# The use of internal cross-docking in just-in-time plants

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**ABSTRACT:** *We study the use of internal cross-docking in Just-in-Time plants. The considered plants consist of a cross-docking zone, a picking zone and assembly lines. The cross-docking zone is used to receive, store (temporarily) and ship pallets. Pallets are then broken into cases and stored in the picking zone which supplies the assembly lines. Cross-docking is used instead of mass storage in order to accelerate the physical flows of pallets. In this paper, we introduce different cross-docking policies (set of rules which specify how to store pallets) commonly used in practice. A cross-docking cost evaluation model is developed in order to compare the cross-docking policies considered in terms of required labour and surface costs.*

**KEYWORDS:** *in-house logistics, cross-docking, just-in-time, picking, facilities planning.*

## 1 INTRODUCTION

Cross-docking is defined by Stephan and Boysen (2011) as a logistics concept, which integrates intermediate nodes into a transportation network. Within a cross-docking terminal (called cross-dock) incoming shipments delivered by inbound trucks are collected, sorted by destination, and moved across the terminal to be directly loaded onto outbound trucks. Cross-docks are high speed warehouses, said Bartholdi and Hackman (2008). Cross-docking (in distribution systems) has led to reduce significantly warehousing costs. However cross-docking success in distribution systems, it still remains not well known for manufacturing systems. In this paper, we propose a cross-docking model that can be applied to Just-in-Time (JIT) plants.

The model addressed in this paper is a cross-docking zone used to receive, store and ship pallets. The customer of the cross-docking zone represents the picking zone of the plant (also called the supermarket) which supplies the assembly lines (see Figure 1). The cross-docking zone contains inbound docks where the suppliers' trucks delivering assembly components are received. Each supplier has a given delivery frequency. The cross-docking storage area is composed of I-shape parallel lanes.

Each time slot (e.g., one hour), a pick-list is released by the picking zone and pallets are loaded from the cross-docking zone to the picking zone. Note that the main difference between cross-docking used in distribution systems and cross-docking used in JIT plants is the downstream part. In distribution systems cross-docking, there are many customers and outbound docks. Some practitioners use the term “Internal cross-dock” to describe cross-docking used in JIT plants.

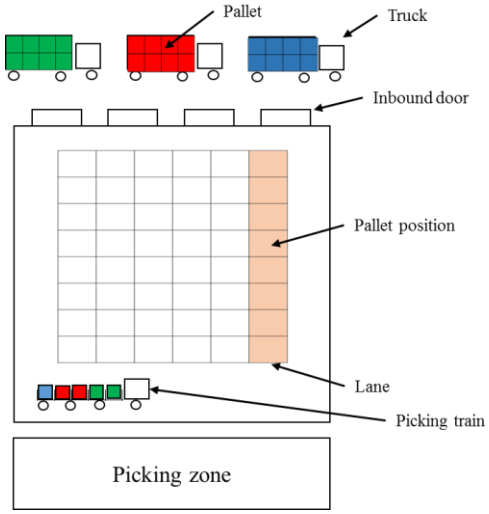



Figure 1 : Internal cross-docking in JIT plants

We call a cross-docking policy, a set of rules that specifies where to store pallets in the

cross-docking zone. We start by presenting two cross-docking policies commonly used in practice: cross-docking per supplier and cross-docking per time slot. In cross-docking per supplier, the pallets of each supplier are stored in the same lane(s). In cross-docking per time slot, each lane contains all the pallets (from different suppliers) that will be consumed during a fixed time slot and hence, shipped to the picking zone during this time slot. The advantages and limits of each policy are presented. To cope with these limits, two new cross-docking policies are developed.

We develop a cross-docking cost calculation model in order to compare the different cross-docking policies considered in this paper. The model developed is applied to the case an auto parts supplier.

The literature review is presented in the next section. Section 3 describes the model and different cross-docking policies used in JIT plants. Section 4 presents the cost calculation model, section 5 presents the numerical example and section 6 concludes.

## 2 LITERATURE REVIEW

Our work is related to two research streams: 1) cross-docking operations and 2) in-house logistics.

