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Value of Information in Improving Daily Operations in High-Density Logistics

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ABSTRACT

In this paper we investigate the value of shared information between chain actors for improving daily operations in high-density logistics processes at distribution warehouses. We first define a generic high-density logistics process at a distribution warehouse based on real-world cases. Utilizing daily shared information about inbound flow (i.e. truck-arrival time) and outbound flow (i.e. required timeframes), we then propose daily process redesign on changing process parameters and evaluate their impact on the process performance using a discrete-event simulation model of a floricultural supply chain. Additionally, the impact of different information characteristics (i.e. timeliness, accuracy and completeness) on the effectiveness of the redesign decision are studied through different scenarios. This work contributes to a better understanding of the value of information in supporting decision-making at the operational level, particularly in warehouse operations. It also helps to raise the awareness of industrial managers regarding the use of information for improving process performance as well as the importance of information characteristics.

Keywords: *value of information, information characteristics, distribution, warehouse operations, information sharing, discrete-event simulation*

1. Introduction

Warehouses are a critical component of any supply chain where different products ordered from various suppliers are consolidated for combined delivery to retailers (Gu et al., 2007). In order to meet the increasingly diverse and dynamic demand of end customers nowadays, retailers are ordering many types of products in smaller quantities with even smaller required lead-time, see for examples about floricultural supply chains reported by De Keizer et al. (2015). This development leads to highly dense logistics context in which small quantities of a wide assortment of products have to be distributed more frequently and in shorter timeframes. The logistic processes could be even more challenging for agro-food products that operate under time constraint and the need for conditioning because of products' perishability (van der Vorst et al., 2005). In this paper, we focus on the daily operations in distribution warehouses of agro-food supply chains where products from inbound trucks are unloaded, subjected to value-added processes (e.g. labeling, quality checking), and shipped to outbound trucks within a short timeframe of less than twelve hours.

Information about inbound and outbound flows plays an important role in facilitating efficient and fast processes in such distribution warehouses (Apte & Viswanathan, 2000). Besides detailed information about products on item level based on tracking technologies such as RFID and bar codes (Connolly, 2008), shared information from suppliers and/or retailers can be valuable in improving the process performance. For example, the suppliers can share the truck-arrival time information and the retailers can provide the required outbound time window. The work presented in this paper particularly investigates the value of truck-arrival time information shared by suppliers in enhancing the decision-making at the distribution warehouse.

Chopra & Meindl (2013) suggest that information should be of the right kind, accurate and accessible in a timely manner to be valuable in decision-making. In the rich literature on information sharing, information is often assumed to meet the requirement of information characteristics desired by its user. As a result, the impact of information characteristics on the value of information has not been studied extensively. In reality, many factors (i.e. human and environment) can intentionally or accidentally distort the information characteristics. This paper contributes to the

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literature by analyzing the value of truck-arrival time information in different scenarios considering different information characteristics, i.e. information timeliness, accuracy and completeness. Thus the objective of this paper is twofold: (1) to demonstrate the use of available information in improving daily operations at distribution warehouses and (2) to stress on the importance of information characteristics.

The remainder of this paper is organized as follows. Section 2 reviews the literature and elaborates the generic theoretical framework to assess the value of information in supply chain process redesign. Section 3 introduces the high-density logistic context at distribution warehouses and the case study of a floricultural supply chain. The simulation framework and the results of the case study are presented in section 4. In the last section, we summarize the work in progress and discuss the next steps.

2. Literature review and theoretical framework

2.1 Literature review

Value of information (VOI) is a core and growing topic in supply chain management research (Shiau et al., 2015). In most of the literature, value of a piece of information is defined as *the advantage/cost-saving/benefit achieved through the use of the information in decision-making relative to the base scenario when the information does not exist*, see for examples Ketzenberg et al. (2006), Choudhury et al. (2008), Davis et al. (2011), and Ganesh et al. (2014).

The largest part of the current literature on VOI is about the value of information sharing in decisions on inventory management. For this type of decision, main interests are in the values of inventory-related types of information including demand, inventory level, order planning and manufacturing process. The general conclusion from these studies is that the VOI can be significant yet very sensitive to supply chain process parameters (Li et al., 2005; Schmidt, 2009). Ketzenberg et al. (2007) investigated 27 papers and introduced a useful framework that helps to explain how supply chain process parameters affect the value of information sharing in inventory replenishment decision. Five dimensions in that framework are (i) the level of uncertainty in the supply chain, (ii) the sensitivity of the supply chain to uncertainty, (iii) the responsiveness of the supply chain, (iv) the available information in the supply chain and (v) the uses of information in the supply chain decision-making.

