation

Irrespective of warehouse design and storage options, two different technologies for consignment preparation/formation can be identified.

The first, simultaneous formation, is based on selecting products in the warehouse according to their type, simultaneously for a given number of orders. From each stack in the warehouse G_i , $(i=\overline{1,m})$ the quantities $\sum_{j=1}^{n} g_i^j$ required to form the consignment E^j, $(j=\overline{1,n})$ are picked up (Table 1). These are then selected according to the E^j destinations (customer orders). The quantities g_i^j, picked up from each stack G_i for the consignment/delivery *j*, E^j are quasi-simultaneously transferred to the locations assigned for each consignment formation E^j, $(j=\overline{1,n})$. In the end, each delivery E^j will carry the quantity $\sum_{i=1}^{m} g_i^j$. This means that quasi-simultaneously all the planned n consignments have been formed and loading for delivery to customers can commence almost simultaneously.

Table 1 Consignments E^j (structure,size) and stacks G_i

Consignment structure / Stacks	E^1	E^2	…	E^j	…	E^n	Ordered quantities
G_1	g_1^1	g_1^2	…	g_1^j	…	g_1^n	$\sum_{j=1}^{n} g_1^j$
G_2	g_2^1	g_2^2	…	g_2^j	…	g_2^n	$\sum_{j=1}^{n} g_2^j$
. . .	. . .	. . .	…	…	…	…	…
G_i	g_i^1	g_i^2	…	g_i^j	…	g_i^n	$\sum_{j=1}^{n} g_i^j$
. . .	. . .	. . .	…	. . .	…	. . .	. . .
G_m	g_m^1	g_m^2	…	g_m^j	…	g_m^n	$\sum_{j=1}^{n} g_m^j$
Consignment size	$\sum_{i=1}^{m} g_i^1$	$\sum_{i=1}^{m} g_i^2$	…	$\sum_{i=1}^{m} g_i^j$	…	$\sum_{i=1}^{m} g_i^n$	$\sum_{i=1}^{m}\sum_{j=1}^{n} g_i^j$

The second approach, successive formation, is based on selecting products for each consignment, E^j. The quantities g_i^j are picked up successively from the stacks $G_i, \left(i = \overline{1,m}\right)$ according to the customer's order. Each quantity g_i^j picked up from stacks G_i for a certain delivery/consignment E^j is transferred to the location assigned for consignment E^j formation. This is prepared for loading to be delivered to customer j. Then the equipment and operators can move on to prepare the next consignment. All the planned consignments are prepared successively.

Each of the consignment preparation technologies is a reflection of the warehouse design and storage decisions. Both have great impact on warehouse efficiency and productivity, influencing the size and frequency of consignments, the storage cost, the quality of service to customers and the warehouse working conditions (Hebert, 1995; Owens and Mann, 1994; Owens, 1986).

The warehouse design concept and the various storage options generate a large number of scenarios. Thus, just in the case of palletized goods for example, the efficiency and productivity of the system varies depending on the storage systems, with/without racking, with fixed/mobile racking, static/dynamic (Günthner, 1988; Tompkins and Harmelink, 1994), or the handling equipment, different types of stacking equipment, forklift reach trucks, forklift deep reach truck, forklift turret truck, etc. (Robeson and Copacino, 1994), and randomized storage (depending on available spots) or dedicated storage, or based on principles of compatibility, complementarity, popularity (stock turnover) (Hebert, 1995).

This is the reason why in the comparative examination of the two technologies mentioned above the analysis is limited to the case of a high rack warehouse for general palletized goods, with dedicated storage, using reach trucks, and forklift trucks (Figure 1).

There is a platform for consignment preparation at the base of the racking (Figure 1a) or in the tunnel space, at the base of the racking, on one of the corridors used by the forklift stackers (Figure 1b). On each side of the platform a row of storage cells has been removed, so the area is limited only by one rack. Both forklift stackers and forklift trucks moving goods onto pallets have access to the area.

Figure 1 corresponds to a distribution centre with storage, in a simplified manner. Figure 2 presents the incoming/outgoing flows. As shown, in zone II, where the goods are selected according to orders, both pallets that don't need to be touched again (λ_3 flow), and complete or incomplete pallets (λ_4 flow) arrive from the warehouse with the goods required to match the ordered quantities (when they are not multiples of the quantity on a pallet). The extra quantities in λ_4 flow are going back to the warehouse (λ_2 flow). In these conditions the flow of deliveries to the customers is $\lambda_3 + \lambda_4 - \lambda_2$ (Figure 2).