The literature on cross-docking addresses decision problems which can be: i) strategic such as cross-dock location, cross-dock design, ii) tactical such as cross-dock network and iii) operational such as truck scheduling and storage assignment (see Van belle et al (2012) for a literature review on cross-docking). Bartholdi and Gue (2000) proposed a model to construct efficient layout of cross-docking terminals. Their model seeks to minimize worker travel time and worker waiting time required in sorting and consolidating freight within the terminal. De Koster et al (2007) reviewed literature about order picking systems. They focused on layout design, storage assignment, zoning, batching and routing policies. In this paper we address a storage assignment problem which consists on assigning pallets to pallet locations before they can be picked to fulfil the picking zone orders. The cross-docking per supplier policy considered in this paper is somewhat similar to dedicated storage explained in De Koster et al (2007).

Vis and Roodbergen (2008) determined the temporary storage locations that minimize the total travel distance in the cross-dock. They gave a row-based storage assignment algorithm to resolve the problem of storage locations. Boysen and Fliedner (2010) proposed a classification of truck scheduling problems studied in literature. A truck scheduling problem consists on the assignment of trucks to dock doors and the sequence of all inbound and outbound trucks. Larbi et al (2011) addressed the scheduling of outbound trucks problem in a cross-docking centre where the sequence of arrival of inbound trucks can be fully known, partially known or unknown.

In a recent review, Ladier and Aplan (2016) compared the literature on cross-docking operations with cross-docking practices in industry. The different industry practices were mainly extracted from the visits and interviews of 8 different cross-docks in France. They provided several future research directions to answer industrial needs.

Concerning in-house logistics, Battini et al (2013) reviewed literature on JIT-supermarket concept commonly used in the automotive industry. In our paper, JIT-supermarket corresponds to the picking zone. Emde and Boysen (2012) studied the optimization of the number and the placement of supermarket-areas. Boysen and Emde (2014) addressed the scheduling problem of refill events in line-integrated supermarkets. Sali and Sahin (2016) studied the problem of line feeding in JIT assembly lines. They compared the performance of three line feeding modes: line stocking, kitting and sequencing.

In our work, we show how cross-docking can be integrated in internal-logistics. We present different cross-docking policies commonly used in practice. An exact cost calculation model of cross-docking costs is proposed.

## 3 MODEL

We consider an internal cross-docking zone used to receive, store and ship pallets (i.e., unit loads) received from suppliers. Without loss of generality, we assume that each sup-

plier delivers one component, i.e., all pallets delivered by the same supplier contain the same component. When a supplier shipment arrives (a shipment can be in one or in multiple trucks), pallets are first unloaded from trucks and stored temporarily (very short time) in the receiving area (Figure 2). Then, an operator transfers controlled pallets from the receiving area to the storage area by using a forklift. This operation is called staging (or positioning as described by Vis & Roodbergen (2008)). The storage area is a floor storage area composed of I-shape parallel lanes where each lane consists of several pallet positions. One pallet position can contain one or several pallets; the number of pallets per position is decided by the cross-dock managers.

Each time slot (a time interval defined by plant managers), a pick-list of pallets is released from the picking zone. A pick-list contains several pick-lines where each pick-line specifies what component pallets to pick and in what quantity. An operator transfers pallets requested in the pick-list from the storage area to a picking train by using a stacker (a stacker is smaller than a forklift and can handle narrower space). The picking train is unloaded in the picking zone; pallets that are transferred are broken into cases (boxes) and stored in flow racks. Afterwards, the picking zone feeds the assembly line in terms of quantity of components necessary for assembly operators. The routing problem of the picking train is not addressed in this paper.

Each day, the plant receives different shipments. Each supplier is assumed to have a constant delivery frequency, denoted by $F$, which represents the number of deliveries (or shipments) per day. For example, $F$=2 corresponds to a supplier making 2 deliveries per day while $F$=0.1 corresponds to a supplier making 1 delivery every 10 days (5 working days per week are considered). The number of pallets shipped in each delivery, denoted by $Q$, is assumed to be constant. In all the study, we use the hour as a time unit (which we denoted by $t$) and we assume that there are $H$ working hours (time units) per day.