The second largest logistic area of the VOI literature concerns transportation decisions. Advanced load information from shippers in collaborative transporation enables carriers to better plan their pickup/delivery schedule and routing (Tjokroamidjojo et al., 2006; Zolfagharinia & Haughton, 2014). The value of product location information enabled by tracking and tracing technologies are studied by Yi (2014), Kim et al. (2008) and Flamini et al. (2011).

Literature on VOI in operational warehousing decisions is very limited. The work by Larbi et al. (2011) is the closest to our objective. In the study, the information about the order of arrivals and the content of inbound trucks is used in the operational truck-scheduling decision at a cross-docking warehouse. The study does not cover the internal operations inside the cross-docking warehouse.

A majority of the literature investigate the VOI on the *availability* perspective of information. In other words, these studies consider and compare two scenarios: the decision-making in the supply chain with- and without the information scenarios. However, in practice not only the information availability but also other information characteristics such as timeliness, accuracy, completeness, consistency, format, security, etc. may influence the VOI. Information characteristics are also addressed under different terms such as information quality dimension (Miller, 1996; Gustavsson & Wänström, 2009), or information value attributes (Sellitto et al., 2007; Herrala et al., 2009; Leviäkangas, 2011). We consider the terms to be interchangeable on the perspective of how they affect the VOI. In the theoretical framework on evaluating the value of information in supply chain process redesign decision-making, we especially emphasize the three *intrinsic* characteristics of information (table 1), which are objective and native to the information (Hazen et al., 2014). We argue that other characteristics are subjective and contextual, which can be controlled once the user understands the value of information.

Table 1. Information accuracy, timeliness and completeness

Characteristic	***Definition***
Accuracy	How accurate the information reflects the underlying reality?
Timeliness	Timeliness indicates how up to date the information is and how well it meets the demand for information in a particular time and space.
Completeness	Completeness refers to different levels of detail of the information.

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2.2 Theoretical framework

Grounding on the literature, we propose a generic research framework (figure 1) to study the value of a piece of relevant information in improving the redesign decision-making on a supply chain process. This framework will be applied to the case study in section 3. The *redesign* here refers to the changes in the processes, which can be at the strategic, tactical or operational level. At the strategic level it can be, for example, a new design for a whole distribution network. At the tactical/operational level it can be, for instance, a new ordering rule or a new order quantity in the inventory management process.

In the theoretical framework, there are three decision-making scenarios. These 3 scenarios start with dissimilar inputs for the decision support tool.

- Scenario 1: the input is the base information, which is the existing information in the process.
- Scenario 2: the input includes the base information and the perfect additional information acquired by the decision maker. The additional information is perfect when it meets the requirement of information characteristics desired by its user. Taking information accuracy as the desired information characteristic of the user, accurate information will be considered as perfect information.
- Scenario 3: the input includes the base information and the imperfect additional information. The additional information is imperfect when one of its characteristic deviates from the requirement by its user, e.g. inaccurate information or untimely information.

Accordingly, three different decisions are obtained from the decision support tool. The base decision is evaluated in the current situation whereas process-redesign decisions are evaluated in multiple scenarios on process parameters. Simulation might be preferred to other methods such as optimization in this evaluation step because of its capability to address the high complexity and dynamics of supply chain processes.

The value of information and the impact of information characteristics are measured by the improvement in the process's Key Performance Indicators (ΔKPIs). The ΔKPIs between decision-making scenarios 1 and 2 results in the value of perfect information, while the ΔKPIs between scenarios 2 and 3 indicates the impact of information characteristics on the value of information.

