# UNIVERSITÀ DEGLI STUDI DI PADOVA

**Facoltà di Ingegneria**
Dipartimento di Tecnica e Gestione dei Sistemi Industriali
Corso di laurea in Ingegneria Gestionale


Tesi di Laurea Magistrale

# Cross Dock: analysis of two different strategies in handling and staging freights using simulation


Supervisor: Ing. DARIA BATTINI

Supervisor at DTU: Prof. ALLAN LARSEN

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Laureando: ADAMI ALBERTO


Anno Accademico 2010-2011

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## Abstract

This project develops the models of two different strategies in handling and staging freights within a cross docking terminal to test how they perform in operations. It aims to understand if a sorting process that stages freights in lanes dedicated to the kind of product positively affects the behaviour of the facilities provided by the cross dock and, especially, the loading process. The requirement of resources is considered at the same time, in order to provide useful information about the necessity extra resources.

The main target of this work is reached by the use of the discrete events simulation software Rockwell Arena. To do that, it is first necessary to size the need of resources in the models, in order that they can efficiently perform using all the adopted datasets. Both the models, in fact, are tested with three different distributions in the scheduled incoming/outgoing trucks arrival time because the results could suggest opposite conclusion for the same layout, if subjected to different input data. Their robustness is then tested introducing unexpected disruptions in the models.

Considering that this Master Project has been developed at the Technical University of Denmark (DTU) but it will be defended at the Università degli Studi di Padova, a preface in Italian is added at the beginning of this work. Its target is to summarize the main steps of the work.

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# PREFAZIONE

Il presente lavoro è stato svolto presso il dipartimento di Logistica e Trasporti della Technical University of Denmark (DTU) nel periodo compreso tra Agosto 2010 e Marzo 2011, sotto la supervisione del Prof. Allan Larsen.

Dopo aver svolto un'analisi della letteratura riguardante il tema del cross dock, questo lavoro di Tesi di Laurea Magistrale sviluppa i modelli di due strategie di movimentazione e allocazione della merce al fine di valutare e confrontare le prestazioni delle attività all'interno del terminal. L'obiettivo è capire se l'adozione di un processo di sorting che suddivide e alloca la merce per tipologia di prodotto influisce positivamente sulle prestazioni del processo di carico, tenendo sempre in considerazione l'eventuale differenza nel fabbisogno di risorse necessario al corretto svolgimento delle operations nei due modelli analizzati.

I risultati sui quali è basata l'analisi sono ottenuti attraverso l'utilizzo del software di simulazione di eventi discreti *Rockwell Arena*, attraverso il quale vengono implementati i due modelli di cross dock associati alle strategie analizzate.

**Obiettivi**

L'analisi della letteratura presente sul tema del crossdocking mostra che i principali argomenti ad oggi affrontati sono i seguenti:

| Autore | Anno | Argomento |
|---|---|---|
| L. Y. Tsui, C. Chang | 1992 | Definizione di un algoritmo di assegnazione delle baie di scarico ai carichi in arrivo al cross dock |
| M. Rohrer | 1995 | Spiegazione di come la simulazione possa aiutare ad ottimizzare i processi e prevenire i problemi all'interno di un cross dock. Fornisce inoltre delle linee generali per la costruzione di un modello |
| A. Marin, B. Pelegrin | 1997 | Sviluppo di un algoritmo per l'individuazione della location ottimale dei punti di smistamento |
| Gue K. R. | 1999 | Sviluppo di un modello di assegnazione delle porte di scarico minimizzando le distanze |
| Gue K. R. | 1999 | Sviluppo di un modello di assegnazione delle porte di scarico minimizzando le distanze percorse dai lavoratori all'interno del dock |

| | | |
|---|---|---|
| Gue K. R. | 2000 | Scelta della forma ottimale di un cross dock |
| J. J. Bartholdi, K. R. Gue | 2000 | Partendo da modelli di costo per il trasferimento della merce e dalle 3 più diffuse tipologie di congestione all'interno di un cross dock, costruisce un layout che minimizza tali costi |
| K. R. Gue, K. Kang | 2001 | Sviluppo di un modello di simulazione per studiare il comportamento e la congestione di diverse configurazioni di code nei sistemi di trasporto materiale |
| Fernando G. Dobrusky | 2003 | Definizione di una rete ottimale di cross dock in Argentina |
| Y. Li, A. Lim, B. Rodrigues | 2004 | Sviluppo di un euristico al fine di eliminare o minimizzare le scorte in una programmazione JIT |
| M. Gumus, L. H. Bookbinder | 2004 | Identificazione dei problemi derivanti dall'adozione di cross dock all'interno di una rete distributiva e linee guida per la loro risoluzione |
| G. M. Magableh, M. D. Rossetti | 2005 | Valutazione, attraverso simulazione, dei rischi associati ai servizi forniti da un cross dock in un ambiente dinamico |
| Gue K. R. | 2007 | Trattazione dei motivi che rendono il cross dock capace di diminuire i costi di giacenza e di assicurare consegne più efficienti |
| Wang, Jiana-Fu, A. Regan | 2008 | Utilizzo di informazioni real-time sulla merce al fine di programmare le spedizioni minimizzando il tempo speso dalla merce all'interno del terminal |
| Y. Cohen, B. Keren | 2009 | Discussione sugli euristici esistenti nell'assegnazione delle baie di scarico e proposta di una formulazione alternativa del problema |
| N. Boysen, M. Fliedner | 2009 | Introduzione di una classificazione della programmazione deterministica dei carichi e di una classe di problemi non ancora esplorati |
| J. J. Vogt | 2010 | Definizione dei fattori di successo che caratterizzano una gestione di un cross dock in modo integrato a livello di supply chain |
| K. K . Yang, J. Balakrishnan, C. H. Cheng | 2010 | Analisi dei fattori principali che influenzano le operations all'interno di un cross dock |

Tab. 1. Analisi della letteratura sul tema del Crossdocking

K. Yang, J. Balakrishnan, C. Cheng (2010) utilizzano la strategia di movimentazione e allocazione della merce come variabile di classificazione dei cross dock:

- Single Stage Cross Dock, nel quale la merce in entrata è semplicemente sistemata nelle linee che corrispondono alle baie di scarico in attesa di essere successivamente identificata, prelevata e caricata

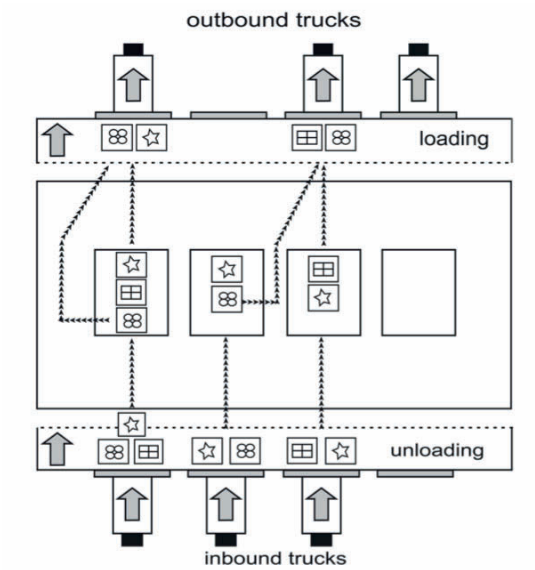



Fig I. Movimentazione merce nel Single Stage Cross Dock analizzato

- Two-Stage Cross Dock, dove la merce in entrata subisce un processo di smistamento attraverso il quale ogni singolo bene viene sistemato in una linea dedicata a quello specifico tipo di prodotto prima di essere caricata

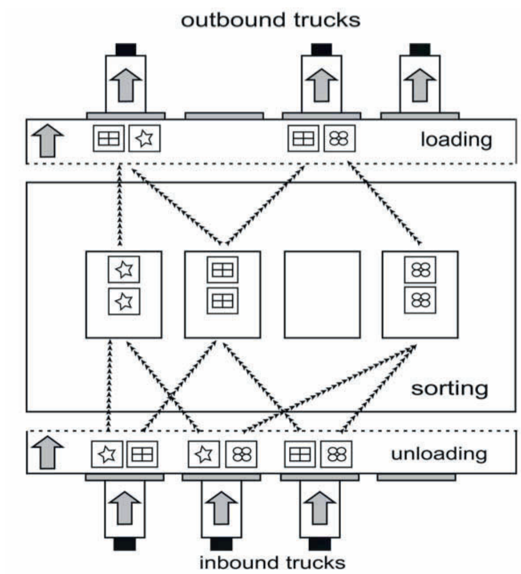



Fig. II. Movimentazione merce nel Two-Stage Cross Dock analizzato

Non emergono tuttavia successivi studi di valutazione delle attività associate ai diversi metodi di movimentazione ed allocazione dei prodotti. Questo lavoro di Tesi è pertanto finalizzato a valutare i processi di carico e scarico all'interno delle due tipologie di cross docking terminal sopra riportate.

Nello specifico, l'obiettivo principale è capire se l'adozione del processo di sorting, che suddivide e alloca la merce per tipologia di prodotto, influisce positivamente sulle prestazioni del processo di carico, tenendo sempre in considerazione l'eventuale differenza nel fabbisogno di risorse necessario al corretto svolgimento delle attività nei due modelli analizzati.

**Strumenti**

L'obiettivo principale di questo lavoro di Tesi è raggiunto grazie all'utilizzo del software di simulazione di eventi discreti *Rockwell Arena*, attraverso il quale l'utente costruisce un modello di sperimentazione utilizzando i *moduli* messi a disposizione ("box" di forma differente) che rappresentano processi o logiche di processo.

Ad ogni modulo sono associati specifiche azioni, tempi ed eventuali risorse impiegate; linee di connessione sono utilizzate per unire questi moduli e specificare il flusso delle entità.

Dati statistici, come ad esempio tempi ciclo e livelli WIP (Work In Progress), possono infine essere registrati e ottenuti come output del software.

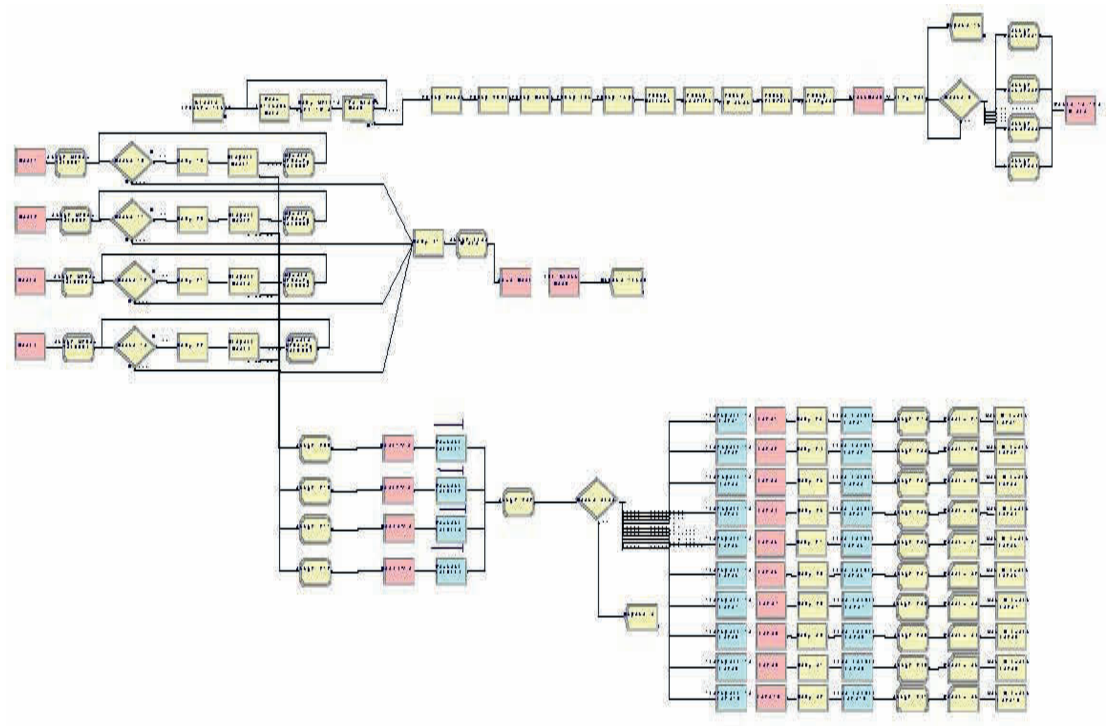


Fig. III. Particolare del modello *Arena*: Two Stage Cross Dock - Processo di Sorting

*Rockwell Arena* ha poi numerose funzioni di animazione che possono essere aggiunte al modello, tra le quali la scelta (da un'ampia libreria) dell'immagine da associare alle entità, la possibilità di disegnare attraverso l'utilizzo di strumenti grafici, la rappresentazione delle code e la visualizzazione dello stato delle risorse utilizzate (impegnato, non utilizzato, inattivo).