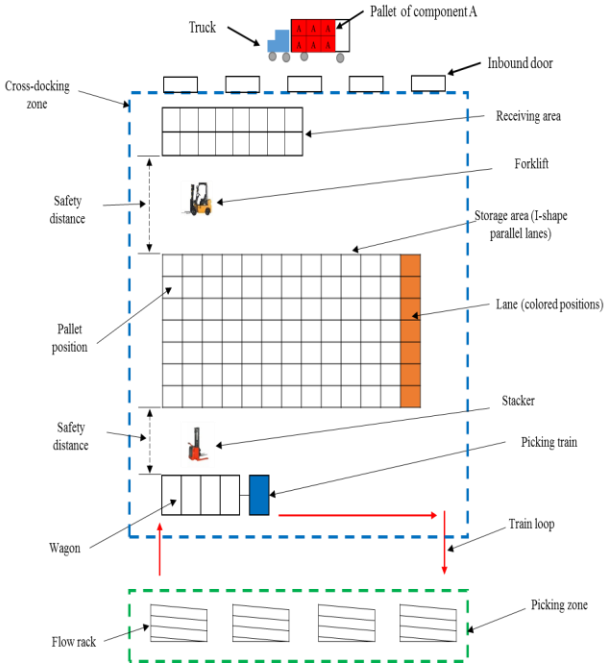



Figure 2. Layout of internal cross-docking zone in JIT plants

The below assumptions are introduced in the model developed:

- The receiving area consists of two parallel lanes where pallets are put temporarily before being positioned in the storage area.
- Each I-shape parallel lane of the storage area has the same number of pallet positions, i.e., the storage area is of rectangular shape. The number of pallet positions per parallel lane can be calculated or fixed by the cross-dock managers as it will be discussed after.
- The picking train contains $w$ wagons. Each wagon can hold one pallet.
- Pallets positioned in the same position can belong to different suppliers. We remind that one pallet position can contain one or several pallets.
- There are two safety distances to facilitate movements for the forklift and the stacker: one is between the receiving and the storage areas and the other between the storage area and the picking train.

In this paper, we are interested in studying the performance of different staging policies. A staging policy, equivalently a cross-docking policy, is a set of rules used to tell operators where to put each pallet (from the receiving area) in the storage area and how to retrieve them. The objective of this paper is to compare

different cross-docking policies in terms of required labour and surface costs. The way pallets are stored in the storage area impacts the surface of the storage area and the number of operators required to move pallets within the cross-docking area.

We start by presenting two cross-docking policies commonly used in practice:

### 3.1 Cross-docking per time slot

In this policy, each lane in the storage area contains the pallets that will be consumed during a fixed time slot. For illustration purposes, we consider the case of two suppliers delivering components A and B with daily delivery frequency ($F_A$=$F_B$=1). Supplier A (we call a supplier of component A, supplier A) delivers 8 pallets per shipment and supplier B delivers 4 pallets ($Q_A$=8 pallets and $Q_B$=4 pallets). The number of time units per day $H$ equals 8 hours and the duration of a one time slot, denoted by STS, is equal to 2 hours (hence, there are 4 time slots per day). We also assume that one pallet position can contain one pallet. The pick-lists are known in advance and are presented in Table 1 (column STS 1 represents the pick-list released at the beginning of time slot STS 1).

| | STS 1 | STS 2 | STS 3 | STS 4 |
|---|---|---|---|---|
| Supplier A | 2 | 2 | 2 | 2 |
| Supplier B | 1 | 1 | 1 | 1 |

Table 1. Pick-lists in cross-docking per time slot (numbers represent the number of pallets)

Suppliers' shipments are assumed to be received at the beginning of the day and a pick-list is released at the beginning of each time slot. A top view of the storage area at the beginning of each time slot (before the stacker retrieves pallets) would look as represented in Figure 3. In this example, the number of lanes in the storage area is 4 and the number of positions per lane is 3.