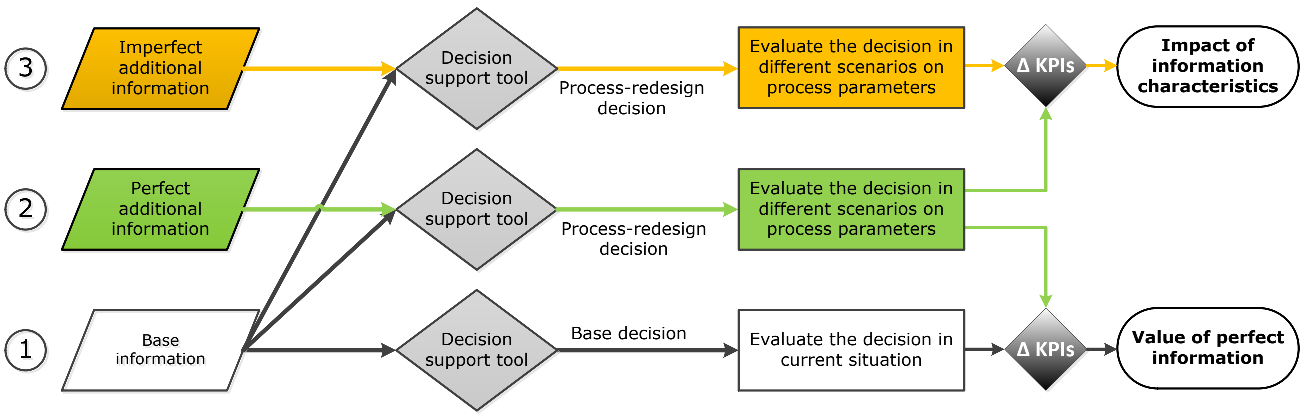

Figure 1. Framework on evaluating the value of information in supply chain process redesign decision-making

3. High-density logistics and the case study

In this section, we provide a generic definition for high-density logistics process at distribution warehouses. Afterwards, we discuss a case of a floricultural supply chain and appropriately map the concepts in the theoretical framework to the case.

High-density logistics. The term "high-density logistics" have been used in the literature without being formally defined, see for example in Lee & Whang (2001, p. 59). Considering two important aspects in a logistics process, i.e. the timeframe and the number of logistics flows, we define high-density logistics process as *a logistics process that consists of a high number of logistics flows which are required to be accomplished in a short timeframe.* Below, we give an example of a high-density logistics process in a cross-docking distribution warehouse.

The distribution warehouse in this example is a mixed warehouse, as presented in the study by Apte & Viswanathan (2000) (appendix A) where inbound shipments from several suppliers are splitted and then consolidated again to create

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multiple multi-product shipments. The internal logistic process at such a distribution warehouse is illustrated in figure 2. The process consists of three primary stages: Splitting, Merging & Aggregating and Shipping. The size of Stock Keeping Units (SKUs) changes in each stage:

- From the moment the trucks arrive until the entry of stage S1 – Splitting, products are in big SKUs.
- At stage S1, the big SKUs can be directly brought to stage S2 or can be splitted into many small SKUs, which go to different lines of stage S2 – Merging & Aggregating.
- At stage S2, many small SKUs are merged into full big SKUs and multiple big SKUs are aggregated before being shipped at stage S3 - Shipping. Note that there is a limitation for the aggregating size.

Because the retailers frequently order small quantities of many products, the number of big SKUs split at stage S1 increases, and so does the average number of small SKUs that a big SKU is split into. This means there are increasing number of logistics flows (i.e. the number of operations and the movements of products between S1 and S2). Moreover, the timeframe is short because of the small required lead-time of the order.

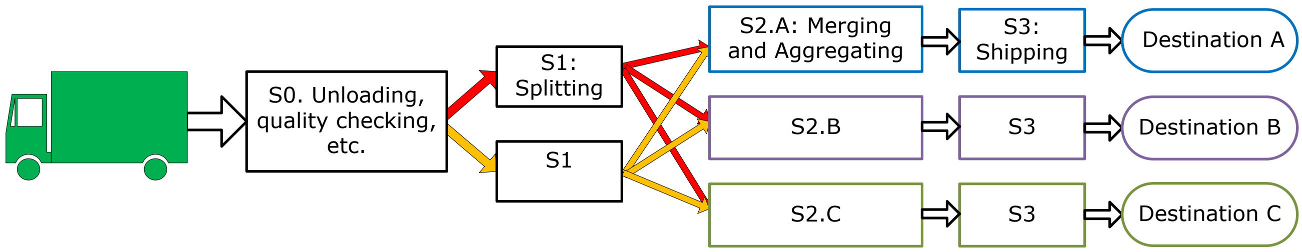

Figure 2. Multi-stage distribution process

Case study. The distribution warehouse in this case study is part of a Dutch floricultural supply chain. The flower buyers are located in the neighborhood of the warehouse. We focus on the cut-flower area of the distribution warehouse.