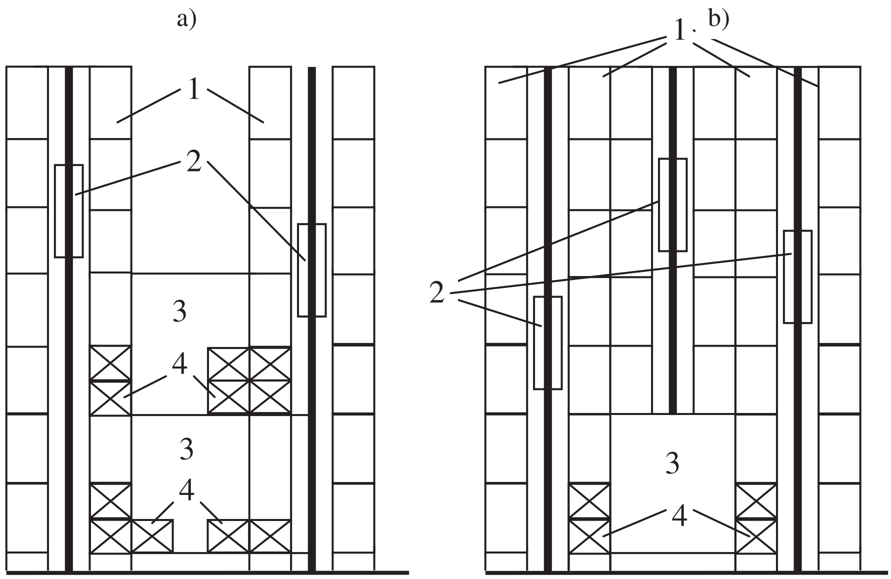

Figure 1 Vertical section of a high rack warehouse

(a – preparation platforms on two levels; b – preparation platform at the base of racking)
1 – high racks; 2 – forklifts; 3 – consignment preparation platform; 4 – sorted loads for consignment formation.

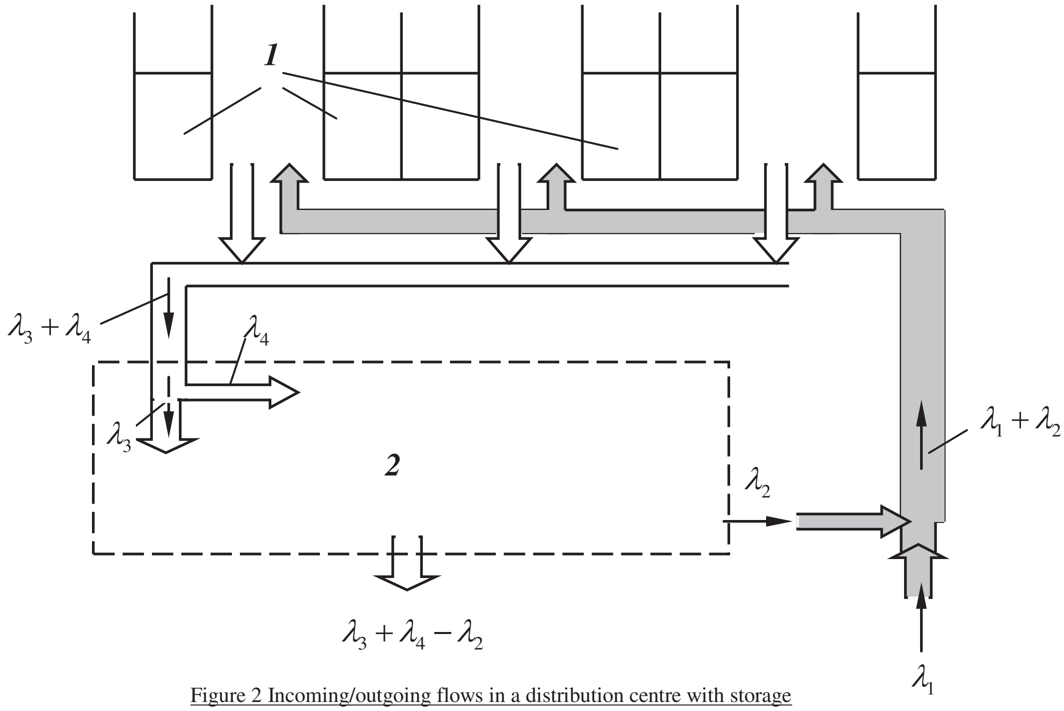

Figure 2 Incoming/outgoing flows in a distribution centre with storage

1 – storage area for loading units (pallets, crates); 2 – consignment preparation area; λ_1 - average arrival rate of the loading units in the warehouse; λ_2 - average flow of the loading units which return into the warehouse from the consignment preparation area; λ_3- average rate of the loading units picked from the warehouse to form consignments; λ_4- average rate of loading units used in the consignment preparation area (make up heterogeneous or incomplete loading units).