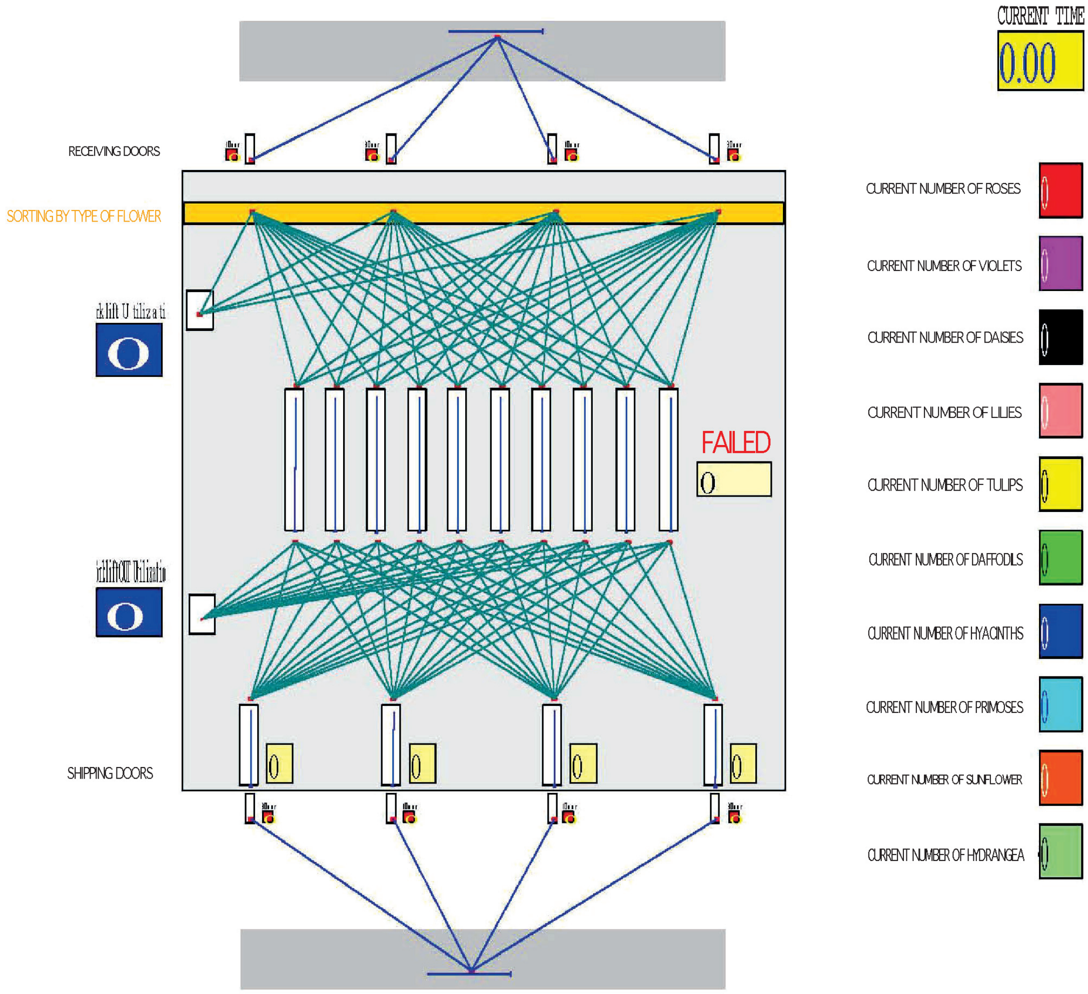



Fig. IV. Animazione del modello di Two-Stage Cross Dock analizzato

L'animazione, infatti, è molto importante nell'aiutare a verificare che il modello lavori come programmato ed assume quindi un ruolo attivo nel convalidare il modello di simulazione costruito come rappresentazione fedele del sistema reale.

*Rockwell Arena* permette, pertanto, di costruire i modelli di cross dock associati alle due diverse strategie di movimentazione ed allocazione merce e di ottenere i KPI necessari per la loro valutazione e confronto (Tab. 2).

| KPI | Descrizione |
|---|---|
| Transit Time $T_T$ | Tempo medio per il trasferimento di un prodotto dall'area di scarico alla linea di stazionamento |
| Loading Time $T_L$ | Tempo medio per il carico di un camion |
| Staging Time $S_T$ | Tempo medio speso da un prodotto nella linea di stazionamento |
| Crossing Time $C_T$ | Tempo medio speso da un prodotto all'interno del terminal, comprese le operazioni di carico e scarico |
| Number of Forklifts | Numero di carrelli elevatori necessari per il corretto svolgimento delle operazioni di carico/scarico |
| Forklift Utilization | Livello di utilizzo delle risorse impiegate |
| Outgoing Trucks Waiting Time | Tempo medio atteso da un camion prima di essere caricato |
| Number of Failed Orders | Numero di ordini non caricati a causa di inefficienza dei processi di carico/scarico |

Tab. 2. KPI utilizzati nella valutazione e confronto delle strategie analizzate

Entrambi i modelli sono testati utilizzando tre diversi orari e frequenze di arrivo/partenza dei carichi in modo tale da simulare il comportamento delle attività all'interno dei cross dock in tre casi differenti:

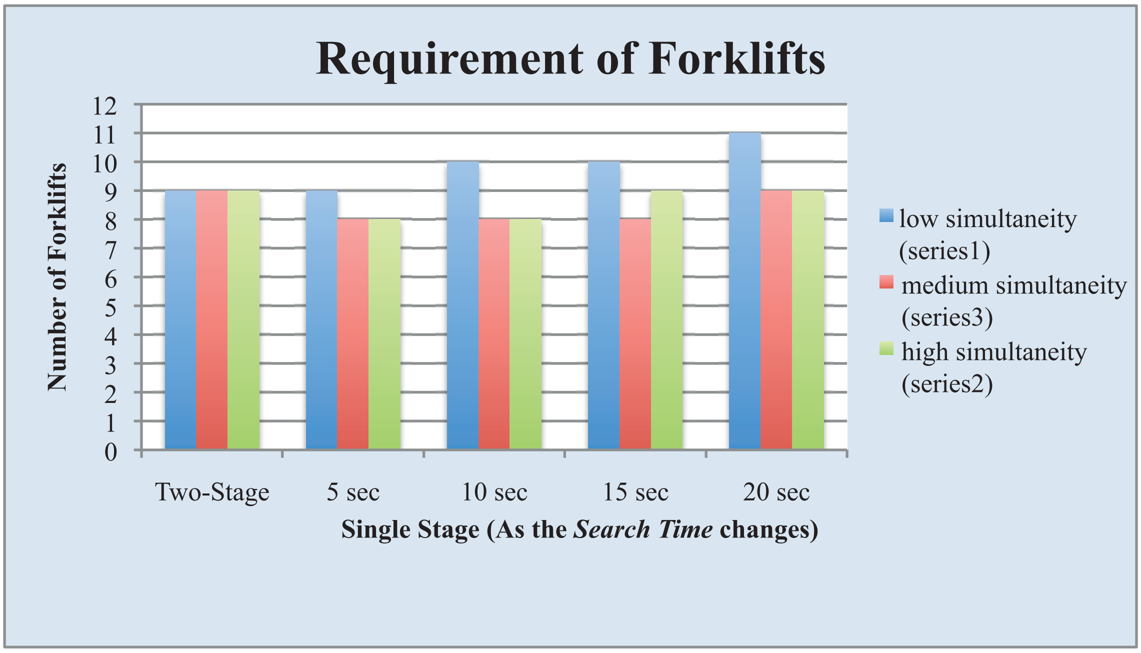
1. Le operazioni di carico e scarico avvengono prevalentemente in momenti diversi della giornata lavorativa con una frequenza crescente negli arrivi/partenze fino a un punto di picco (series1)
2. Le operazioni di carico e scarico avvengono pressoché contemporaneamente e la frequenza negli arrivi/partenze è sempre costante (series2)

3. Le operazioni di carico e scarico sono contemporanee ma la frequenza negli arrivi/partenze è soggetta a diversi picchi durante la giornata lavorativa (series3)

I dati utilizzati come input del sistema sono costruiti prendendo a riferimento un centro di smistamento operante nell'industria floreale sul territorio danese; tali dati, assieme ai modelli, sono stati validati dal Prof. Allan Larsen sulla base della sua esperienza e conoscenza nel settore della logistica e dei trasporti.

**Risultati Ottenuti**

Le informazioni necessarie allo svolgimento dell'analisi sono ottenute tramite simulazione dopo aver dimensionato il gruppo di carrelli elevatori necessari a svolgere efficacemente i processi di carico/scarico nei due scenari a seconda dei diversi orari e delle diverse frequenze di arrivo/partenza dei carichi utilizzati (Graf. I).




Graf. I. Fabbisogno di carrelli elevatori nelle diverse situazioni analizzate

Il dimensionamento delle risorse necessarie al corretto svolgimento delle attività di carico e scarico mostra come nel Two-Stage Cross Dock sia sempre necessario lo stesso numero di carrelli elevatori (correttamente distribuiti tra area di carico e area di scarico) per tutte tre le serie di dati analizzate.

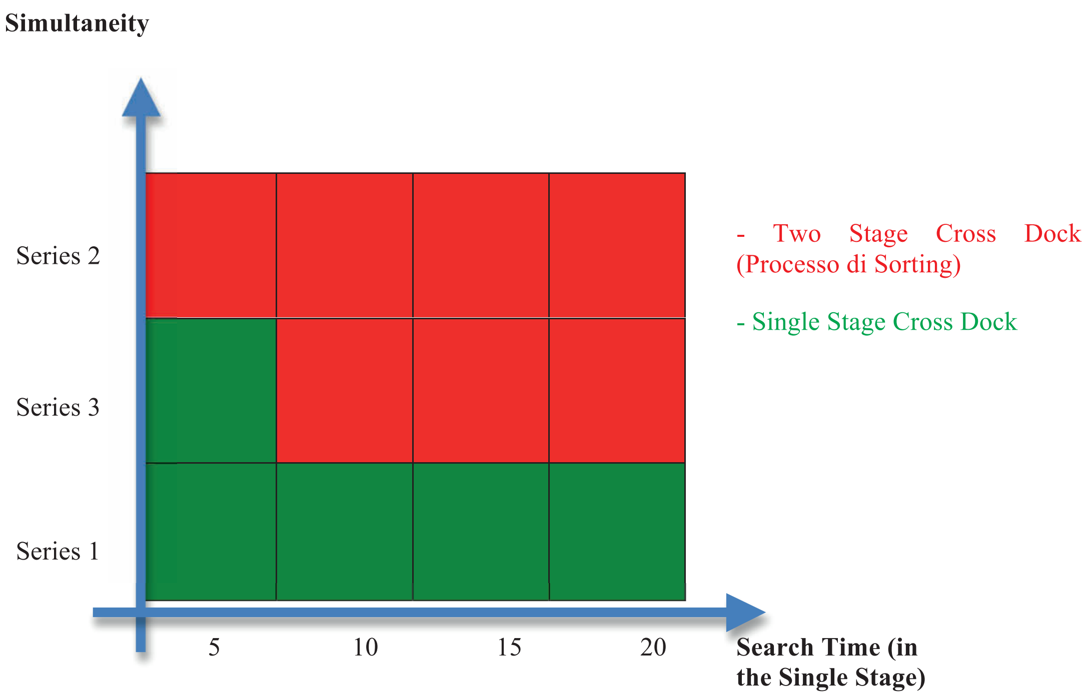
Per quanto riguarda il Single Stage Cross Dock, invece, il fabbisogno di carrelli elevatori è differente al variare della serie di dati utilizzata e di una seconda variabile chiamata *Search Time* (tempo di ricerca della merce nelle linee). In questo caso, infatti, le linee di stazionamento non sono dedicate alla tipologia di prodotto e bisogna quindi considerare un tempo necessario all'operatore per identificare il prodotto corretto. Pertanto, un'analisi di sensitività è stata svolta variando tale tempo di ricerca al fine di comprendere come influisca sul numero di risorse necessarie al corretto svolgimento delle attività di spedizione della merce.

A prescindere dai successivi risultati sulle performance delle due diverse strategie, è quindi possibile notare come il Two Stage Cross Dock presenti una maggiore versatilità rispetto il Single Stage. Una volta dimensionato, infatti, riesce a garantire il corretto svolgimento delle attività con il medesimo numero di risorse pur variando la modalità di gestione degli arrivi e delle partenze dei carichi cui può essere soggetto.

Utilizzando il numero di risorse corretto per ogni scenario, sono poi state svolte tutte le simulazioni necessarie all'ottenimento degli indicatori di performance per le due strategie analizzate al variare di:

- Organizzazione temporale degli arrivi/partenze dei carichi.
- Tempo di ricerca della merce all'interno delle linee di stazionamento nel modello Single Stage (con il processo di Sorting questo tempo è nullo poiché le linee sono dedicate alla tipologia di prodotto).

Il grafico seguente mostra, nelle diverse situazioni, quale sia la strategia di movimentazione e allocazione della merce che mostra i migliori KPI, soprattutto nell'attività di carico.




Graf. II. Cross Dock che ottiene le migliori performance nelle diverse situazioni analizzate

Si può notare come la variabile maggiormente discriminante sia la simultaneità delle operazioni di scarico/carico dei mezzi in entrata/uscita.

Se le attività di carico e scarico iniziano in momenti differenti della giornata lavorativa, le simulazioni portano a sostenere, infatti, che un processo di smistamento merce in linee dedicate alla tipologia di prodotto non porta benefici all'attività di carico che si mantiene sempre su tempi inferiori, anche nel caso di Search Time elevati. Tale risultato si può spiegare con il fatto che l'intervallo temporale tra le due attività consente un riempimento notevole delle linee di stazionamento e quindi la presenza di merce appartenente a tutto il mix di prodotti in ognuna di esse. Così, trovando la maggior parte dei prodotti necessari nella linea di stazionamento corrispondente la baia di carico, le distanze che i carrelli elevatori devono percorrere sono notevolmente inferiori rispetto al caso Two-Stage, ottenendo così migliori performance dell'attività di carico anche con elevati Search Time.

Contrariamente, aumentando la simultaneità delle operazioni di carico e scarico (viene concesso soltanto un warm-up time di un'ora), sia nel caso di frequenza costante o di picco degli arrivi/partenze, la probabilità che un determinato prodotto non sia presente nella linea corrispondente la baia di carico aumenta, costringendo i carrelli elevatori a cercare nelle altre secondo un preciso algoritmo. In questo modo, le simulazioni dimostrano che il processo di Sorting secondo tipologia di prodotto, eliminando il *Search Time* e fornendo una gestione precisa e ordinata della merce, porta a migliori performance nelle attività di carico. C'è un'unica eccezione. I frequenti picchi nella frequenza degli arrivi (series3) consentono, infatti, un buon refilling delle linee di stazionamento; questo, se abbinato a bassi tempi di identificazione merce, porta a preferire il Single Stage Cross Dock.