Subsequent to the order transaction between flower growers and buyers, online electronic forms are sent from growers to the warehouse indicating the content and the destinations of each flower trolley. The trucks transporting the flowers arrive at the warehouse after a lead-time ranging from a few hours to one day according to the nature of the order (i.e. infrequent urgent or regular orders). In this case, we only consider the regular orders, which means the online information arrives one day in advance to the arrival of flowers. The warehouse is responsible for distributing the flowers to the right buyers in the right time, right product, and right quantity.

The distribution process follows the multi-stage distribution process presented in figure 2. It starts with unloading trolleys from trucks, and then sorting and quality-checking. Next, the trolleys are moved to a queue buffer where they are either carried directly to the Merging and Aggregating line of a client, or split over a number of buyers. A flower trolley often consists of 30 buckets of cut-flower. On average 60% of inbound trolleys are split among the buyers. At Merging and Aggregating line, flower buckets are merged in full trolleys again. Many full trolleys are aggregated and physically connected before they are shipped to the buyers.

Mapping. The mapping of the theoretical framework to the case is as follows.

- *Base information*: the daily quantity of trolleys delivered to each buyer
- *Additional information*: the truck-arrival time information provided by the growers
- *KPI*: the KPI is defined as the number of trolleys that are distributed in time to the buyers before their specified time T.
- *The decision to be made*: In this case study, we aim to demonstrate the possible use of the additional information on daily decision-making. The decision from this decision-making should be practical so that the implementation of the decision does not require considerable effort by the workers in the process. We intend to use the information to improve the daily decision on a process parameter, i.e. the aggregating sizes before the trolleys are shipped to the buyers. The aggregating sizes directly affect the KPI. Intuitively, knowing the truck-arrival time enables an estimation on the throughput time before the trolleys are ready at the aggregating stage. As a result, the decision maker can choose the aggregating sizes that maximizes the KPI.
- *Decision support tool for process-redesign decision*: A heuristic (figure 3) is developed to make decision on the aggregating sizes in case truck-arrival time information is available. The heuristic loops backward every c time units

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from the specified time T; c is very small compared to T. The additional information allows the calculating of the arrived quantity Q of trolleys at any (T – kc) timing. We use an algorithm (appendix B) to estimate the processing time to deliver the Q trolleys to the buyers. If it is possible to do so, the heuristic will select the aggregating sizes that maximizes the KPI.