2.1. Simultaneous formation

If $t_{d,i}$ is the time necessary to pick up from stack G_i (Figure 3) the quantities $\sum_{j=1}^{n} g_i^j$ needed for all the orders E^j, $(j=\overline{1,n})$ of the plan period T, and if t_t^j is the time required to transfer all the quantities of all types i, $(i=\overline{1,m})$ which make up the consignment E^j, and if the transfer from zone II to zone III (Figure 3) commences only after the entire freight quantity of all types $\sum_{i=1}^{m}\sum_{j=1}^{n} g_1^j$ has been extracted from the stacks , then the earliest time for the consignment formation, from the n corresponding to the plan period is

$$\underline{\theta} = \max_i t_{d,i} + \min_j t_t^j \tag{1}$$

and the time interval in which all n consignments are formed is

$$\Delta\theta = \overline{\theta} - \underline{\theta} \tag{2}$$

where, $\overline{\theta}$ is the time the last consignment is completed.

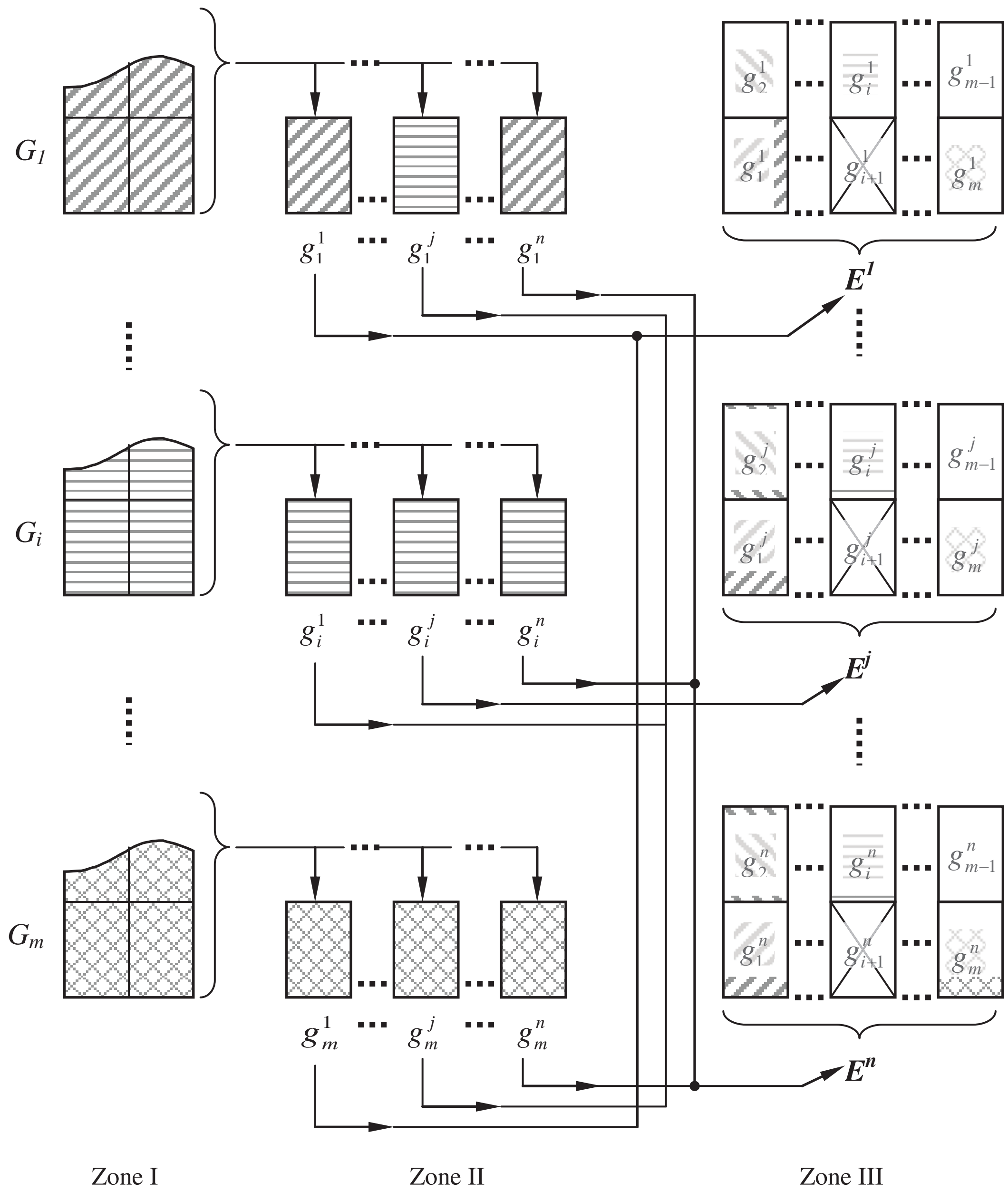

Figure 3 Simultaneous preparation (in zones II and III of the warehouse) of the n consignments (E^1, E^j, … E^n)