*Ai miei genitori e a mia sorella*

*It's never good to live in the past too long…*

*The future could be whatever you want it to be.*

# CHAPTER 1: INTRODUCTION

In today's logistical environment where small orders and frequent deliveries are expected, cross docking offers an important advantage. Cross docking is a logistical activity that consolidates shipments from inbound trailers to outbound trailers in buildings known as cross docks. Here, incoming deliveries of inbound trucks are unloaded, sorted, moved across the dock and finally loaded onto outbound trucks, which immediately leave the terminal towards their next destination in the distribution chain. In particular, in the sorting process there are different handling strategies connected to the method of staging freights.

## 1.1. Thesis Overview

This project develops the models of two different strategies in handling and staging freights within a cross docking terminal to test how they perform in operations. It aims to understand if a sorting process that stages freights in lanes dedicated to the kind of product positively affects the behaviour of the facilities provided by the cross dock and, especially, the loading process. At the same time, the requirement of resources is considered in order to provide useful information about the necessity of extra resources.

The main target of this work is reached by the use of the discrete events simulation software *Rockwell Arena*, in which the user builds an experiment *model* by placing *modules* (boxes of different shapes) that represent processes or logic. Connector lines are used to join these modules together and specify the flow of *entities*. While modules have specific actions relative to entities, flow, and timing, the precise representation of each module and entity relative to real-life objects is subject to the modeler. Statistical data, such as cycle time and WIP (work in process) levels, can be recorded and outputted as reports. Therefore, it allows us to create the two different models of the cross docking terminal and to obtain their own performance indicators in order to make an analysis and compare them.

To do that, it is first necessary to size the need of resources in the models, in order that they can efficiently perform using all the adopted datasets. Both the models, in fact, are tested with three different distributions in the scheduled incoming/outgoing trucks arrival time because the results could suggest opposite conclusion for the same layout, if subjected to different input data. Their robustness is then tested introducing unexpected disruptions into the models.

## 1.2. Introduction to cross-docking

Cross docking is a logistical activity that consolidates shipments from inbound trailers to outbound trailers in buildings known as cross-docks. At the cross-dock, each inbound truck that typically arrives from a different origin, is directly assigned to a receiving door upon arrival, or has to wait in a queue on the yard until they are assigned. Once docked, the products of an inbound trailer are unloaded and scanned to identify their respective destinations. Then, products are quickly moved by some means of conveyance, i.e. forklift, hand stacker, or some kind of automated conveyor belt system. The goods are forwarded to the designated shipping doors for different destinations, discharged in front of the outbound trailer and then loaded onto it to an immediate delivery elsewhere in the distribution system (Fig. 1.1). Once an outbound (inbound) trailer has been completely loaded (unloaded), it is removed from the cross-dock door, replaced by another trailer and the course of action repeats.

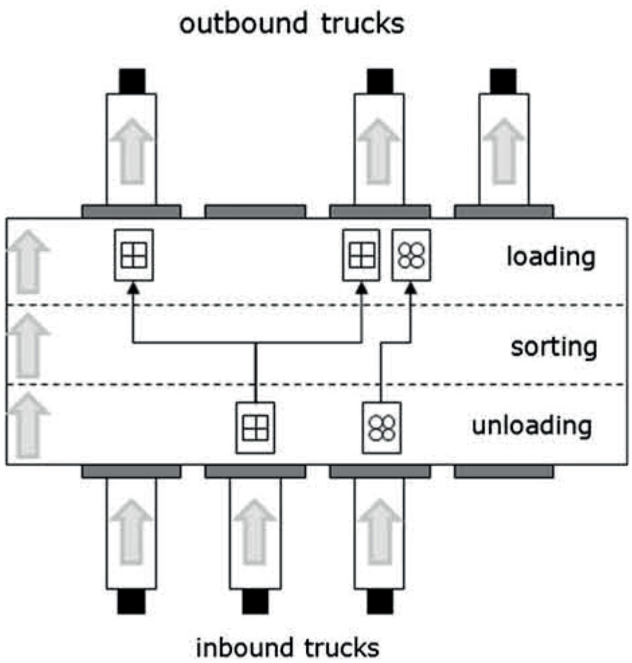



Fig. 1.1. Representation of a cross docking terminal

Therefore, a cross docking terminal is an intermediate node in a distribution network in which shipments from inbound trucks are unloaded, sorted, moved across the dock and directly loaded onto outbound trucks with a minimum dwell time in between, in order to achieve the targets this distribution strategy has been created for.

The primary purpose of cross docking, in fact, is to eliminate storage through the use of a synchronization of inbound and outbound flows (according to a theoretically point of view because in real cases it is an unfeasible target so that cross docking aims to minimize storage costs) and to reduce excessive handling and lead-time, while simultaneously maintaining (or increasing) the level of customer service. An additional major advantage of cross docking is to enable a consolidation of differently sized shipments with the same destination to full truck loads (instead of shipping small orders directly as less-than-truck-load shipments between origin and destination), so that economies in transportation costs can be realized [1].

These advantages make cross docking an important logistic strategy receiving increased attention in today's globalized competition with its ever increasing volume of transported goods and where small orders and frequent deliveries are expected.

### 1.2.1. Classification of cross docks

A cross docking terminal is a distribution center carrying no (or at least a considerably reduced amount of) stock. Incoming shipments delivered by inbound trucks are unloaded, sorted, moved and loaded onto outbound trucks waiting at the dock, which forward the shipments to the respective locations within the distribution system.

According to *Napolitano* [2], cross-dock can exists in different forms:

- *Manufacturing cross-dock* - it receives and consolidates inbound supplies to support Just-in-Time manufacturing.
- *Distributor cross-dock* - it consolidates inbound products from different vendors into a multi-products pallet which is delivered as soon as the last product is received.
- *Transportation cross-dock* - it consolidates small orders from different shippers into truck-load shipments to gain economies of scale.

- *Retail cross-dock* - it receives products from multiple vendors and sorts them onto outbound trucks for different stores.
- *Opportunistic cross-dock* - in a warehouse, transferring an item directly from the receiving dock to the shipping dock to meet a known demand.

The common elements to all of these operations are consolidation and extremely short gap time between inbound and outbound operations (usually less than a day). The short cycle time is possible because the destination for goods is known before or immediately determined when they are receipt. With regards to this we can divide cross-docks into two categories:

1. *Pre-distribution cross-docks*, where the destinations are predetermined and labeled on the shipments before they arrive at the cross-dock, so that workers can transfer such freights directly from inbound to outbound trucks. It is difficult to implement because the vendors of the cross-dock must know which customers of the cross-dock need before they send the shipment. This involves a lot of information transfer, system integration and coordination (Fig. 1.2).

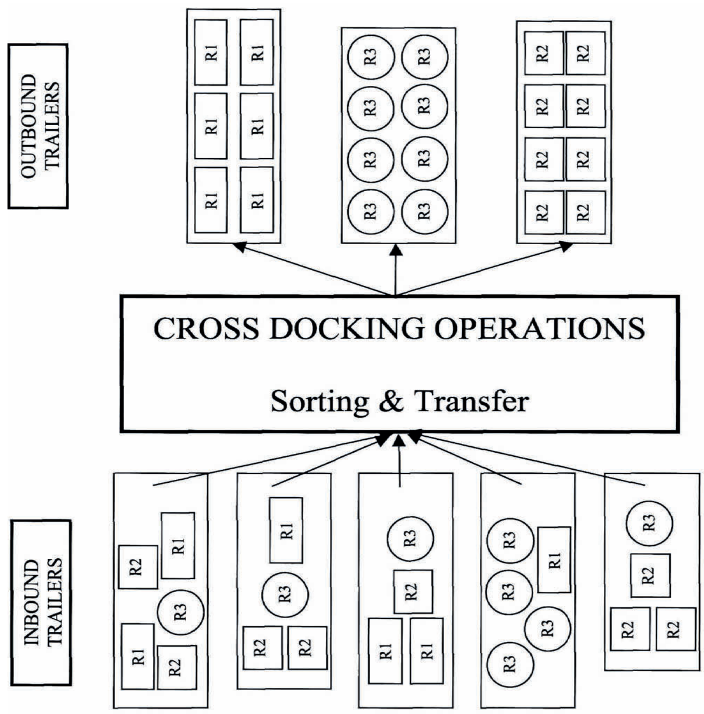



Fig. 1.2. Representation of a pre-distribution cross-dock

2. *Post-distribution cross-docks*, where inbound load arrives without a pre-determined destination, and workers at the cross dock assign the destinations to the shipments. The major advantage of postponing the final destinations is that some value-adding activities (such as price-tagging and re-packing) can take place at the cross-dock terminal (Fig.1.3).

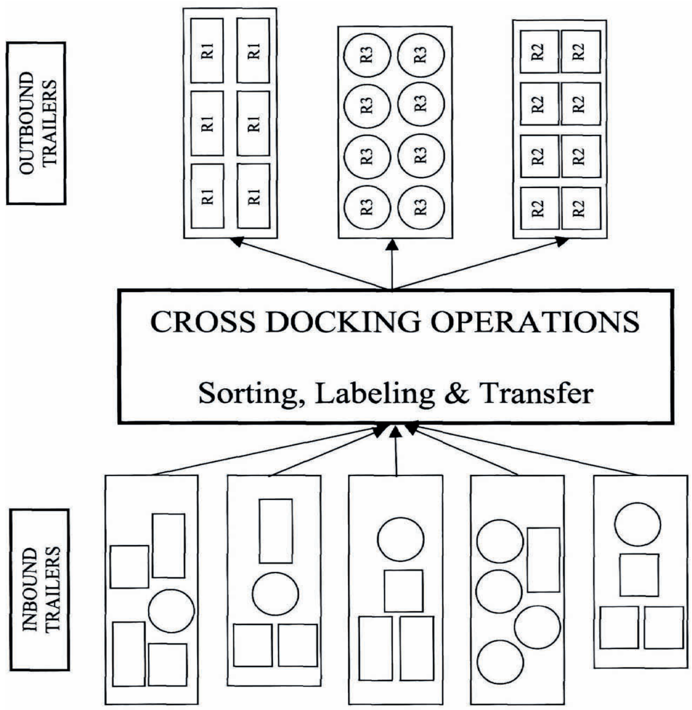



Fig. 1.3. Representation of a post-distribution cross dock

### 1.2.2. Classification based on the method of staging freight

Another way to classify cross-docks is according to the method of staging freight [1]:

1. *Single-stage cross-dock* in which pallets are unloaded and staged into lanes corresponding to the receiving doors when final destinations are still unknown on arrivals (Fig.1.4);

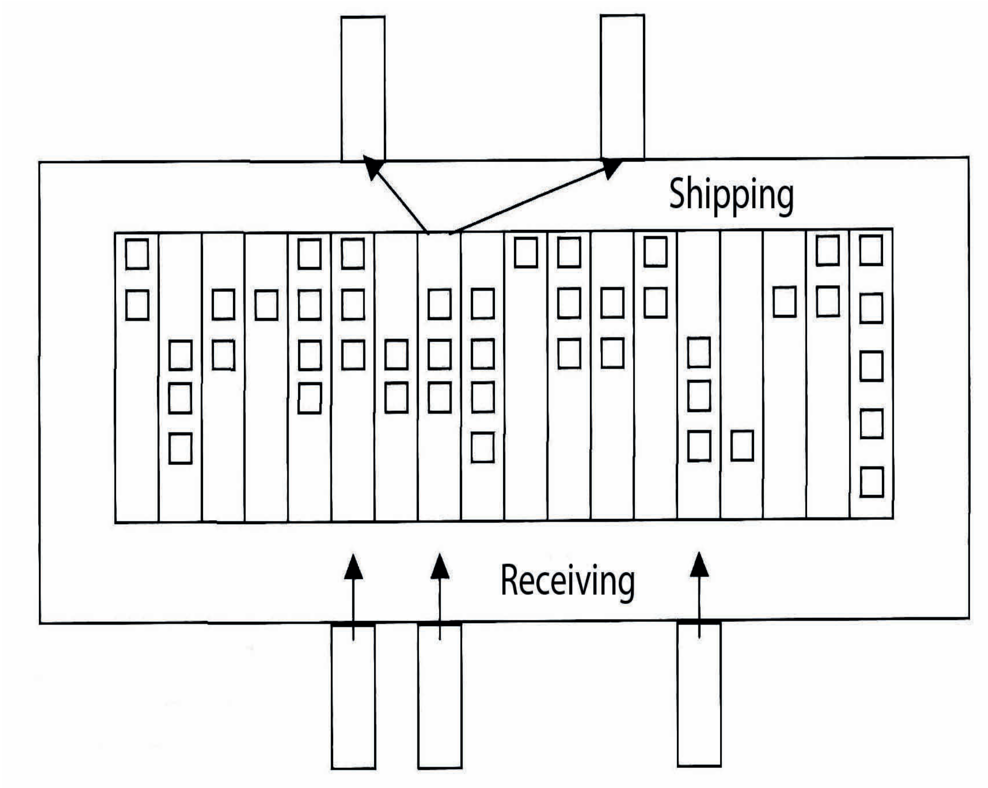



Fig.1.4. Representation of a single-stage cross-dock

2. *Two-stage cross-dock* that allows workers in the centre aisle to re-sort or re-pack pallets, from the staging lanes that correspond to the receiving doors into the staging lanes that correspond to the shipping doors. On the one hand this type of cross-dock offers the advantage of re-packing shipments from the receiving lanes into tightly packed pallets and better visibility. On the other hand each pallet is handled one more time, it is in need of more floor to accommodate the additional centre aisle and staging lanes so that the cross-dock terminal becomes

larger, which may result in a larger time lag between inbound and outbound operations (Fig. 1.5);