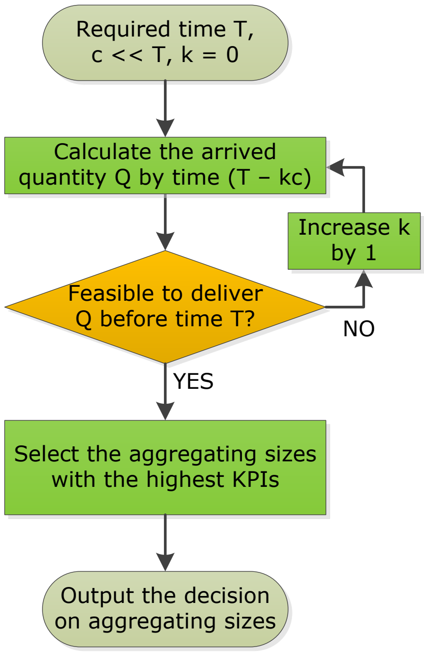

Figure 3. Heuristics with information

- *Decision support tool for base decision*: It is crucial to obtain a proper base decision that can serve as a benchmark for calculating the VOI. With only the base information, i.e. the total inbound quantity of each buyer, the base decision can only minimize the processing time of the entire inbound trolleys using the same algorithm in appendix B. Note that the base decision and the process-redesign decision are different upon their objectives. While the base decision aims to minimize the processing time, the process-redesign decision aims directly to maximize the KPI.
- *Information characteristics*:
  - ➢ Information accuracy: is the provided truck-arrival time accurate? In reality, delays may occur because of unexpected traffic conditions.
  - ➢ Information completeness: is the provided time specified in hours, or quarters or minutes?
  - ➢ Information timeliness: what if a number of growers do not provide the information in time before the moment of decision-making?
- *Process parameters*
  - ➢ The inter-arrival time of trucks
  - ➢ The specified time T by the buyers
  - ➢ The cycle time at stage S3
- *Evaluating the decisions*: Discrete-event simulation is widely used for modelling supply chain distribution and transport planning (Tako & Robinson, 2012). It should be noticed that the heuristic can only accept deterministic inputs in its calculation. To evaluate the decisions, we use a discrete-event simulation model in which the process parameters are stochastic. As a result, the dynamic characteristics of the process is reflected in the simulation results.

4. Simulation framework and results

The simulation model is implemented using Enterprise Dynamics 9 package (EnterpriseDynamics, 2017). In reality, there are multiple buffers for different group of destination. We choose to model one buffer area and limit the number of buyers to 3. There are two employees working at the Splitting and Merge and Aggregating stages, and one employee at stage Shipping. Their shifts are finished as soon as all the trolleys are delivered to the clients.

The steps in the simulation framework is as follows.

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- Step 1: randomize truck-arrival time (Poisson distribution) and product quantity for each buyer
- Step 2: run the algorithm in appendix B to obtain the aggregating sizes in base information
- Step 3: run the heuristic to obtain the aggregating sizes in process-redesign decision
- Step 4: run the simulation model to obtain the KPIs for base decision and process-redesign decision. 100 runs were performed on each input dataset in order to obtain a narrow 95% confidence interval. By this way, the means can be used for comparison in step 5.
- Step 5: compare the KPIs to obtain the VOI

Note that in order to assess the value of perfect information, we input the same truck-arrival time data in both the heuristic and the simulation model. In case of imperfect information, we use the two different inputs: the original truck-arrival time data for the simulation model and the distorted truck-arrival time data for the heuristic.

4.1 Value of perfect information

The theoretical highest VOI can be achieved if one has enough time and computational capacity to test all the combinations of aggregating sizes with the simulation model. Hereby we present the practical value of perfect information using the heuristic-based process-redesign decision. As discussed in the literature review, VOI is sensitive to the process parameters. As a result, it is meaningless to provide a numerical value as the VOI. In this sub-section, we investigate the general significance of the VOI and the effect of the process parameters.

Table 2 presents the setting of process parameters. The parameters of the current situation are in bold. In order to examine the sensitivity of VOI to a process parameter, we alter its value while fixing the values of the other parameters at the current situation. The results are shown in figure 4.

The results indicate that (1) the VOI is positive in a majority of input datasets and parametric settings. Nonetheless, there are cases in which the VOI is close to zero, which implies that the process-redesign decision is just as good as the base decision. (2) The process parameters significantly influence the VOI, yet the impact is non-monotonic. For instance, we expected that the longer the outbound required time would be, the higher number of trolleys could be processed, thus the higher VOI could be. The results show that it is true until a threshold (in this case, T = 4 hours). Beyond this threshold, the quality difference between the base decision and process-redesign decision becomes small because the outbound required time is close to the processing time of the entire inbound trolleys.

Table 2. Process parameters setting

Parameter	***Values***
Inter-arrival time of trucks	5, 8, **12**, 15 (minutes)
Specified time T by the buyers	2, 3, **4**, 5 (hours)
Cycle time at stage S3	10, **15**, 20, 25, 30, 35 (minutes)

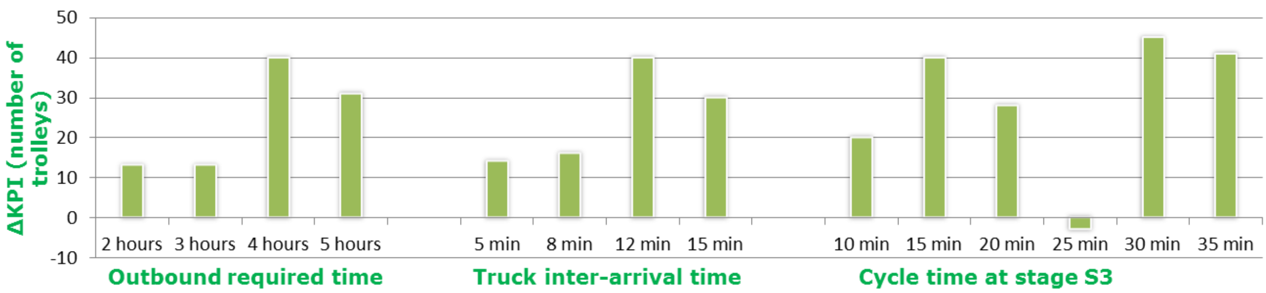

Figure 4. The sensitivity of VOI to process parameters

4.2 Value of imperfect information

While implementing the scenarios on information characteristics, we realized that the impact of information characteristics depends on to what extent the heuristic relies on the information characteristics. In the case study, since