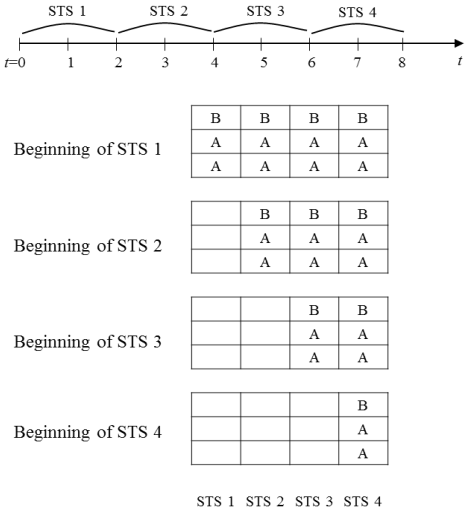



Figure 3. Top view of the storage area in a cross-docking per time slot policy

As illustrated by the example, cross-docking per time slot has many characteristics:

First, the number of positions per lane depends on the maximum number of pallets per pick-list and the number of pallets per position. Second, the number of lanes in the storage area depends on the time slot duration and on the minimum delivery frequency per supplier.

The advantage of using cross-docking per time slot is facilitating the loading of picking train for stacker operators. Because each lane represents one time slot, operators have to pick all the pallets of the same lane without looking for pallets in other lanes. The disadvantages of cross-docking per time slot are:

- The number of lanes increases with decreasing the minimum delivery frequency. For instance, if the time slot duration is 1 hour, $H$=8 hours and the minimum delivery frequency is 0.1 (one delivery every 10 days), the number of lanes in the storage area is 80 (a very big number).
- Staging of pallets towards the storage area is complicated for the forklift operator because he is obliged to go to different lanes and to know how many pallets to put in each lane.

In the example above, the pick-list for each time slot is assumed to be given. If the pick-list is not defined in advance, it has to be built. Let's take another example to show how pick-lists can be generated.

In this example, there are 4 time slot per day, and one pallet position can contain one pallet: Supplier A delivers 8 pallets per day ($F_A$=1) which will be consumed during the 4 time slots. Under the assumption that customer demand is regular, 8/4=2 pallets are consumed during each time slot. Hence, 2 pallets will be put per lane.

In addition to supplier A, we consider a second supplier, i.e., supplier B which delivers 10 pallets per day. Each lane will contain at least 2 pallets (⌊10/4⌋=2) of supplier B and there still remains 2 pallets to be positioned. Where will these 2 pallets be stored ? For example, we can put 1 pallet in the first lane (in STS 1) and the other one in the third lane (in STS 3). The pick-lists will thus be as given in Table 2.

| | STS 1 | STS 2 | STS 3 | STS 4 |
|---|---|---|---|---|
| Supplier A | 2 | 2 | 2 | 2 |
| Supplier B | 3 | 2 | 3 | 2 |

Table 2. Pick-lists with suppliers A and B

In addition to suppliers A and B, we consider supplier C which delivers 10 pallets per day ($F_C$=1). Similar to supplier B, each lane will contain at least 2 pallets of supplier C and there still remains 2 pallets to be positioned. If we put 1 pallet in the first lane and the other one in the third lane, there will be 8 pallets in lanes 1 and 3 and 6 pallets in lanes 2 and 4. The storage area is not optimally used because 2 pallet positions will always be empty in lanes 2 and 4. That is why, to reduce storage area, one would put one pallet of supplier C in the second lane and the other one in the fourth lane as shown in Table 3.

| | STS 1 | STS 2 | STS 3 | STS 4 |
|---|---|---|---|---|
| Supplier A | 2 | 2 | 2 | 2 |
| Supplier B | 3 | 2 | 3 | 2 |
| Supplier C | 2 | 3 | 2 | 3 |

Table 3. Pick-lists with suppliers A, B and C

Under the assumption that customer demand is regular, the generation of pick-lists can not be done randomly and a calculation algorithm is required to smooth the arriving pallets over the lanes. When customer demand is not regular, the generation of pick-lists should follow the non-regularity of demand. For example, a component demand is high in the first time slot and low in the other time slots. The pattern of this component demand should be respected in the generated pick-lists. In our paper, we consider only the case of regular customer demand.

### 3.2 Cross-docking per supplier

In this policy, the pallets of the same supplier have to be put in the same lane(s). Let's consider the same explanatory example taken in cross-docking per time slot. We add the following precision: the maximum number of positions per lane is fixed to 5 (in cross-docking per supplier, the number of positions per lane is defined in advance). The pick-lists presented in Table 1 are used. A top view of the storage area at the beginning of each time slot would look as represented in Figure 4.