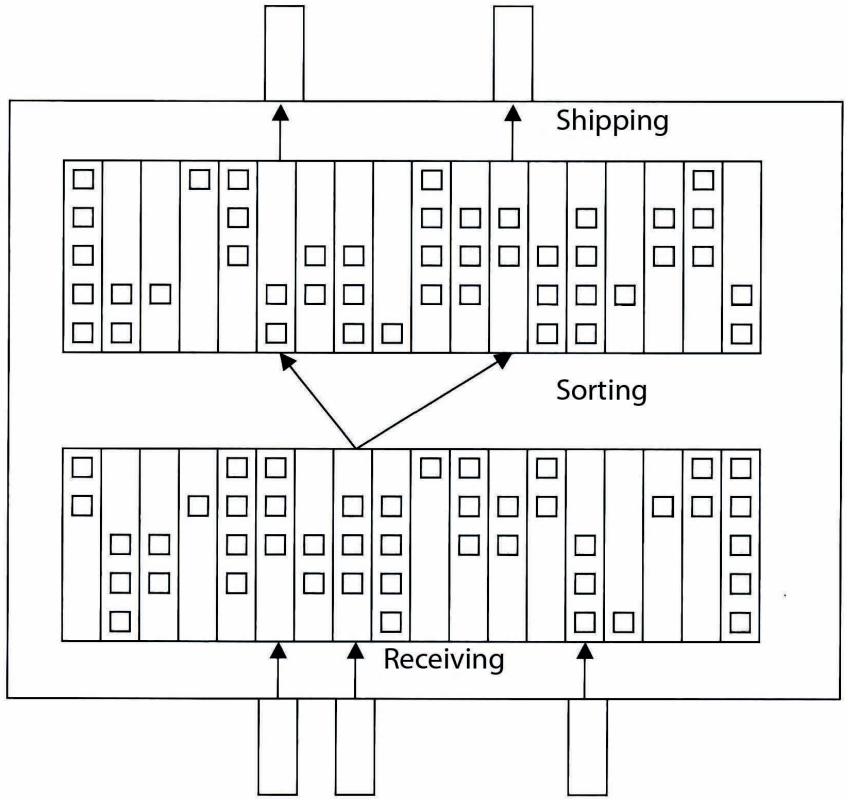



Fig.1.5. Representation of a two-stage cross-dock

3. *Free staging cross-dock* that does not use any queue where pallets are placed but a free staging area is reserved next to each receiving, shipping, and/or both doors.

While various reasons and benefits have been cited for staging freight and performing post distribution activities in a cross-dock, the distribution activities are usually done before the shipments are sent to a cross-dock terminal, so that the costs of double handling and staging freight in a cross-dock are eliminated.

1.2.3. Requirements and decision problems

Cross docking is one excellent way to accomplish the cost reduction goal. This approach reduces material handling time and expense by sending received goods directly to other company locations or customers. The process eliminated storing and picking, which are the two most expensive handling operations, and increases inventory turns, reduces inventory carrying cost and speeds product flows.

Like all systems, cross docking is not the remedy for all logistic problems but its success, when it is used appropriately, depends very much on:

- How well the system is designed and managed (e.g. where the cross dock is located to connect the origins and destinations together).
- How well each individual cross-dock is designed and managed (a poorly designed and managed cross dock will obviously negate the benefit associated with cross docking. Managers have to decide, for example, the appropriate layout, number of doors, the number of forklifts and to manage the terminal daily).

Therefore, cross docking is a difficult logistical activity that requires much effort. On the first hand, it is in need of some necessary requirements to be applied to the system. These requirements can be divided into four categories:

1. *Partnership with other members of the distribution chain*

   Involving receiving and shipping means that cross docking encounters other members of the distribution chain thence it affects other parts incurring increased effort and cost. The tactic of forcing the other members of the supply chain to absorb this cost will only result in grudging cooperation and it could cause total failure.

2. *Absolute confidence in the quality and availability of product*

   Cross docking is a real-time operation and demands material flows without interruption. Therefore, the cross docking operation has to be absolutely certain that the correct products, with the required quality, are available when needed.

3. *Communications between members*

Since cross docking is a real-time operation, information must be immediately available. Therefore, the receiving function must know which product was sent by the supplying operation before it arrives (using EDI or other computer-to-computer techniques).

4. *Communications and control within the cross-dock*

Materials arrived at the cross docking terminal must be moved swiftly through the facility without interruption (using bar coding and RF communications).

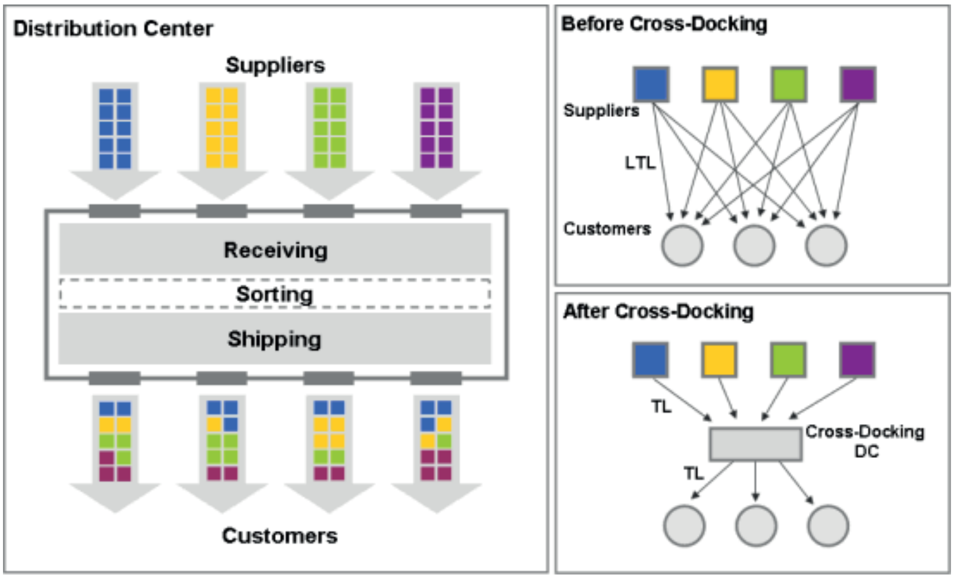



Fig. 1.6. Representation of a cross-dock-integrated supply chain

On the second hand, a high level of tactical management is necessary not to void efforts carried out at the supply chain level. In fact, to design and manage a cross docking terminal, managers have to solve many decision problems during its life cycle.

According to *Nils Boysen* and *Malte Fliedner* [3] they can be classified, ordered from strategic to operational, as follows:

1. *Location of cross docking terminal(s)*

   There is a vast literature that deals with optimization for location models and cross docking. It starts with Pierre de Fermat (1601-1655) who stated the problem as follows: “given three points in the plane, find a fourth point such that the sum of its distances to the three given points is a minimum”. Nowadays a lot of articles propose different algorithms to solve this problem referred to the location of cross-docks, i.e. “A branch-and-bound algorithm for the transportation problem of p transshipment points” by Alfredo Marin and Blas Pelegrin, or “A heuristic method for large scale multi-facility location problems” by Yuri Levin and Adi Ben-Israel that locates the facility and reassigns customer to facilities using the heuristic of “nearest center reclassification”.

2. *Layout of the terminal*

   Firms acquire their cross-docks in a variety of ways and do not always have the possibility of building new ones. If they lease or convert an existing facility they may be heir to someone else’s bad design. Even if they design new facilities, the lead designers are not often likely to pay close attention to internal performance measures like travel cost or congestion, which lie at the bottom of the efficiency of the cross-dock. The article “The best shape for a cross dock” by Bartholdi and Gue analyzes the variation of the labor costs as the layout of the terminal changes.

3. *Assignment of destination to dock doors*

   Operating a cross-dock facility requires assigning, receiving and shipping doors to trailers. The assignment determines the amount of freight handling within the cross-dock facility and therefore its efficiency. Typically this is a short-term problem, so that each door may serve multiple destinations in varying succession per day depending on the actual truck schedule. But it can also be executed on a middle-term horizon, with the result of each dock door exclusively serving a specific inbound or outbound destination for a longer period of time. On the one hand, such a fixed assignment eases the allocation of shipments to trucks, since workers can "learn" the topology of the terminal and respective information systems become superfluous. On the other hand, a fixed assignment of door to destinations restricts the degrees of freedom for short-term trucks scheduling, because the peak loads for single destinations cannot be absorbed by additional dock doors. Due to the immense complexity of optimal formulations, dock-door assignment has been typically solved using heuristics. Tsui and Chang with their article "An optimal solution to dock assignment problem", were the first to tackle the mid-term problem of assigning doors to destinations and they solve this problem as a quadratic assignment problem, which minimizes the shipments flows between doors. If the decision of assigning doors to destination is solved at a mid-term stage, the short-term truck scheduling problem reduces to sequencing all trucks of equal destinations at the respective dock door.

4. *Vehicle routing*

Dealing with cross docking the vehicle routing problem concerns the determination of a set of routes for the outbound fleet of vehicles for a number of geographically dispersed customers. The object is to deliver the set of customer with known demands on minimum cost vehicle routes originating and terminating at the cross docking terminal. The vehicle routing problems is a well-known integer-programming problem and it is widely treated and tackled by modern firms.

5. *Truck scheduling*

The efficiency of a cross docking terminal depends critically on the appropriate coordination of inbound and outbound flows. The truck scheduling problem generally comprises the assignment of each inbound and outbound truck to a door of the dock and the schedule of all trucks assigned per door. Thus, the respective dispatcher faces two interrelated decision: where and when the trucks should be processed at the terminal. Further, the scheduling task has to consider one additional constraint, because outbound trucks can be processed not until all required products have been delivered by their respective inbound trucks. Thus, to reduce the delay of shipments at the cross-dock (in order to obtain a high efficiency of the cross-dock), a synchronization of inbound and outbound product flows becomes crucial.

6. *Resource scheduling inside the terminal*

For a given truck schedule, the problem of resource scheduling inside the terminal (i.e. scanning, sorting and moving shipments across the dock) is a complex scheduling problem in itself, since multiple resources need to be coordinated. "Cross Docking – JIT scheduling with time windows" by Li et al and "Cross docking – Just in Time scheduling: an alternative solution approach" by Alvarez-Perez et al. model these tasks as a machine scheduling problem and present different meta-heuristics for its solution. Truck scheduling is heavily interdependent with this problem, because the actual time lag between each inbound and outbound task is the result of a detailed resource scheduling; consequently both planning tasks could be solved in a simulation manner. However, existing research abstains from such an improvement, because this would require to schedule each worker in detail. Thus, average handling times, determined for example from historical data, should capture this relation with sufficient preciseness allowing to assume fixed time lags between inbound and outbound tasks, which only depend on the pair of doors between which the shipments is moved.

7. *(Un-)Packaging loads into (from) trucks*

The problem of packing shipments inside trailers also influences task times for truck processing and handling times inside the dock. But it seems not meaningful to interrelate packing decisions with truck scheduling because the packing of inbound trucks is usually not known at the cross dock before opening the trailer and, integrating packing aspects at the outbound side would also require to integrate vehicle routing that would result in a very complex planning approach. According to these reasons it is usually assumed that the influence of packing times is negligible and already included in the transportation time lag.

### 1.3. Thesis Organization

After the description of the operations, the different types and the main decision problems of existing cross docks in Chapter 1, the rest of this thesis is organized as follows. In Chapter 2 the different models implemented in this work, based on a different method of staging freights within the cross dock, are explained. In Chapter 3, after presenting the data availability, the requirement of resources is sized using simulations, depending on the input data, in order to obtain efficient operations in both the models. It is the basis to start the analysis in Chapter 4, that represents the core of the project, evaluating two different strategies in handling and staging freights. To test their robustness, simulations are then run introducing disruptions, in order to understand how the results are affected in the case of unexpected events. Finally, Chapter 5 summarizes the findings of this research and suggests areas for future analysis.

## CHAPTER 2: DESCRIPTION OF THE MODELS

It is necessary to explain that this project aims to evaluate possible benefits to the loading operations coming from the utilization of a sorting process that stages different freights in dedicated lanes within a cross docking terminal. It does not concern the optimization of the truck scheduling or the number of necessary doors. Therefore, it is supposed that the given cross docking terminal (in both the different models) can serve the scheduled incoming trucks without waiting time. The requested resources, the right number of doors and all the optimization problems to make it possible are not treated in this project, because they are outside of the target of the work. Thence, it is assumed that all the goods from the incoming trucks are unloaded into an area adjacent to the receiving doors, from where the operations treated in this dissertation start. They basically concern the different methods of handling and staging freights. According to Section 1.2.2, the analyzed models can be classified as:

1. *Single Stage Cross Dock*, where assets are moved and simply staged into lanes corresponding to the receiving doors after being unloaded.

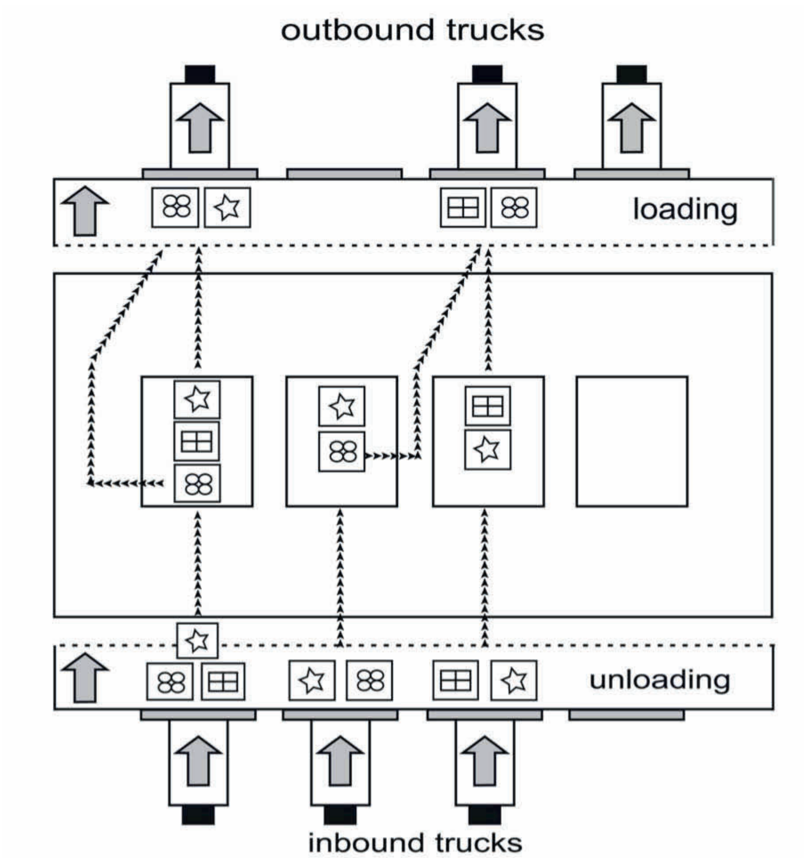



Fig 2.1. Single Stage Cross Dock – Logic used in handling and staging freights

2. *Two-Stage Cross Dock* in which assets are subjected to a sorting process before being staged into lanes dedicated to the single kind of product.