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the heuristic utilizes the information to calculate the arrived quantity of trolleys before a predefined time, i.e. (T – kc), the requirement is that whether or not the trucks arrive before that time. Therefore we only considered the information timeliness at this moment.

We carried out different scenarios to study the impact of untimely information. From the input data of the current situation, we randomly omit the arrival-time of one truck, two trucks, three trucks and five trucks. Accordingly, the arrived quantity of these trucks are not counted in the heuristic. Interestingly, with the 3-truck omitted dataset, the output from the heuristic remains the same with the case of perfect information.

The results (figure 5) show that information untimeliness does not necessarily reduces the VOI. In the case of set 2 of two-truck omitted, the decision even outperforms the decision from the perfect additional information. Note that theoretically the value of imperfect information cannot surpass the value of perfect information. This leads to the confirmations that the quality of the heuristic determines the VOI, and the proposed heuristic needs improvement in order to exhaustively exploit the information. Nevertheless, we expect that a more complicated heuristic might impose extra requirements on information characteristics, which in turn amplifies the impact of information characteristics on the VOI.

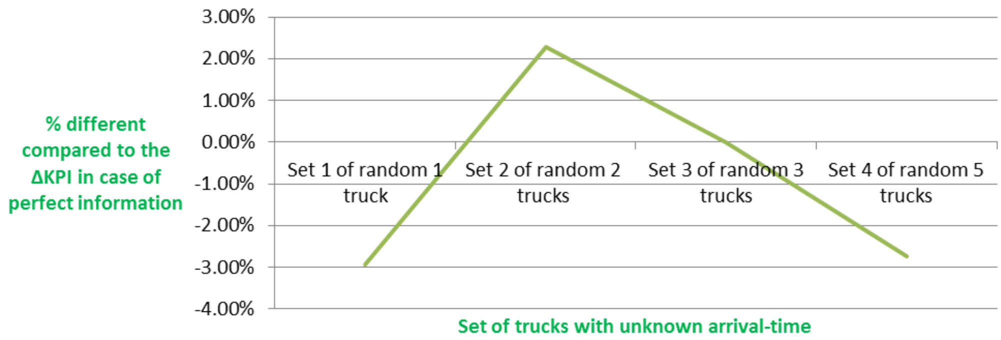

Figure 5. The impact of untimely information

5. Summary and next research steps

In this paper, we demonstrated a practical approach to use shared information from the suppliers for improving the decision-making on daily operations at distribution warehouses. A generic research framework on evaluating the value of information in supply chain process redesign was applied to the distribution process of a floricultural supply chain. The value of truck-arrival time information was studied. The results on the VOI from the case study show that the VOI is positive, yet numerically sensitive to supply chain process parameters. The importance of information characteristics is subject to how the information is used in the decision support tool (i.e. the heuristic).

The plan for next research steps is as follows.

- Integrating the second KPI, i.e. the total processing time of the entire inbound flow.
- Extending the constraint to multiple outbound required times in a day.
- Given the limitation of the current heuristic, we plan to extensively explore the literature on queueing theory and warehousing in order to improve the quality of the heuristic.
- Developing more complicated scenarios on information characteristics (including also information accuracy and completeness) to reflect the dynamic reality.