G_1, … G_i,… G_m are stacks of products 1, 2, …i, … m ; $g_1^1, \ldots g_1^j, \ldots g_1^n$ are products picked up from the stacks G_1 for the consignments E^1,…E^j,…E^n; $g_i^1, \ldots g_i^j, \ldots g_i^n$, respectively $g_m^1, \ldots g_m^j, \ldots g_m^n$ for the stacks G_i, respectively G_m for the consignments E^1,…E^j,…E^n; zone I is the warehouse area for the storage of the selected goods sorted by category; zone II is the warehouse area for consignment preparation (homogenous loads picked up from the G_1, … G_i,… G_m racks with the required quantities awaiting to be moved in zone III for consignment E^1,…E^j,…E^n preparation; zone III is the area of the loading ramps, consolidated consignments awaiting delivery.

Because

$$\bar{\theta} = \max \sum_i \sum_j \left(t_{d,i} + t_t^j\right) \tag{3}$$

results

$$\Delta\theta = \max_j t_t^j - \min_j t_t^j \tag{4}$$

Hence an average time interval between the formation of the *n* consignments

$$I = \frac{\Delta\theta}{n-1} \tag{5}$$

and a period (Figure 4):

$$\theta' = \bar{\theta} - \Delta\theta \tag{6}$$

when the warehouse won't have any other consignments prepared for delivery (if the same technology is applied for the formation of the next n consignments when θ is up).

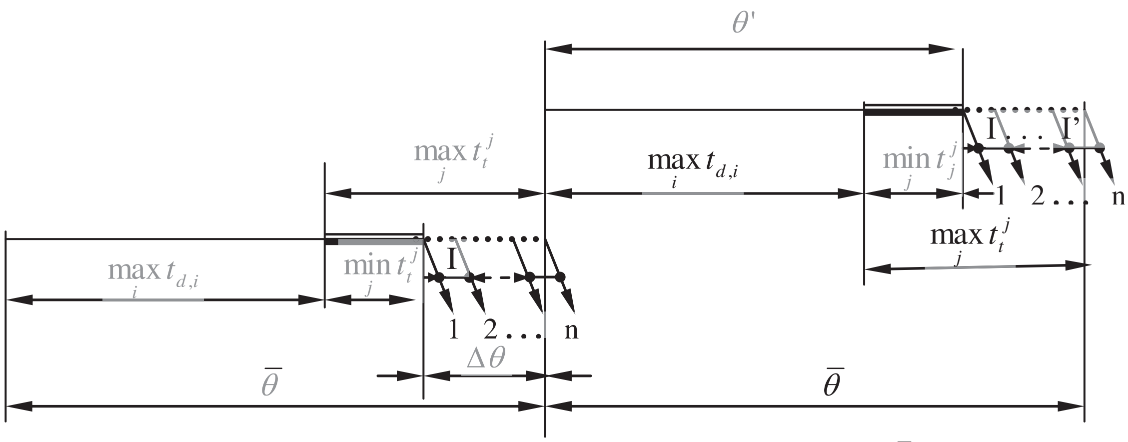

Figure 4 Sequence of n consignments formation in two consecutive plan periods $\bar{\theta}$

The time $t_{d,i}$ required to pick up the goods $\sum_{j=1}^{n} g_i^j$ from the stack G_i for all the *n* consignments E^j can be written as a linear function of the freight quantity from stack *i*, so

$$t_{d,i} = a_{d,i} + \sum_{j=1}^{n} b_{d,i}^j g_i^j$$

where,

$a_{d,i}$ is the duration of the operations which do not depend on the quantity handled (product identification, preparation and completion of the product pick up from the stack operation, only dependent on stack G_i;

$b_{d,i}^{j}$ is the specific duration of the handling operation of picking up from stack G_i the quantity g_i^j required for the consignment E^j, expressed for example in minutes/loading unit;

g_i^j is the quantity of freight extracted from stack G_i for the consignment E^j, in loading units.

If average values for the a_d, b_d and, $\overline{g}_i$ parameters are used, then the duration of the operations $t_{d,i}$ for any of the G_i stacks is

$$t_{d,i} = a_d + n \cdot b_d \cdot \overline{g}_i \tag{7}$$

and the total activity duration of the equipment used for these operations (for all G_i stacks)

$$T_d = \sum_{i=1}^{m} t_{d,i} = m \cdot a_d + n \cdot b_d \cdot \sum_{i=1}^{m} \overline{g}_i \tag{8}$$

or

$$T_d = m \cdot a_d + b_d \cdot G. \tag{9}$$

taking into account that $m.n.\overline{g}_i = \sum_{i=1}^{m}\sum_{j=1}^{n} g_i = G$, the sum of the quantities leaving the warehouse with the n deliveries in the plan period $\overline{\theta}$.