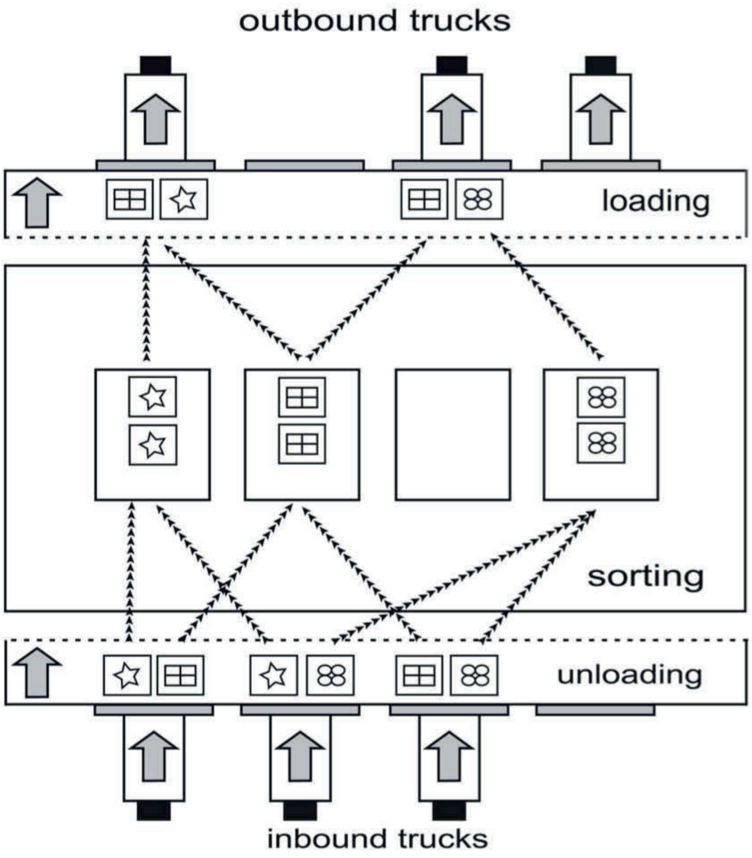



Fig. 2.2. Two-Stage Cross Dock – Logic used in handling and staging freights

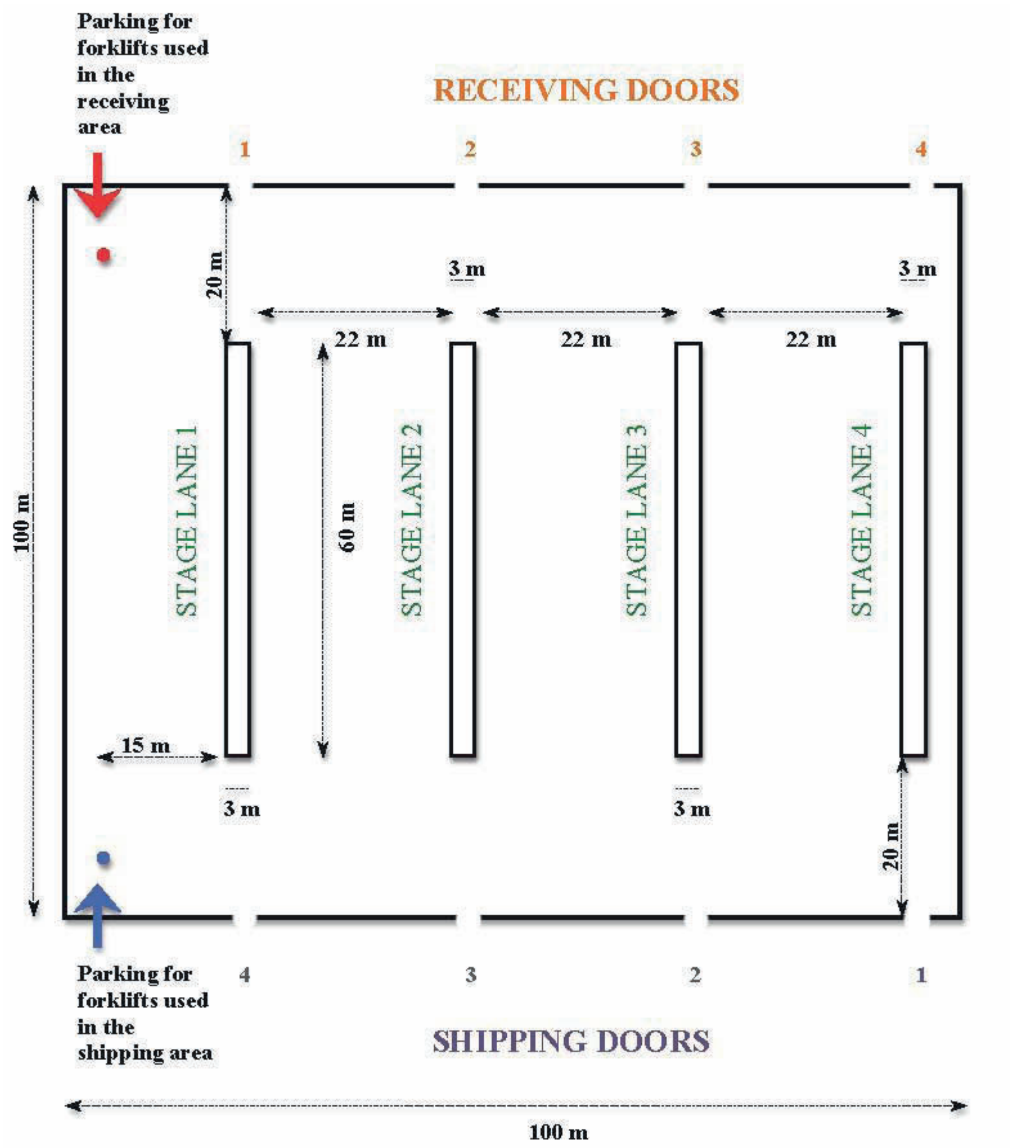
Different methods of handling and staging freights mean different methods, logics and times in the loading operations, as it is explained in the two next sections.

## 2.1. Single Stage Cross Dock Model

Incoming trucks transport mixed loads composed by ten different types of freight to the cross dock. In this model, unloaded goods are simply carried to the staging lane that corresponds to the receiving door using a suitable number of forklifts that is later determined through simulations (Section 3.3.1), in order to obtain a good trade-off between the transit time that permits to find the freight in the lane when it has to be loaded, and resources utilization.

It is assumed that each staging lane can allocate every kind of the ten different goods handled in the cross dock.

The layout of the Single Stage cross dock is shown in Figure 2.3. Two different pools of forklifts, one in the receiving area and one in the shipping area, are utilized to perform operations. Finally, it is assumed that forklifts always move between two general points in the cross docking terminal according to the Euclidean distances.




- Forklifts parking Area

1, 2, 3, 4 Receiving Doors

1, 2, 3, 4 Shipping Doors

Fig. 2.3. Layout of the Single Stage Cross Docking Terminal

2.1.1. Single Stage: Handling Freight

The average transit time $T_T$ of a general good from the unloading area to the lane can be calculated as follows

$$T_T = FWT + TTL + AT + 2*t_F \qquad \text{Eq. 2.1}$$

Where

- *FWT = Average Waiting Time For a Free Forklift* is the average of the average times in the queues associated to each receiving door. They are an output of the simulation software.
- *TTL =Average Transportation Time Until the Lane* is the average time one forklift takes to carry an asset from the loading area to the staging lane. It can be obtained as output from the simulation software that calculates it using the set of distances supplied as input to the model (Fig. 2.3) and the average speed of a forklift ($v_F = 3$ m/s).
- *AT =Arranging Time* is the time needed to arrange the good into the lane. For each good, the value changes according to a normal distribution with *mean* = -10 and *variance* = 25 limited between 0 and 5 seconds. The expression used in the software is

  *mx(0,mn(norm(-10,25),5))*

- $t_F$ *=Forks Time* is the time needed to drop the good off the forklift. It is constant in $t_F = 3$ seconds. It is multiplied by 2 because it is considered the same of the time necessary to pick the good up in the unloading area.

2.1.2. Single Stage: Goods Allocation

The staging lanes are considered provided with a dynamic system (i.e. Dynamic Roller System) thanks to that the good is always left at the beginning of the lane and it autonomously reaches the last position in it. A general good stays in the lane until a forklift picks it up from its rank in the queue (that changes simultaneously with the arrival of other goods) when it is requested to load it onto an outgoing truck. This is the staging time $T_S$. The forklifts utilised to load the outgoing trucks do not belong to the same pool of forklifts utilised to transport the good from the unloading area to the staging lanes. This is to make the implementation of the model easier, otherwise all the distances between all possible places one forklift can be during the simulation must be set, and to make the animation clear. Their number is later chosen using simulations (Section 3.4.1) in order that the loading process can serve the outgoing trucks (they arrive according to a scheduled time) without they have to wait in the yard outside the terminal.

### 2.1.3. Single Stage: Loading Outgoing Trucks

When an outgoing truck reaches one of the four shipping doors of the terminal at a scheduled time, the loading process starts. One available forklift seeks the good in the closest staging lane and loads it onto the trailer after carrying it. If the needed good is not in this lane, the forklift looks for it in the second closest lane and so on.

Table 2.1 shows the order of the lanes visited by the forklifts to seek the goods into, depending on the number of the shipping door they are serving.

| Shipping Door Served | 1st lane visited | 2nd lane visited | 3rd lane visited | 4th lane visited |
|---|---|---|---|---|
| 1 | 4 | 3 | 2 | 1 |
| 2 | 3 | 4 | 2 | 1 |
| 3 | 2 | 1 | 3 | 4 |
| 4 | 1 | 2 | 3 | 4 |

Tab. 2.1. Order of the lanes visited by the forklifts as the shipping door changes

The search algorithm ends when the forklifts have sought all the goods that have to be loaded onto the trailer. If all of them have been found (and so loaded onto the trailer) the truck leaves the door. On the contrary (maybe because the transportation from the unloading area to the lane is too slow) it waits 10 minutes at the door, keeping it engaged. After this waiting time, the forklifts look for the missed goods using the same search algorithm explained above. Now, after a second search ten minutes later, the truck leaves the door and if some goods it has to transport have not been loaded, they are classified as "failed order".

Therefore, the average time $t_L$ one forklift takes to find, pick up and load one general good onto the trailer is

$$t_L = RLT + S_t + RGPT + TTD + AT + 2 * t_F \quad \text{Eq. 2.2}$$

Where

- *RLT = Average Time to Reach the Beginning of the Lane* is the average time one forklift takes to go from the shipping door to the lane it has to seek into. It can be obtained as output from the simulation software that calculates it using the set of distances supplied as input to the model (Fig. 2.3) and the average speed of a forklift ($v_F$ = 3 m/s).
- $S_t$ = *Search Time* is the time needed to find the right good into the staging lane. A sensitivity analysis is made afterwards in the project (Section 3.4.2) in order to understand how it affects the loading time.
- *RGPT = Time to Reach the Position of the Founded Good in the Lane* is the time the forklift takes to go from the beginning of the lane to the position of the good within the lane. It is calculated using the rank of the good in the lane (that can be known during the simulation). It is assumed that the length of a good is constant in 0.5 m. Thence, the time to reach the position of the good from the beginning of the lane can be calculated as follows:

$$T = 2 * mn(((0.5 * J) / v_F), 20) \quad \text{Eq. 2.3}$$

Where $J$ is the rank of the good in the lane and $v_F$ is the average speed of the forklift chosen as 3 m/s. The expression also limits the time to the maximum of 20 seconds, corresponding to the last place in the lane (60 meters long). It is necessary to explain, in fact, that in the models there are not restrictions on the capacity of the lane and a driving time that correspond to a distance greater than the real length of the lane could be used without this restriction. Therefore, if $J$ is bigger than 120 a time of 20 seconds is automatically used. Finally, it is multiplied by 2 because the forklift has to go back to the beginning of the lane before driving to the door.