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Appendix A

Mixed warehouse structure (Apte & Viswanathan, 2000, p. 295)

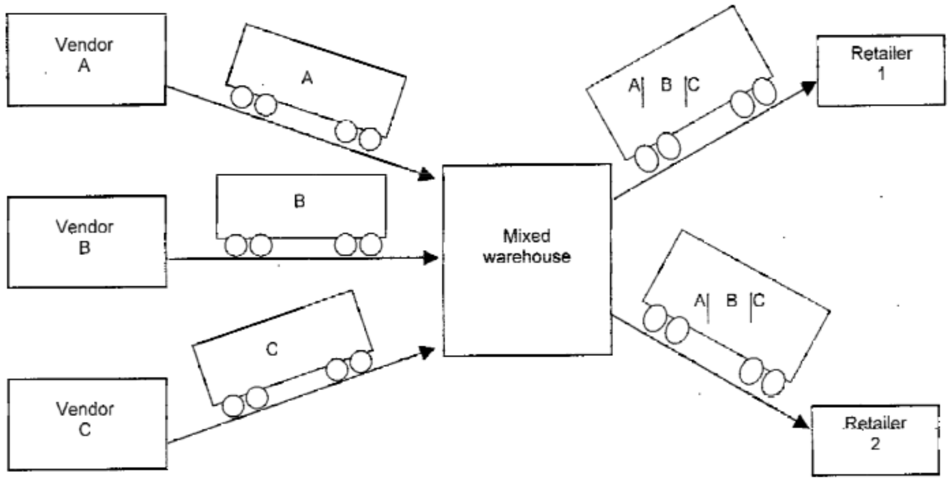

Figure 6. Mixed warehouse structure

Appendix B

This appendix presents the algorithm which estimates the throughput time from the first stage S1-Splitting through stage S2-Merging and Aggregating to the final stage S3-Shipping.

Considering each aggregated set of trolley as a product and the only worker at stage S3 as a server, the generic queueing model represents the distribution process following Kendall notation is $D/D/1/\infty/\infty$. However, there are as many types of products as many buyer lines. Each type of product has a different inter-arrival time because of different aggregating sizes at each buyer lines.

- Let α be the average time that a full trolley appears at the aggregating lines. In the case study, α is based on the splitting time and merging time. α varies according to input datasets on quantities allocated to buyers. We assumed that in practice the process manager is able to estimate the numerical value of α and re-estimate this value regularly. The value of α used in the heuristic is obtained from the simulation model. We selected the maximum mean of α. The VOI is slightly sensitive to the accuracy degree of estimating the value of α (figure 7).
- Let N is the number of buyer lines in the distribution process.
- With i = 1,2, …, N:
  - Let x_i are the aggregating sizes at the buyer line I, then $T_i = \alpha x_i$ will be the inter-arrival time of product from line i
  - Let k_i is the inbound quantity of product at line i; $K = \sum_{i=1}^{N} k_i$
  - Let β_i is the service time for product at line i.

The problem is formulated as "given T_i, k_i, β_i, calculate the processing time of the entire inbound K products". The pseudo-code of the algorithm is as follows.

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Initialization

    t = 0

    FOR i = 1 to N:

        Li = { tuples (kT_i , β_i) with k = 1, 2, ..., k_i }

    ENDFOR

    L = { $\cap_i^N$ Li }

    L = sorted L in the ascending order of the first items in the tuples

FOR i = 1 to K:

    Add the second item of the tuple i to t

ENDFOR

Return t

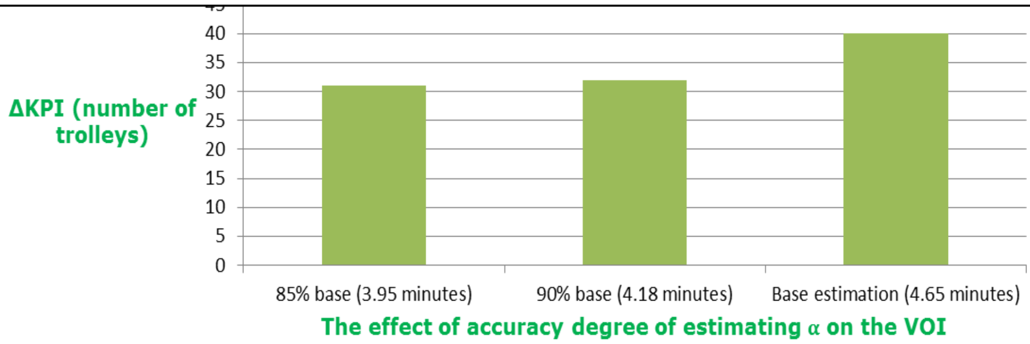

Figure 7. Sensitivity of VOI to estimated α

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