Similarly for the t_t^j transfer duration of the loading units from zone II to zone III for consignment E^j preparation

$$\overline{t}_t^{j} = m \cdot \left(a_t + b_t \cdot \overline{g}^{j}\right) \tag{10}$$

where a_t, b_t are the parameters corresponding to the transfer durations of the average quantity $\overline{g}^{j}$ extracted from any of the stacks G_i for delivery, and the total activity duration of the equipment used to complete the transfer

$$T_t = m \cdot n \cdot a_t + b_t \cdot G, \tag{11}$$

The $b_{d,i}$ and b_t^j parameters used to estimate the pick up time of the goods from the G_i stack, respectively the consignment E^j preparation time depend on the number of equipment s, used to complete these operations simultaneously.

If according to the assumptions made about the warehouse structure, goods are picked up from each stack using a sole equipment, $s_d = 1$, then for the transfer from zone II to zone III (Figure 3) is possible s_t^j equipment (forklift stackers) will work simultaneously to consolidate each consignment E^j. This means that b_t^j is a function of s_t^j, so

$b_t^j(s_t^j)$, for each $\bar{t}_t^j$. The b_t^j parameter is the inverse of the operation productivity $Q_e(s_t^j)$ of the s_t^j equipment doing the transfer, so

$$b_t^j\left(s_t^j\right)=\frac{1}{Q_e\left(s_t^j\right)},\tag{12}$$

where, if in a single operation cycle of the equipment a single load is transferred, the operation productivity is

$$Q_e\left(s_t^j\right)=\frac{60}{t_{i-d}+\frac{2d}{\mathrm{v}}}\cdot s_t^j\left[\frac{loading\_units}{hour}\right],\tag{13}$$

where,
t_{i-d} is the loading/unloading time of the loading unit, in minutes;
d is the average distance between the origin in zone II and the destination in zone III, in metres;
v is the average speed, in metres/minute.

Since the transfer equipment operates in a limited space, it is natural to assume the forklift speed is dependent on their number, so $\mathrm{v} = \mathrm{v}(s_t^j)$.

Assuming for example a linear variation (Figure 5) as a function of $s_t^j = s$, can write

$$\mathrm{v}=-\frac{\mathrm{v}_1}{\mathrm{s_M}-1}\left(s-s_M\right),\tag{14}$$

where,
v_1 is the speed in the case of a single equipment,
$\mathrm{s_M}$ is the number of equipment for which the space is quasi saturated and movement becomes nearly impossible $(\mathrm{v}_M \cong 0)$.

In these conditions, the operation productivity $Q_e(s)$, given by equation (13) isn't a linear function of the number of equipment s, but there is a value $s_0 < s_\mathrm{M}$ for which $Q_e(s)$ = maximum; respectively, a value for which $b_t^j(s)$ = minimum.

From equations (12), (13) and (14) results

$$b_t^j=\frac{t_{i-d}-\frac{2d\left(s_M-1\right)}{\mathrm{v}_1\left(s-s_M\right)}}{60s},\tag{15}$$

or, in a more condensed form

$$b_t^j=\frac{A_s-B}{s^2-s_M s},\tag{16}$$

where, $A=\frac{t_{i-d}}{60s}$, $B=\frac{1}{60}\left[t_{i-d}\cdot s_M+\frac{2d}{\mathrm{v}_1}\left(s_M-1\right)\right]$.

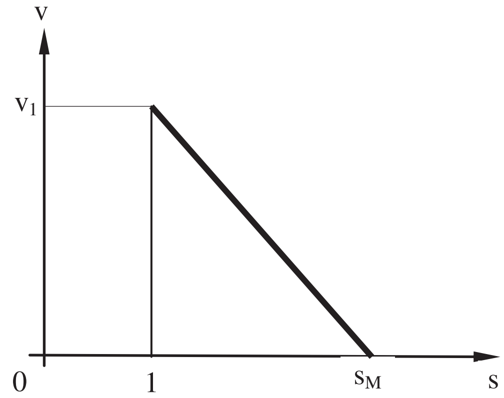

Figure 5 Speed variation of equipment, v, as a function of their number, s(limited space operation)

The minimum value of $b_t^j = b_t^0$ corresponds to a number of equipment $1 \le s_0 \le s_M$ given also by the equation

$$s_0 = \frac{B}{A} - \sqrt{\frac{B^2}{A^2} - \frac{B}{A} s_M}\ , \tag{17}$$

which means that for the b_t^0 corresponding to s_0 calculated for the average conditions of all the orders corresponds a minimum operation time of the equipment which completes the transfer

$$T_t(s_0) = m \cdot n \cdot a_t + b_t(s_0) \cdot G\ . \tag{18}$$

2.2. Successive formation

The consignment preparation in this case, as described before, is geared towards picking up from the G_i , $(i = \overline{1,m})$ stacks, the products g_i^j which make up the consignment E^j, operations completed in zone I, followed by the move of all products g_i^j in zone III, where the consignment E^j is consolidated (Figure 6).