- *TTD = Average Transportation Time to the Door* is the average time one forklift takes to go from the beginning of the lane to the shipping door. It can be obtained as output from the simulation software that calculates it using the set of distances supplied as input to the model (Fig. 2.3) and the average speed of a forklift ($v_F$ = 3 m/s).
- *AT = Arranging Time* is the time the forklift takes to arrange the good on the trailer. It is assumed to be variable according to the expression

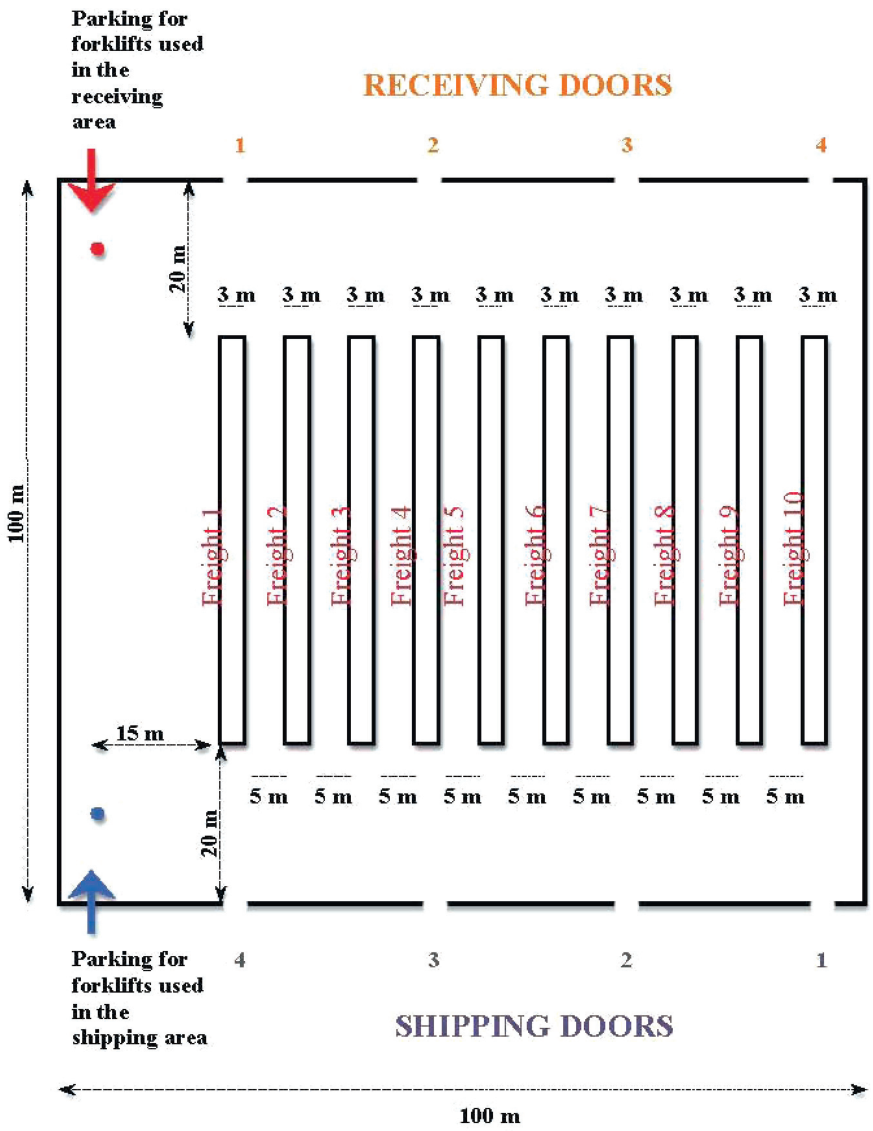
$$mx(0, mn(norm(-5,20),8))$$

It means that the time to arrange the good on the trailer can adopt values according to a normal distribution with *mean* = -10 and *variance* = 25, limited between 0 and 8 seconds.

- $t_F$ = *Forks Time* is the time needed to drop the good off the forklift. It is constant in $t_F$ = 3 seconds. It is multiplied by 2 because it is considered the same as the time necessary to pick the good up in the staging lane.

## 2.2. Two-Stage Cross Dock Model

In the two-stage cross dock, goods are not just transferred from the unloading area to the lane corresponding to the receiving door but a sorting process takes place and forklifts carry goods to staging lanes dedicated to each kind of good. Therefore, the layout of the terminal (Fig. 2.4) considerably changes compared to the Single Stage one. It this case, in fact, ten different staging lanes must be created in order to allocate the ten different types of good that have to be handled within the cross docking terminal.




- Forklifts parking Area

1, 2, 3, 4 Receiving Doors

1, 2, 3, 4 Shipping Doors

Fig. 2.4. Layout of the Two-Stage Cross Docking Terminal

The requirement of forklifts is later determined through simulations (Section 3.3.2), in order to obtain a good trade-off between the transit time that permits to find the freight into the lane when it has to be loaded and resources utilization.

Also in the Two-Stage cross dock, two different pools of forklifts (one in the receiving area and one in the shipping area) are utilized to perform the operations. Finally, it is important to remember that forklifts always move between two general points in the cross docking terminal according to the Euclidean distances.

### 2.2.1. Two-Stage: Handling Freight

The average transit time $T_T$ of a general good from the unloading area to the dedicated lane is calculated in the same way explained in the Section 2.1.1. It is easily understandable that it is greater than the transit time in the Single Stage cross dock. It is caused by a higher value of the *Average Transportation Time Until the Lane* that inevitably affects the *Average Waiting Time For a Free Forklift*. It occurs because the forklifts do not have just to carry the goods to the lane corresponding to the receiving door (driving always the distance of 20 meters). In this case the method of staging freights requires that forklifts carry the goods to the right lanes that are located in a range of distances between 20 and 88 meters. Simulations in Chapter 3 confirm what stated above.

### 2.2.2. Two-Stage: Goods Allocation

In this case each staging lane is dedicated to one kind of freight. As in the Single Stage terminal, they are considered provided with a dynamic system that allows the good to be unloaded from the forklift at the beginning of the lane and it autonomously reaches the last position in it. The good stays within the lane until a forklift picks it up from the first position in the staging lane. This is the staging time $T_S$.

### 2.2.3. Two-Stage: Loading Outgoing Trucks

In the Two-Stage layout the loading process changes compared to the Single Stage one. When an outgoing truck reaches one of the four shipping doors of the terminal at a scheduled time, the available forklifts (from the pool used for the loading operations) start to load it.

In this case, it is not necessary to seek the requested goods into the staging lanes because they have been already allocated into dedicated lanes indeed. The forklifts have just to drive until the right lanes (as many times as the requirement of each type of good is) and pick the goods up at the beginning of the staging lanes; this fact because it is known that there is only one type of good in every lane.

After being picked up, the goods are carried to the shipping door where they are loaded onto the trailer. If the whole load has been found (and so loaded onto the trailer) the truck leaves the door, otherwise it waits 10 minutes at the door, keeping it engaged. After this waiting time, the forklifts pick the missed goods up from the dedicated staging lanes and load them onto the outgoing truck.

Now, the truck has to leave the cross dock in any case, and if some goods are not available yet, they are classified as “failed order”.

Therefore, in the Two-Stage layout, the average loading time for a general good $t_L$ can be calculated as follows

$$t_L = 2*TRL + AT + 2*t_F \qquad \text{Eq. 2.4}$$

Where

- *TRL = Average Time to Reach the Right Lane* is the average time one forklift takes to go from the shipping door to the lane. It can be obtained as output from the simulation software that calculates it using the set of distances supplied as input to the model (Fig. 2.4) and the average speed of a forklift ($v_F$ = 3 m/s). It is multiplied by 2 because the forklift has to drive the same distance to go back to the door.

- *AT = Arranging Time* is the time needed to arrange the good on the trailer. It is assumed to be variable according to the expression

  $$mx(0, mn(norm(-5,20),8))$$

  It means the time can change according to a normal distribution with *mean* = -10 and *variance* = 25, limited between 0 and 8 seconds, and it is the same used in the Single Stage model.
- $t_F$ = *Forks Time* is the time needed to drop the good off the forklift. It is constant in $t_F$ = 3 seconds. It is multiplied by 2 because it is considered the same of the time necessary to pick the good up in the staging lane.

Chapter 2 explains the different logics (that mainly depend on the strategy in handling and staging freights) adopted in the Single Stage and in the Two-Stage cross docking models that are the subject of the study in this project. Therefore, in Chapter 3, after a dissertation about the availability of the data and the different dataset tested, the requirement of forklifts is sized for the models as the input dataset changes. An efficient performance of the operations in serving the scheduled trucks within the cross docks is, in fact, the starting point for the following analysis and it is necessary in order to compare the performances of the two different strategies in handling and staging freights.

# CHAPTER 3: SIZING OF THE RESOURCES

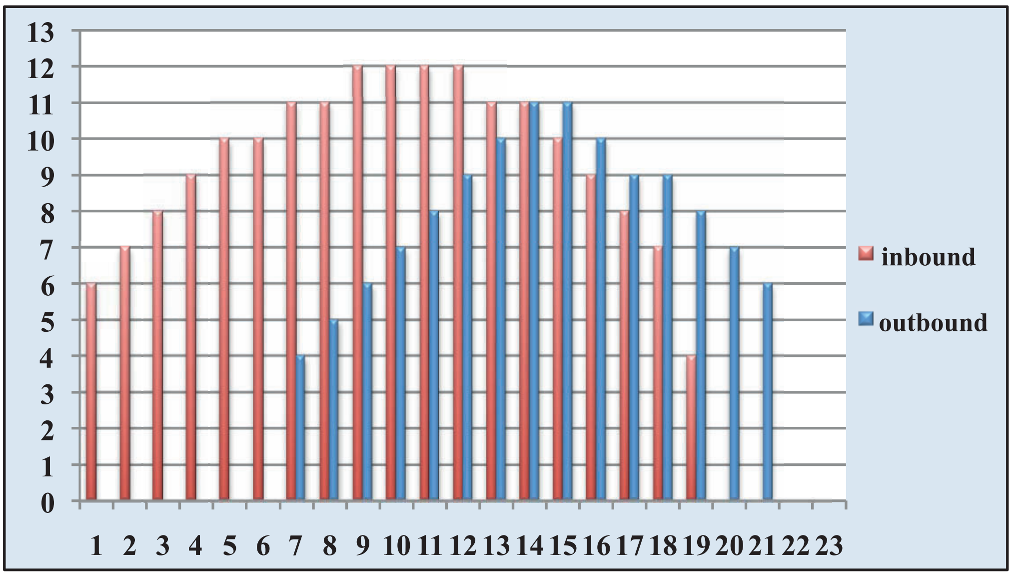
## 3.1. Data availability

The development of the simulation models is based on a dataset thanks to that, for both the incoming and outgoing trucks, the following information are always known:

1. Scheduled Arrival Time at the cross docking terminal
2. The total load of the truck
3. The number of each type of different good the truck is transporting to/has to transport from the cross docking terminal

The models are tested using three different distributions in the trucks arrival time but the total load of a truck and the variety of goods carried by each truck are always the same. The ratio between incoming and outgoing trucks is always 1.5, with 180 incoming trucks and 120 outgoing trucks served. A "warm up time" (a time-lag between the arrivals of the first incoming and outgoing trucks at the terminal) is always considered. Thanks to that it is possible to fill up the staging lanes in order to efficiently start the loading activities. The three different distributions in the arrival time are reported below.

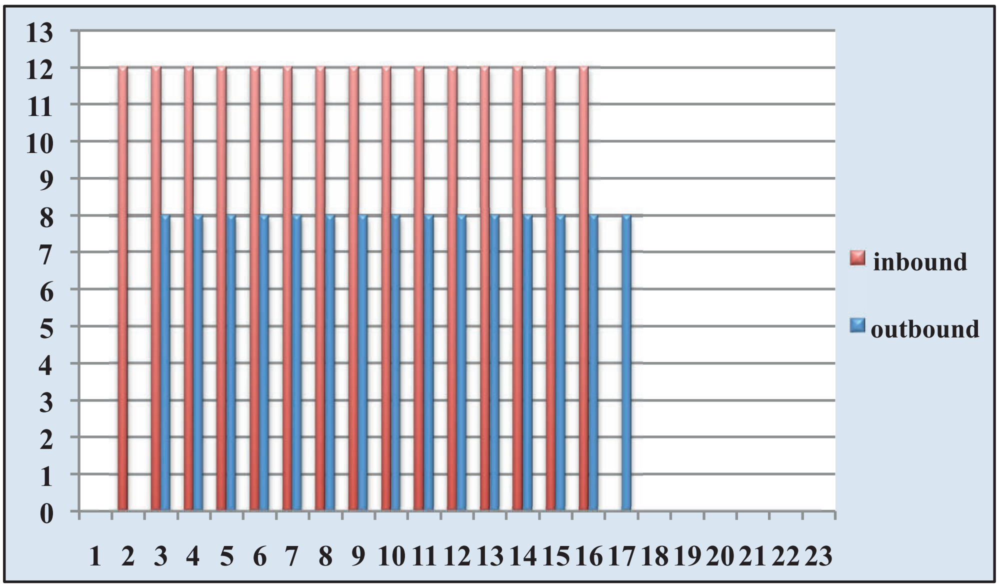
- Dataset "Series 1"




Graph.3.1. Trucks Arrival Distribution "Series 1" (absolute frequencies)

In this series of data the number of incoming trucks increases until a peak of 12 trucks/hour during the first hours in the morning. Then it decreases reaching the minimum value of 4 trucks/hour between 7 and 8 p.m. The outgoing trucks scheduled arrival time follows the same trend reaching a peak of 11 trucks/hour between 2 and 3 p.m. The last outgoing truck is served between 9 and 10 p.m., two hours after the arrival of the last incoming truck. It wants to reproduce a scenario in which the unloading and the loading activities mostly take place in different moments of the day, having a warm up time of 6 hours.