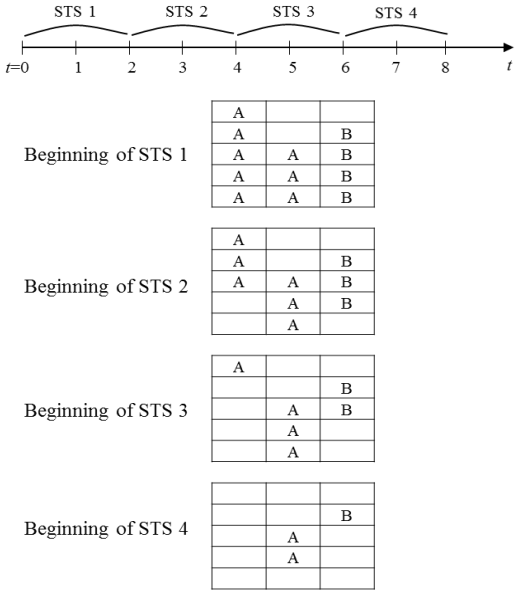



Figure 4. Top view of the storage area in a cross-docking per supplier policy

There is a specified picking rule in cross-docking per supplier: if a supplier's pallets are stored in many lanes (such as supplier A pallets stored in 2 lanes in Figure 4), then the pallets of each lane have to be picked totally before beginning picking from other lanes. For example, supplier A pallets are to be picked from the first lane before passing to the second lane.

As said before, in cross-docking per supplier, the number of positions per lane is fixed by the cross-dock managers and is not calculated as in cross-docking per time slot. The advantage

of using cross-docking per supplier is that the staging of pallets is easy for operators since all the pallets of the same supplier are put in the same lane(s) without dispatching them according to time slots. Another advantage of this policy concerns the number of lanes which depends on the number of positions per lane (lane capacity) and the number of pallets per shipment $Q$. For example, if the number of positions per lane is 10 and a supplier delivers 25 pallets per shipment; as a result, 3 lanes are required to store the pallets of this supplier (we assume that one pallet position can contain one pallet). Unlike cross-docking per time slot, the number of lanes in cross-docking per supplier does not depend on the delivery frequency of suppliers. This advantage would make cross-docking per supplier interesting for suppliers with low delivery frequency. The disadvantages of using this policy are:

- Loading the picking train would be complicated for stacker operators because they are obliged to constitute the pallets requested by the pick-list.
- The storage area is not optimally used because lanes are permanently assigned to suppliers (e.g., lanes 1 and 2 are always assigned to supplier A and can not be used to store another supplier's pallets even when they are partially used).

To cope with the limits of cross-docking per time slot and cross-docking per supplier, new cross-docking policies based on these two policies are developed:

### 3.3 Cross-docking per supplier/time slot

In this policy, suppliers are divided into two classes: suppliers with high delivery frequency and suppliers with low delivery frequency. A threshold level, denoted by $\gamma$, is used to separate the two classes where a supplier having a delivery frequency $F \geq \gamma$ is considered to be a high delivery frequency supplier. $\gamma$ is often fixed by cross-docking managers. Cross-docking per time slot is used for the staging of pallets of suppliers with high delivery frequency and cross-docking per supplier is used for the staging of pallets of suppliers with low delivery frequency. The example below illustrates this:
Suppliers A, B and C have respectively delivery frequencies equal to $F_A$=1, $F_B$=1 and $F_C$=1/3 (1 delivery every 3 days) with delivered total quantities $Q_A$=12, $Q_B$=6 and $Q_C$=18. There are 8 time units per day ($H$=8 hours) and the time slot duration is set equal to 2 hours. The threshold level $\gamma$ is set equal to 0.5. Therefore, supplier C is considered as a supplier having a low delivery frequency and its pallets are staged according to a cross-docking per supplier. The pick-lists of this cross-dock for 3 days (the time interval covered by one delivery of supplier C) are generated using the smoothing algorithm explained in subsection 3.1 and are presented in Table 4.

| | Day 1 | | | | Day 2 | | | | Day 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | STS 1 | STS 2 | STS 3 | STS 4 | STS 1 | STS 2 | STS 3 | STS 4 | STS 1 | STS 2 | STS 3 | STS 4 |
| Supplier A | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Supplier B | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 |
| Supplier C | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |

Table 4. Example of pick-lists in cross-docking per supplier/time slot

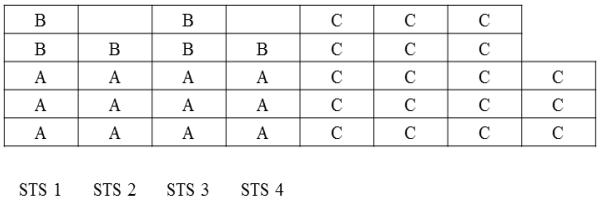



Figure 5. Top view of the storage area in a cross-docking per supplier/time slot policy

Figure 5 depicts a top view of the storage area at the beginning of the first day where the number of positions per lane is set equal to 5. The pallets put in the storage area are picked according to the pick-lists given in Table 4. The number of lanes required in this policy is equal to 8. If cross-docking per time slot were used in this policy, then the number of lanes would be equal to 12 lanes. In cross-docking per supplier, this number would be equal to 9. Cross-docking per supplier/time slot policy may be limited because lanes where suppliers with low delivery frequency are staged are not

fully used and may stay empty for a long time (inefficient use of surface).

### 3.4 Cross-docking per big/small time slots

Similar to cross-docking per supplier/time slot policy, two supplier classes are considered: suppliers with high delivery frequency and suppliers with low delivery frequency. In addition, we consider two types of pick-lists: 1) a pick-list released each small time slot STS and 2) a pick-list released each big time slot, denoted by BTS. The first type is similar to pick-lists used in the previous policies and the second type has the same format as the first type but instead of being released each time slot STS, it is released, less frequently, each time slot BTS. This policy has the same logic as cross-docking per time slot presented in subsection 3.1 where each lane contains the pallets that will be picked during a time slot (STS or BTS). In this new policy, there are two types of lanes: those which contain pallets that are picked each STS and those which contain pallets that are picked each BTS. Logically, the STS lanes are used to store the pallets of suppliers with high delivery frequency and the BTS lanes are used to store the pallets of suppliers with low delivery frequency. The reason behind the use of BTS lanes is the fact that the number of STS lanes required to store the pallets of suppliers with low delivery frequency would be very high. In this policy, the smoothing algorithm used to generate pick-lists start by generating the pick lists corresponding to STS lanes, then the pick-lists corresponding to BTS lanes are generated independently of STS lanes. For the example considered in section 3.3, the pick-lists in cross-docking per small/big time slots are presented in Table 5 where the duration of big time slot is set equal to 1 day (the duration of STS is 2 hours and the duration of BTS is 8 hours). The top view of the storage area using this policy is presented in Figure 6. The number of lanes required in this policy is equal to 7 (less than the other policies).

| | Day 1 | | | | | Day 2 | | | | | Day 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | STS 1 | STS 2 | STS 3 | STS 4 | BTS 1 | STS 1 | STS 2 | STS 3 | STS 4 | BTS 1 | STS 1 | STS 2 | STS 3 | STS 4 | BTS 1 |
| Supplier A | 3 | 3 | 3 | 3 | 0 | 3 | 3 | 3 | 3 | 0 | 3 | 3 | 3 | 3 | 0 |
| Supplier B | 2 | 1 | 2 | 1 | 0 | 2 | 1 | 2 | 1 | 0 | 2 | 1 | 2 | 1 | 0 |
| Supplier C | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 6 |

Table 5. Example of pick-lists in cross-docking per big/small time slots

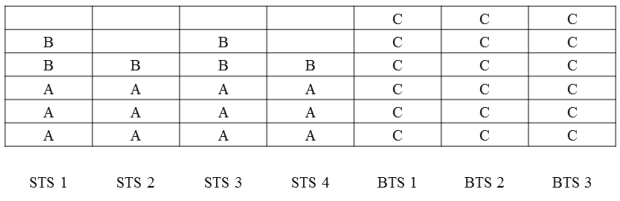



Figure 6. Top view of the storage area in a cross-docking per small/big time slots policy

We remind that the objective of this paper is to compare the four cross-docking policies presented in this section: cross-docking per time slot, cross-docking per supplier, cross-docking per supplier/time slot and cross-docking per small/big time slots. The comparison is done in terms of required surface and labour costs. In the next section, we present the method used to evaluate the average labour and surface costs per day.