The time period required for the successive formation of the *n* orders is

$$\Omega = \sum_{j=1}^{n} \max_i \left(\tau_{d,i}^j + \tau_{t,i}^j \right), \tag{19}$$

where,

$\tau_{d,i}^j$ is the time required to pick up from stack G_i the freight quantity g_i^j which makes up the E^j, consignment

$\tau_{t,i}^j$ is the transfer time of the extracted quantity, from zone I to zone III, where the consignment E^j is consolidated.

If $\tau_{d,i}^j$ and $\tau_{t,i}^j$ can be expressed as linear functions of the quantity g_i^j, then

$$\tau_{d,i}^j = a'_{d,i} + b'^j_{d,i} \cdot g_i^j \tag{20}$$

and

$$\tau^{j}_{t,i} = a'_{t,i} + b'^{j}_{t,i} \cdot g^{j}_{i} \tag{21}$$

or, using the average values of the parameters a'_d, a'_t şi b'_d, b'_t and of the quantities $\bar{g}$ forming the consignment

$$\tau_d = a'_d + b'_d \cdot \bar{g}, \tag{22}$$

respectively

$$\tau_t = a'_t + b'_t \cdot \bar{g}, \tag{23}$$

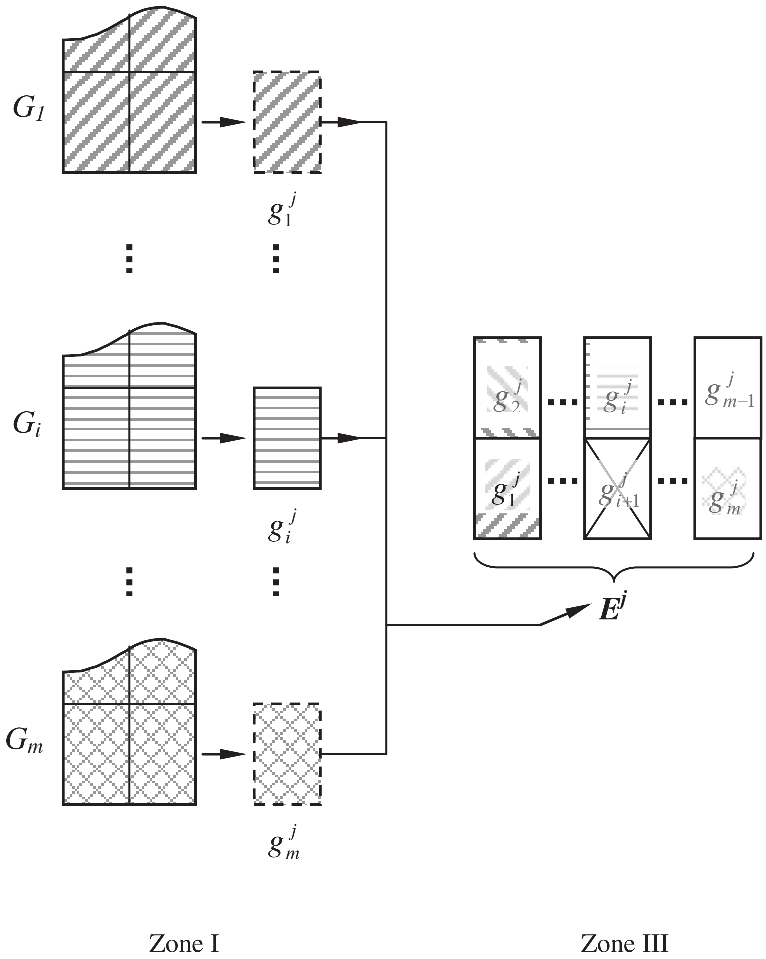

Figure 6 Consignment (Ej) preparation in zone III of the warehouse

(the case of successive preparation of each consignment $E_1, E_2, \ldots, E_j, \ldots, E_n$)
$G_1, \ldots G_i, \ldots G_m$ are the stacks where the 1, 2, …i, … m products are stored, required in the quantities to form the Ej consignment; zones I and III have the meaning explained in Figure 3

In relation to these average values, the total operation time of the equipment which extracts the goods from the stacks to form the n consignments is

$$T'_d = m \cdot n \cdot \tau_d = m \cdot n \cdot a'_d + b'_d \cdot G \quad , \tag{24}$$

and for those which perform the transfer

$$T'_t = m \cdot n \cdot \tau_t = m \cdot n \cdot a'_t + b'_t \cdot G , \tag{25}$$

Because $a'_d \cong a_d$ and $b'_d \cong b_d$, this results in $T_d' < T_d$, same as if $a'_t \cong a_t$ and $b'_t \cong b_t$ this results in $T'_t \cong T_t$, which means that in the hypothesis same equipment is used, the energy consumption for the preparation of the n consignments doesn't differ substantially.