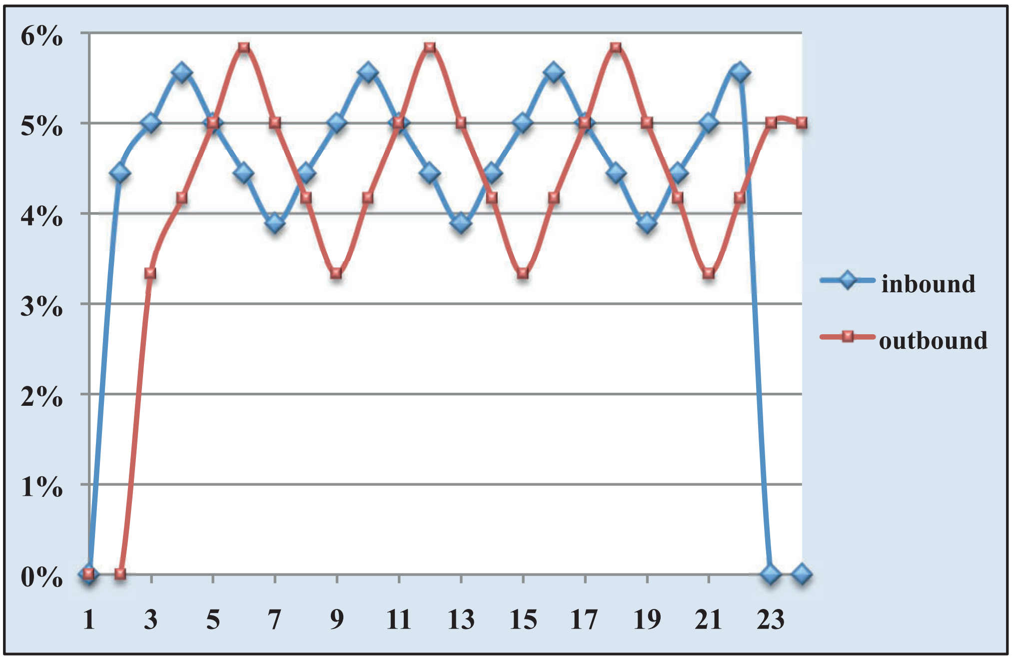
- Dataset "Series 2"




Graph. 3.2. Trucks Arrival Distribution "Series 2" (absolute frequencies)

In this series of data the number of incoming trucks is constant in 12 trucks/hours during the working day. The number of outgoing trucks is also constant in 8 trucks/hour. The last outgoing truck is served between 5 and 6 p.m., one hour after the arrival of the last incoming truck. The warm up time is 1 hour. It wants to reproduce a scenario in which the unloading and the loading activities are nearly concurrent.

• Dataset "Series 3"




Graph. 3.3. Trucks Arrival distribution "Series 3" (relative frequencies)

In this series of data the number of incoming and outgoing trucks that arrive at the cross dock every hour follow the same trend, reaching one peak every three hours. The warm up time is 1 hour. Therefore, the peaks in the number of outgoing trucks per hour take place 1 hour after the peak in the number of incoming trucks per hour. The last outgoing truck is served between 11 and 12 p.m., two hours after the arrival of the last incoming truck. It wants to mix the previous scenarios creating a distribution in which the unloading and the loading activities are nearly concurrent and the terminal is subjected to different peaks during the day.

### 3.2. Resources Sizing Criteria

In order to achieve the main target of the project, the first necessary step is to determine the requirement of resources thanks to that the operations can be efficiently carried out (without orders classified as “failed”) using the adopted datasets. Therefore, in the following Sections, both the models are sized through the use of simulation.

The sizing of the requirement of resources is executed for all the three distributions in the incoming/outgoing trucks arrival time considered in the project (Section 3.1), because it could be different as the dataset changes.

The sizing process has to lead to the choice of the number of resources that permits to achieve the following target performances.

- *Receiving Area*
  After being unloaded from the inbound trucks, it is important to quickly move the goods to the staging lanes, in order to avoid the formation of long queues in the receiving area and to allow the forklifts in the shipping area to find the freight in the staging lane and efficiently perform the loading operations. According to this, the sizing process aims to find the number of forklifts that guarantees an *Average Waiting Time for a Free Forklift* smaller than 4 minutes, that is considered enough to achieve the targets explained above. In the event of more than one option, the number of forklifts that shows a higher utilization of the resources is chosen.

- *Shipping Area*
  Using a scheduled arrival time, every truck should be immediately served once it has reached the cross dock. Therefore, the sizing process aims to choose the number of forklifts that guarantees an *Average Outgoing Trucks Waiting Time* smaller than 1 minute. As in the receiving area, in case of more options, the number of forklifts that shows a higher utilization of the resources is chosen.

### 3.3. Sizing of the Receiving Area

3.3.1. Single Stage Terminal – Requirement of Forklifts

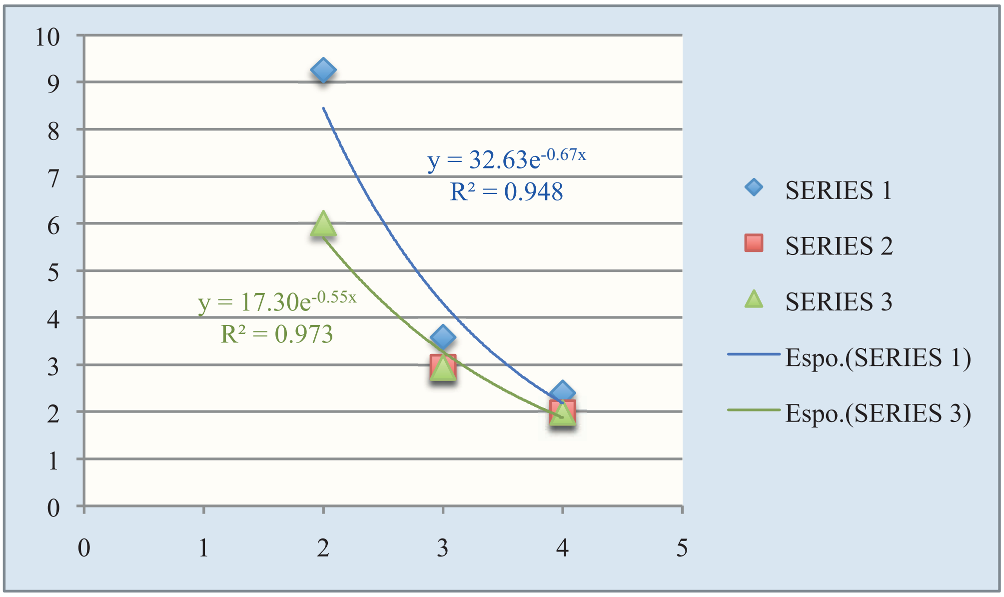
In order to understand the number of forklifts thanks to that the operations in the receiving area perform according to the criteria explained in Section 3.2, simulations are run changing the number of the resources utilized. This practice is carried out for all the three different distributions in the arrival time of the trucks. The results are shown in the table below.

| Dataset | Number of Forklifts | Av. Waiting Time for Forklift |
|---|---|---|
| SERIES 1 | 2 | 9.3 minutes |
| | 3 | 3.6 minutes |
| | 4 | 2.4 minutes |
| SERIES 2 | 2 | Not enough to get efficient operations |
| | 3 | 3.0 minutes |
| | 4 | 1.9 minutes |
| SERIES 3 | 2 | 6.0 minutes |
| | 3 | 2.9 minutes |
| | 4 | 1.9 minutes |

Tab. 3.1. Single Stage Cross Dock - Variation in the Av. Waiting Time for Forklift

Table 3.1 shows that the requirement of forklifts that guarantees an *Average Waiting Time for a Free Forklift* smaller than 4 minutes in the receiving area is always 3 forklifts in all the three different datasets.

It is also possible to notice (Graph. 3.1) that the *Average Waiting Time for a Free Forklift* decreases according to an exponential function in all the series, but, while in the series 2 and 3 it follows the same curve, it is bigger in the series 1. The reason for this is the difference between series 1 and series 2 and 3 in the number of goods to carry in the same interval of time, caused by the peak of incoming trucks per hour in the series 1.




Graph. 3.1. Comparison between Average Waiting Times for a Free Forklift using the three different datasets

3.3.2. Two-Stage Terminal – Requirement of Forklifts

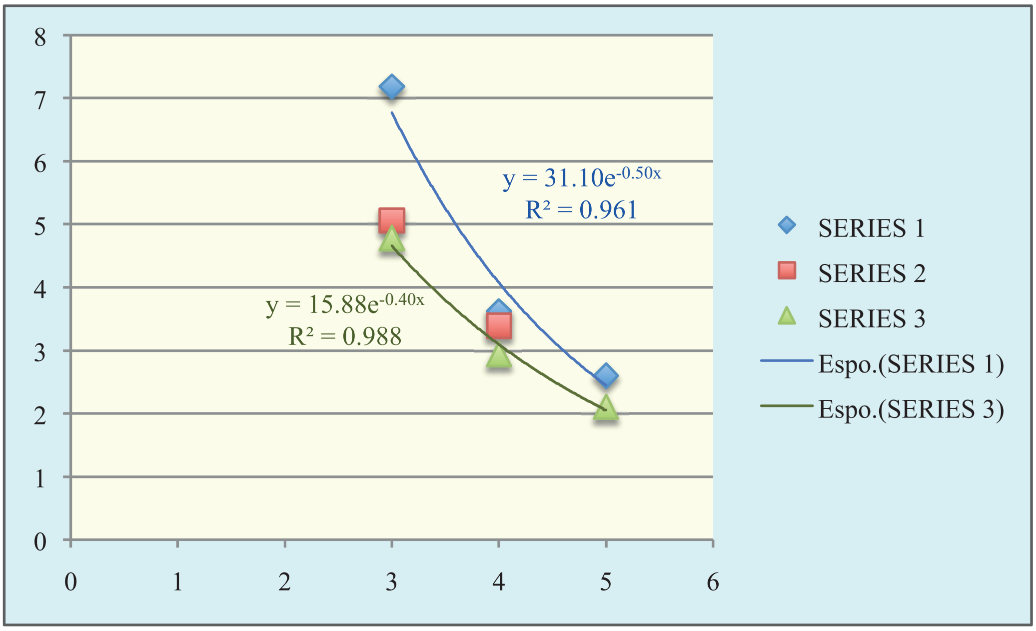
The same practice executed in Section 3.3.1 is carried out using the Two-Stage model. The results are reported in the following table.

| Dataset | Number of Forklifts | Av. Waiting Time for Forklift |
|---|---|---|
| SERIES 1 | 2 | Not enough to get efficient operations |
| | 3 | 7.2 minutes |
| | 4 | 3.6 minutes |
| | 5 | 2.6 minutes |
| SERIES 2 | 2 | Not enough to get efficient operations |
| | 3 | 7.2 minutes |
| | 4 | 3.4 minutes |
| SERIES 3 | 2 | Not enough to get efficient operations |
| | 3 | 4.8 minutes |
| | 4 | 2.9 minutes |
| | 5 | 2.1 minutes |

Tab. 3.2. Single Stage Cross Dock - Variation in the Av. Waiting Time for Forklift

The results show that the requirement of forklifts that guarantees an *Average Waiting Time for a Free Forklift* smaller than 4 minutes in the receiving area is 4 forklifts for all the three different datasets.

The *Average Waiting Time for a Free Forklift* decreases according to an exponential function in all the series analysed (Graph. 3.2). The biggest value is in the series 1 and it is caused by the higher number of goods to carry in the same interval of time, when the peak condition occurs.




Graph. 3.2. Comparison between Average Waiting Times for a Free Forklift using the three different datasets

### 3.4. Sizing of the Shipping Area

3.4.1. Single Stage Cross Dock

In order to understand the number of forklifts thanks to that the loading operations guarantee an *Average Outgoing Trucks Waiting Time* smaller than 1 minute, simulations are run changing the number of resources utilized. But the *Average Outgoing Trucks Waiting Time* depends on the *Average Time* $t_L$ (Eq. 2.2) that changes according to the value its component *Search Time* ($S_t$) is set to. Just in order to start the sizing, a medium *Search Time* of 10 seconds is chosen. Then, one sensitivity analysis is done in order to understand how much it affects the results.

| Dataset | Number of Forklifts | Av. Out. Trucks Wait. Time |
|---|---|---|
| SERIES 1 (*Search Time*=10 s) | 5 | 22.4 minutes |
| | 6 | 1.3 minutes |
| | 7 | 0.1 minutes |
| SERIES 2 (*Search Time*=10 s) | 4 | 3.7 minutes |
| | 5 | 0.5 minutes |
| SERIES 3 (*Search Time*=10 s) | 4 | 1.3 minutes |
| | 5 | 0.3 minutes |

Tab. 3.3. Single Stage - Variation in the Av. Outgoing Trucks Waiting Time with $S_t$=10 s

The results show that the requirement of forklifts that guarantees an *Average Outgoing Trucks Waiting Time* smaller than 1 minute is 7 forklifts for the series 1 and 5 forklifts for the series 2 and 3. The peak in the number of truck per hour causes the higher requirement of forklifts in the first dataset.

3.4.2. Sensitivity Analysis

In the previous Section the requirement of forklifts in the shipping area is determined using a medium *Search Time* of 10 seconds. But it is important to understand how different values of $S_t$ affect the outgoing yard congestion and the sizing process. Thence, simulations are run, starting with the requirements of forklifts chosen after the sizing in Section 3.4.1, using different *Search Times* (Tab. 3.4). It aims to understand if the number of forklifts that permits to achieve the sizing criteria changes using different values of Search Time $S_T$.

| Type of *Search Time* $S_t$ | Value |
|---|---|
| Low | 5 seconds |
| Medium | 10 seconds |
| High | 15 seconds |
| Very High | 20 seconds |

Tab. 3.4. Different values of $S_t$ used in the simulations

**Sensitivity Analysis - Dataset "Series 1"**

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 7 | 0.1 minutes |
| 10 seconds | 7 | 0.2 minutes |
| 15 seconds | 7 | 0.4 minutes |
| 20 seconds | 7 | 7.1 minutes |

Tab. 3.5. Sensitivity analysis as $S_t$ changes - "SERIES 1"

Table 3.5 shows that, using 7 forklifts, the *Average Outgoing Trucks Waiting Time* is very low; therefore it is presumable to reduce the number of necessary forklifts to 6 when the *Search Time* is less then 15 seconds. When its value is very high, instead, more than 7 forklifts are necessary to achieve the sizing conditions.

Simulations are run in order to evaluate it (Tab 3.6).

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 6 | 0.2 minutes |
| 10 seconds | 6 | 1.3 minutes |
| 20 seconds | 8 | 0.2 minutes |

Tab. 3.6. “SERIES 1” – Check of the previous sizing

Looking at Table 3.6 it is possible to state that 6 forklifts are enough only when the *Search Time* is low but not when it is set to a medium value. 8 forklifts are required when it is considered very high instead.