## 4 CROSS-DOCKING COSTS EVALUATION

Two types of cost are considered: surface and labor costs. We mean by surface cost, the cost incurred by using the storage area. This cost is the product of the storage area surface and the generic surface cost. Labour cost represents the wages of person-hours spent to move the pallets from the receiving area to the storage area and from the storage area to the picking train. The average total cost per day of a cross-docking policy, denoted by *C*, is calculated using the following expression:

$$C = l * \mathrm{E}[O] + s * \mathrm{E}[S] \quad (1)$$

where:
E[*O*]: average number of person-hours spent per day
E[*S*]: average storage area surface per day
*l*: unit labour cost per person-hour (€/person hour)
*s*: unit surface cost per square meter per day (€/m2/day)
The average storage area surface E[*S*] is the product of the number of cross-dock lanes and the number of pallet positions per lane.

### 4.1 Calculation of average person-hours per day E[*O*]

To calculate the average number of person-hours spent per day, we need to know where operators (persons) are exactly involved in the cross-docking zone. Operators mainly take action in the following activities:

- Pallets receiving: this activity consists on unloading suppliers' trucks and storing the load temporarily in the receiving area. We do not include this activity in the evaluation of labour cost because it does not depend on cross-docking policy and its cost is the same whatever is the cross-docking policy.
- Pallets staging: this activity is directly impacted by the cross-docking policy used. It can be divided into 4 elementary activities:
  - Loading pallet(s) from the receiving area in the forklift.
  - Moving the forklift (filled) from the receiving area to the storage area.
  - Unloading the forklift in the pallet position.
  - Returning of the forklift to the next pallet(s) to be moved (if there still remains pallets to move) or to its initial position (the initial position of the forklift is set by the cross-dock managers).
- Pallets loading in the picking train: this activity is also impacted by the cross-docking policy used. Similar to pallets staging, this activity can be divided into 4 elementary activities:
  - Loading pallet(s) from the storage area in the stacker.
  - Moving the stacker from the storage area to the picking train.
  - Unloading the stacker and loading the picking train.
  - Retuning of the stacker to the next pallet position or to its initial position (the initial position of the stacker is set by the cross-dock managers).
- Driving the picking train to the picking zone: when the picking train is totally filled (*w* wagons are occupied) or when all the pallets in the pick-list have been loaded in the picking train, then the train goes to the picking zone where pallets are unloaded, and broken. Component cases are stored in the flow racks of the picking zone. This activity is not directly impacted by cross-docking policies and its labour cost is not included in the calculation.

To summarize, the average number of person-hours spent per day is the average number of person-hours spent to fill cross-dock lanes (pallets staging) and to retrieve pallets (pallets loading in the picking train). Let's explain how E[*O*] can be calculated:

A working day can be viewed as a set of "pallets staging" activities and "pallets loading in the picking train" activities. We associate a coordinate system (O,X,Y) to the cross-docking zone as shown in Figure 7. One pallet staging activity consists on moving the pallet(s) from a position ($x_1$,$y_1$) in the receiving area to a position ($x_2$,$y_2$) in the storage area, then going back to another position ($x_3$,$y_3$) in the receiving area (this position is either the next pallets to stage or the initial position of the forklift). The distance travelled in one pallets staging activity is $d_f = |x_1 - x_2| + |y_1 - y_2| + |x_2 - x_3| + |y_2 - y_3|$.
The number of person-hours spent in a pallets staging activity is calculated using the following expression:

$$\text{Pallet staging time} = lt_f + \frac{d_f}{v_f} + ut_f \qquad (2)$$

where:
$lt_f$: loading time used by the forklift in terms of person-hours
$v_f$: velocity of the forklift
$ut_f$: unloading time used by the forklift in terms of person-hours
Similarly, the time required in a pallets loading in the picking train activity is calculated using the following expression:

$$\text{Pallet loading in picking train time} = lt_s + \frac{d_s}{v_s} + ut_s \quad (3)$$

where:
$d_s$: distance travelled by stacker in one "pallets loading in the picking train" activity
$lt_s$: loading time used by the stacker in terms of person-hours
$v_s$: velocity of the stacker
$ut_s$: unloading time used by the stacker in terms of person-hours