As to the period in which the preparation of the n consignments is completed, $\bar{\theta}$, respectively Ω the comparison doesn't reveal same similarities even if $t_{d,i} \cong \tau^j_{d,i}$ and $t^j_t \cong \tau^j_{t,i}$, because

$$\bar{\theta} << \Omega \tag{26}$$

In order to achieve same warehouse productivity for both consignment preparation technologies, in the successive formation case a number of r equipment should work in parallel:

$$r \geq \frac{\Omega}{\bar{\theta}} , \tag{27}$$

which attracts productivity reductions for each of the r sets.

Supposing the number of equipment r which would work simultaneously only refers to the reach trucks which pick up the quantities g^j_i from the stack for each consignment E^j, (for forklifts which complete the transfer, due to the similarity with simultaneous formation can assume the maximum productivity is achieved for s_0 obtained from equation (17)) we are looking to evaluate the consequences upon their productivity in the case of simultaneous preparation of n/r consignments.

As opposed to the simultaneous formation (presented in 2.1), in this instance there isn't any correlation between the pick ups of goods from a certain stack G_i. The requests for goods to be picked up for each consignment E^j $(j = \overline{1, n/r})$ is done independently, uncoordinated. Thus, multiple requests for pick ups from the same stack G_i for different independent consignments could happen.

If X is the time the pick up from stack G_i has been requested for the E^j consignment, and Y for the $E^{j'}$ consignment, then there will be interaction between the two requests if:

$$-\tau^j_{d,i} \leq X - Y \leq \tau^{j'}_{d,i} . \tag{28}$$

If $X \in (0, \bar{\theta})$ and $Y \in (0, \bar{\theta})$, then the times corresponding to the interaction between the requests for the G_i stack are in the shaded area ω (Figure 7). Since the interactions are cyclic the areas aOb and dOc have also been included in the shaded area.

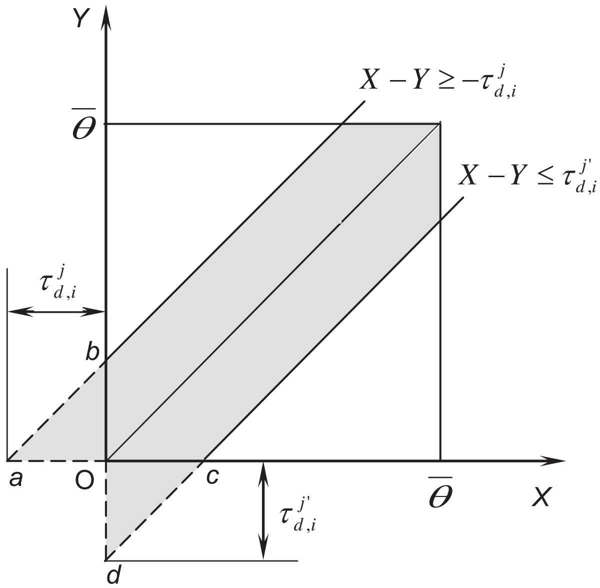

Figure 7 Geometric interpretation of the probability of interaction between order *j* and *j'*

The probability of interaction (rack G_i) between the orders *j* and *j'* is

$$P_{j\wedge j'} = \frac{\omega}{\overline{\theta}^2} = \frac{\tau_{d,i}^{j}\cdot\overline{\theta} + \tau_{d,i}^{j'}\cdot\overline{\theta}}{\overline{\theta}^2} = \frac{\tau_{d,i}^{j} + \tau_{d,i}^{j'}}{\overline{\theta}} \tag{29}$$

In the case of interaction between three orders *j, j'* and *j"*:

$$P_{j\wedge j'\wedge j"} = \frac{1}{2}\left(P_{j\wedge j'}\cdot P_{j"} + P_{j\wedge j"}\cdot P_{j'} + P_{j'\wedge j"}\cdot P_{j}\right), \tag{30}$$

or after calculations

$$P_{j\wedge j'\wedge j"} = \frac{\tau_{d,i}^{j}\cdot\tau_{d,i}^{j'} + \tau_{d,i}^{j}\cdot\tau_{d,i}^{j"} + \tau_{d,i}^{j'}\cdot\tau_{d,i}^{j"}}{\overline{\theta}^2} \quad . \tag{31}$$

In general, for j, j', j", ..., j^k, ..., j^p obtain:

$$P_{j\wedge j'\wedge j"\wedge\ldots j^k\wedge\ldots j^p} = \frac{\prod_{k=0}^{p+1}\tau_{d,i}^{j}\cdot\sum_{k=0}^{p+1}\frac{1}{\tau_{d,i}^{j^k}}}{\overline{\theta}^p} \tag{32}$$

For simplification assume:

$$\tau_{d,i}^{j} \cong \tau_{d,i}^{j'} \cong \tau_{d,i}^{j''} \cong \ldots \cong \tau_{d,i}^{j^p} \cong \tau_d \, , \tag{33}$$

which means:

$$P_{j \wedge j' \wedge j'' \wedge \ldots j^k \wedge \ldots j^p} = \frac{(p+1)\cdot(\tau_d)^p}{\bar{\theta}^p} \tag{34}$$

The average delay in processing an order (delay in picking up the goods from the stack) in the case there is interaction only between two orders is

$$\xi_{j \wedge j'} = \frac{\xi_j \cdot \tau_{d,i}^{j'} + \xi_{j'} \cdot \tau_{d,i}^{j}}{\tau_{d,i}^{j'} + \tau_{d,i}^{j}} \tag{35}$$

where ξ_j and $\xi_{j'}$ are the average delays in processing order *j*, respectively *j'*, delays in picking up goods from stack G_i.

In the simplified conditions of equation (33) and for $\xi_j = \xi_{j'} = \frac{1}{2} \cdot \tau_d$, results

$$\xi_{j \wedge j'} = \frac{1}{2} \cdot \tau_d \tag{36}$$

or in general, for the above situation of the interaction between *p+1* orders, the average delay is

$$\xi_{j \wedge j' \wedge j'' \wedge \ldots j^k \wedge \ldots j^p} = \frac{(p+1)^2}{8} \cdot \tau_d \, . \tag{37}$$

The possible number of interactions being:

$$N = \sum_{k=2}^{p+1} C_{p+1}^{k} = 2^{p+1} - (p+2) \, , \tag{38}$$

means the probable number of interactions is

$$R = N \cdot P \, , \tag{39}$$

where *P* is the probability of occurrence of an interaction between *2, 3, ..., p+1* orders which require pick ups from the G_i stack.

The total delay for a stack G_i will be the number of probable interactions multiplied by the average delay for an interaction. For example, for *p=1* (two orders *j* and *j'*), the total delay is

$$T_{i(2)} = \frac{2 \cdot \tau_d}{\bar{\theta}} \cdot \frac{1}{2} \cdot \tau_d = \frac{(\tau_d)^2}{\bar{\theta}} \, , \tag{40}$$

and for *p=2* (three orders, *j, j'* and *j''*):

$$T_{i(3)} = T_{i(1\wedge 2)} + T_{i(1\wedge 3)} + T_{i(2\wedge 3)} + T_{i(1\wedge 2\wedge 3)}\,, \tag{41}$$

with

$$T_{i(1\wedge 2)} = P_{i(1\wedge 2)} \cdot \tau_{i(1\wedge 2)}\,, \tag{42}$$

where $P_{i(1\wedge 2)}$ refers to the probability of an event completion only in the case of interaction between two orders, excepting the probability of interaction between 3 orders, so:

$$P_{i(1\wedge 2)} = P_{(1\wedge 2)} - P_{(1\wedge 2\wedge 3)}\,. \tag{43}$$

Using equations (34) and (37) results:

$$T_{i(3)} = \frac{3\cdot \tau_d^{\,2}}{\overline{\theta}} - \frac{9\cdot \tau_d^{\,3}}{8\cdot \overline{\theta}^2}\,. \tag{44}$$

Similar expressions as (39) can be written for other values of *p*, noting that the number of terms in the sum is given by N from equation (38).

Because $\tau_d / \overline{\theta} < 1$, the total delay for a single stack only in the hypothesis of interactions between 2 and 3 orders can be approximated to be $4.\tau_d^{\,2} / \overline{\theta}$ and m times greater for all the m stacks, which means the value of Ω in equations (19) and (26) has to be corrected by introducing the average delay for picking up the ordered goods from the stack. Of course, in the next iteration calculations would be completed for the new value $r > r'$ (from (20)).

These delays, confirmed by numeric calculations, reduce the warehouse productivity in relation to consignment preparation. The drop in productivity is more pronounced if the intensity of the deliveries is high, and the structure of each consignment varies (high values for n and m, Table 1).

3. Conclusion

The technologies adopted for consignment preparation in the warehouses of the urban distribution centres have substantial impact on the duration required to form the consignment, and the operation efficiency.

In addition to the arguments about simultaneous consignment preparation will have to add those regarding delivery to retailers in a specified time window. This time window will avoid the congestion on urban arterials, and deliver to retailers certain product categories according to customers' requirements. The results of this paper have been extended by case studies looking at deliveries to urban hyper/supermarkets, and have confirmed the positive effects of the simultaneous consignment preparation upon the quality of delivery and use of resources.

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