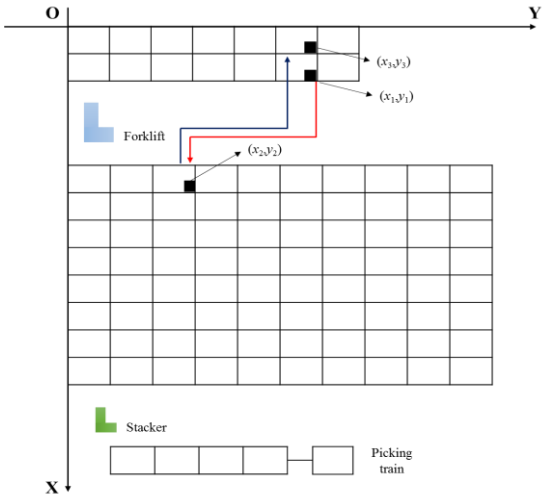
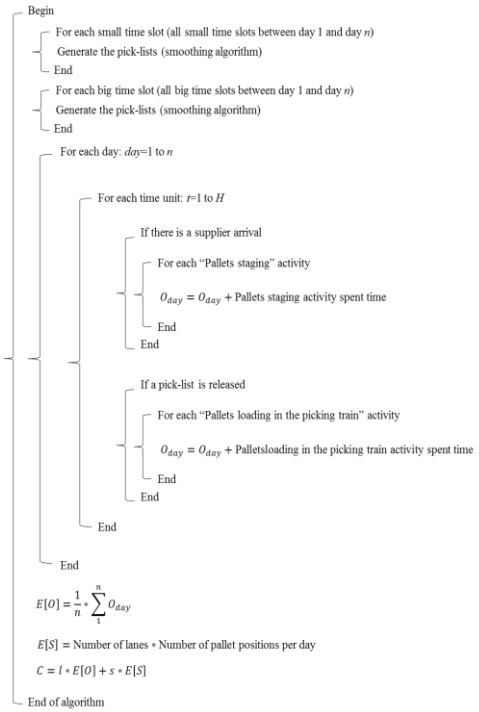



Figure 7. Cross-docking associated coordinate system

We calculate the average number of person-hours spent per day, E[*O*], using a Discrete Event Simulation over *n* days where *n* is the least common multiple of time intervals that separate two consecutive shipments of each supplier (inverse of delivery frequency). *n* is set equal to the least common multiple because it is the first number where all delivered pallets are completely picked. We calculate average cost *C* using the following algorithm:




Algorithm 1. Algorithm of calculation of cross-docking cost

## 5 NUMERICAL EXAMPLE

We apply the tool developed to the case of an auto parts supplier plant in France. The characteristics of the cross-docking zone in this plant are not given for confidentiality reasons.

| Results | Cross-docking policy | | | |
|---|---|---|---|---|
| | Per supplier | Per time slot | Per small/big time slots | Per supplier/time slot |
| Number of lanes | 41 | 80 | 18 | 42 |
| Number of positions per lane | 30 | 34 | 55 | 25 |
| E[*S*] | 1230 | 2720 | 990 | 1050 |
| E[*O*] | 8.87 | 11.85 | 10.50 | 9.10 |
| Average cost | 512 | 1040 | 453 | 456 |

Table 6. Comparison between cross-docking policies in: case study

In Table 6, we compare the four cross-docking policies when applied to the plant considered. It can be seen that cross-docking per small/big time slots is the best policy in terms of average cost per day.

## 6 CONCLUSIONS AND FUTURE RESEARCH

In this paper, we study the use of cross-docking in Just-in-Time plants. Two cross-docking policies commonly used in practice are first presented: cross-docking per time slot and cross-docking per supplier. We showed the advantages and limits of each policy and proposed new policies to cope with these limits. We also developed a cross-docking cost calculation model in order to compare the different cross-docking policies considered in this paper. The cost model allows to calculate the average surface and labour costs. We developed an Excel VBA Script which implements the cost model. The tool was applied to the case of an auto parts supplier.

For future research, it would be of great value to develop efficient approximate analytical expressions to evaluate the labour and surface costs of each cross-docking policy. Such an approximate model would be helpful to avoid computer programming difficulties (hundreds of lines of code) used in the exact cost calculation model. Another interesting direction would be to study a coordinated organization of picking and cross-docking operations.

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