The following table shows the definitive sizing of the requirement of resources depending on the length of the *Search Time* $S_t$.

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 6 | 0.2 minutes |
| 10 seconds | 7 | 0.1 minutes |
| 15 seconds | 7 | 0.4 minutes |
| 20 seconds | 8 | 0.2 minutes |

Tab. 3.7. Definitive sizing in the Single Stage Cross Dock as $S_t$ changes - “SERIES 1”

**Sensitivity Analysis - Dataset "Series 2"**

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 5 | 0.2 minutes |
| 10 seconds | 5 | 0.5 minutes |
| 15 seconds | 5 | 3.3 minutes |
| 20 seconds | 5 | 45 minutes |

Tab. 3.8. Sensitivity analysis as $S_t$ changes - "SERIES 2"

Table 3.8 shows that the *Average Outgoing Trucks Waiting Time* is very low using 5 forklifts when the *Search Time* is 5 or 10 seconds: in these cases it is presumable to reduce the number of the necessary forklifts to 4. When $S_t$ is considered high or very high, instead, more than 5 forklifts are necessary to achieve the sizing conditions.

Simulations are run in order to evaluate it (Tab 3.9).

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 4 | Not enough to get efficient operations |
| 15 seconds | 6 | 0.3 minutes |
| 20 seconds | 6 | 0.9 minute |

Tab. 3.9. "SERIES 2" – Check of the previous sizing

Looking at Table 3.9 it is possible to state that 4 forklifts are not enough also if the *Search Time* is low, because the slowness in the sorting operations would let some outgoing trucks leave the cross dock without their complete load. When it is set to a high or a very high value, instead, 6 forklifts can efficiently perform the loading operations.

The following table shows the definitive sizing of the requirement of resources depending on the length of the *Search Time* $S_t$.

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 5 | 0.2 minutes |
| 10 seconds | 5 | 0.5 minutes |
| 15 seconds | 6 | 0.3 minutes |
| 20 seconds | 6 | 0.9 minute |

Tab. 3.10. Definitive sizing in the Single Stage Cross Dock as $S_t$ changes - "SERIES 2"

**Sensitivity Analysis - Dataset "Series 3"**

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 5 | 0.1 minutes |
| 10 seconds | 5 | 0.2 minutes |
| 15 seconds | 5 | 0.6 minutes |
| 20 seconds | 5 | 1.3 minutes |

Tab. 3.11. Sensitivity analysis as $S_t$ changes - "SERIES 3"

Table 3.11 shows that the *Average Outgoing Trucks Waiting Time* is very low using 5 forklifts when the *Search Time* is 5, 10 or 15 seconds: in these cases it is presumable to reduce the number of the necessary forklifts to 4. When $S_t$ is considered very high (20 seconds), more than 5 forklifts are necessary to achieve the sizing conditions instead.

Simulations are run in order to evaluate it (Tab 3.12).

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 4 | 1.3 minutes |
| 20 seconds | 6 | 0.3 minutes |

Tab. 3.12. "SERIES 3" – Check of the previous sizing

After checking the previous sizing, it is possible to state that 4 forklifts are not enough if the *Search Time* is low. Therefore, they are not enough to achieve the sizing criteria when $S_t$ is medium or high too. When $S_t$ is set to a very high value, instead, 6 forklifts can efficiently perform the loading operations.

The following table shows the definitive sizing of the requirement of resources depending on the length of the *Search Time*.

| Search Time $S_t$ | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| 5 seconds | 5 | 0.1 minutes |
| 10 seconds | 5 | 0.2 minutes |
| 15 seconds | 5 | 0.6 minutes |
| 20 seconds | 6 | 0.3 minutes |

Tab. 3.13. Definitive sizing in the Single Stage Cross Dock as $S_t$ changes - "SERIES 3"

3.4.3. Two-Stage Cross Dock

Also in the Two-Stage cross dock, the *Average Time* $t_L$ ( Eq. 2.4) affects the *Average Outgoing Trucks Waiting Time* but, in this case, the component *Search Time* is not considered.

This is possible thanks to the sorting process that, using one staging lane dedicated to each kind of product, allows the forklifts in the shipping area to pick the freight up from the first position after reaching the right staging lane. It is sure, in fact, that there is just one type of good in each staging lane. Therefore, the simulation software calculates all the values of the components of $t_L$ using the input data.

The following table shows the results of the simulations.

| Dataset | Number of Forklifts | Av. Outgoing Trucks Waiting Time |
|---|---|---|
| SERIES 1 | 3 | Not enough to get efficient operations |
| | 4 | 25.2 minutes |
| | 5 | 0.9 minutes |
| SERIES 2 | 3 | Not enough to get efficient operations |
| | 4 | 1.2 minutes |
| | 5 | 0.3 minutes |
| SERIES 3 | 3 | Not enough to get efficient operations |
| | 4 | 1.3 minutes |
| | 5 | 0.1 minutes |

Tab. 3.14. Two-Stage Cross Dock - Variation in the Av. Outgoing Trucks Waiting Time

As it is shown in the tables above, the requirement of forklifts is 5 forklifts in all the three different datasets utilized in the simulations.

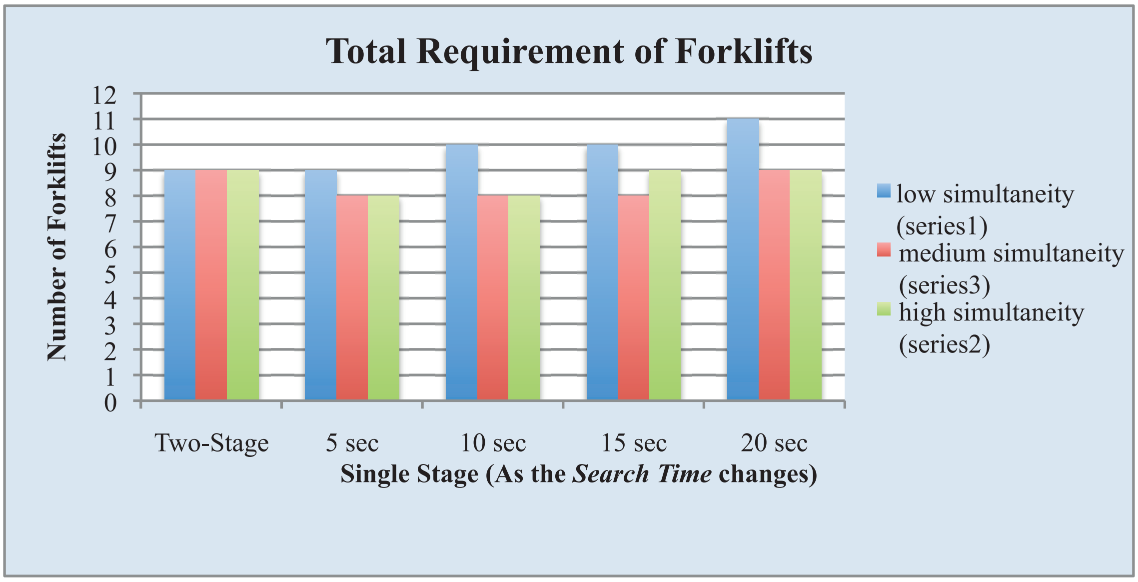
### 3.5. Conclusions from the sizing results

The sizing of the number of forklifts (Tab. 3.14) shows that the Two-Stage Cross Dock always needs one forklift more than the Single Stage to efficiently perform the operations in the receiving area. On the contrary, concerning the operations in the shipping area, the requirement of forklifts is bigger in the Single Stage terminal (or, at most, it is the same as the Two-Stage Cross Dock).

| | Single Stage Cross Dock | | Two-Stage Cross Dock | |
|---|---|---|---|---|
| Dataset | Receiving Area | Shipping Area | Receiving Area | Shipping Area |
| SERIES 1 | 3 | From 6 to 8 | 4 | 5 |
| SERIES 2 | 3 | From 5 to 6 | 4 | 5 |
| SERIES 3 | 3 | From 5 to 6 | 4 | 5 |

Tab. 3.14. Different requirement of forklifts (in the different areas) in both the models

Therefore, it is already possible to state that one extra resource is needed dedicating one staging lane to each kind of freight, as the difference of one forklift in the receiving area between the Single Stage and the Two-Stage terminals shows. But the sizing of resources in the shipping area shows that the number of the necessary forklifts is always smaller whether dedicated staging lanes are used within the Cross Docking terminal. The following graphic shows the total requirement of forklifts (receiving + shipping) in the different situations.




Graph. 3.3. Total requirement of forklifts

At present, nothing can be stated about the performance in the loading activity (in term of time), but Graph. 3.3 points out how the Two-Stage Cross Dock is more versatile than the Single Stage. After being sized, in fact, it can efficiently perform the operations using the same number of resources, even though the management of the incoming/outgoing trailers changes.

After sizing the requirement of forklifts in the Single Stage and in the Two-Stage cross docks, the performance indicators to evaluate their operations are defined in the following Chapter. According to those, an analysis of the behaviour of the facilities within the models is carried out in order to compare the different strategies in handling and staging freights. The robustness of both the models is then tested in case of unexpected disruption.

# CHAPTER 4: SIMULATION STUDY

After sizing the requirement of resources within the cross docking terminals, simulations can be run in order to obtain the necessary performance indicators thanks to those the analysis of the different strategies in handling and staging freights can be done.

## 4.1. Performance Indicators

KPI's are a set of quantifiable measures used to gauge or compare performance in terms of meeting the operational goals.

A cross docking terminal is an intermediate node in a distribution network in which shipments from inbound trucks are unloaded, sorted, moved across the dock and directly loaded onto outbound trucks with a minimum dwell time in between, in order to achieve the targets this distribution strategy has been created for.

The primary purpose of cross docking, in fact, is to reduce storage, through the use of a synchronization of inbound and outbound flows, and excessive handling and lead-time, while simultaneously maintaining (or increasing) the level of customer service. An additional major advantage of cross docking is to enable a consolidation of differently sized shipments with the same destination to full truck loads (instead of shipping small orders directly as less-than-truck-load shipments between origin and destination), so that economies in transportation costs can be realized.

According to this, the following Key Performance Indicators (KPI's) are first used to gauge the models, and then to compare them.

- *The average transit time* $T_T$ a general good takes to be carried from the unloading area to the staging lane within the cross docking terminal, to test the efficiency of operations in the receiving area.

- *The average loading time* $T_L$ a truck takes to be loaded. It is composed by the addition of the average times that the goods take to be carried from the staging lanes to the loading area and the loading time. It tests the efficiency of operations in the shipping area of the cross docking terminal.

- *Average Staging Time* $S_T$ a general good spends in the staging lane before being loaded onto the outgoing truck.

- *Average Crossing Time* $C_T$ that is the average time a good spend inside the terminal between receiving to shipping. It is a general measure of how the cross docking system is performing.

- *Number of Forklift* that is a measure of the need of resources to obtain the reached level of service.

- *Forklift Utilization* to evaluate the saturation level of the utilised resources.

- *Average Outgoing Trucks Waiting Time* in order to determine the Yard Congestion and evaluate the requirement of resources to make the system efficient.

- *Number of Failed Orders* in order to evaluate the operations within the terminal when unexpected disruption occurs.

### 4.1. Simulation using Dataset "Series 1"

Simulations are run for both the models using the number of forklifts chosen after the sizing process in Chapter 3. Tables 4.1 and 4.2 report the average time a truck takes to be loaded ($T_L$) in the Single Stage and in the Two-Stage terminals respectively, using the dataset "series 1".

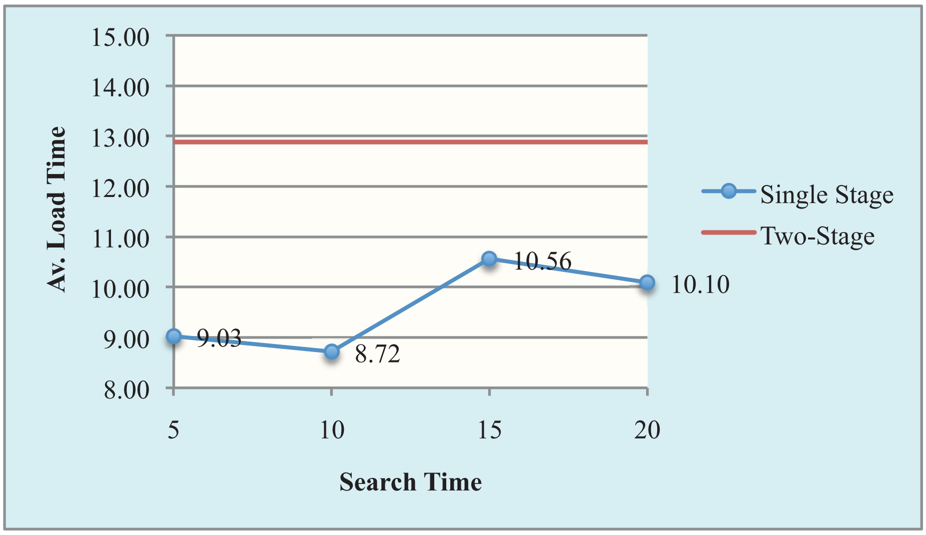
| Forklifts Receiving Area | Forklifts Shipping Area | Search Time | Av. Loading Time $T_L$ |
|---|---|---|---|
| 3 | 6 | 5 | 9.03 minutes |
| 3 | 7 | 10 | 8.72 minutes |
| 3 | 7 | 15 | 10.56 minutes |
| 3 | 8 | 20 | 10.1 minutes |

Tab. 4.1. Single Stage "SERIES 1"- Av. Loading Time $T_L$ as the Search Time changes

| Forklifts Receiving Area | Forklifts Shipping Area | Av. Loading Time $T_L$ |
|---|---|---|
| 4 | 5 | 12.88 minutes |

Tab. 4.2. Two-Stage "SERIES 1" – Av. Loading Time $T_L$

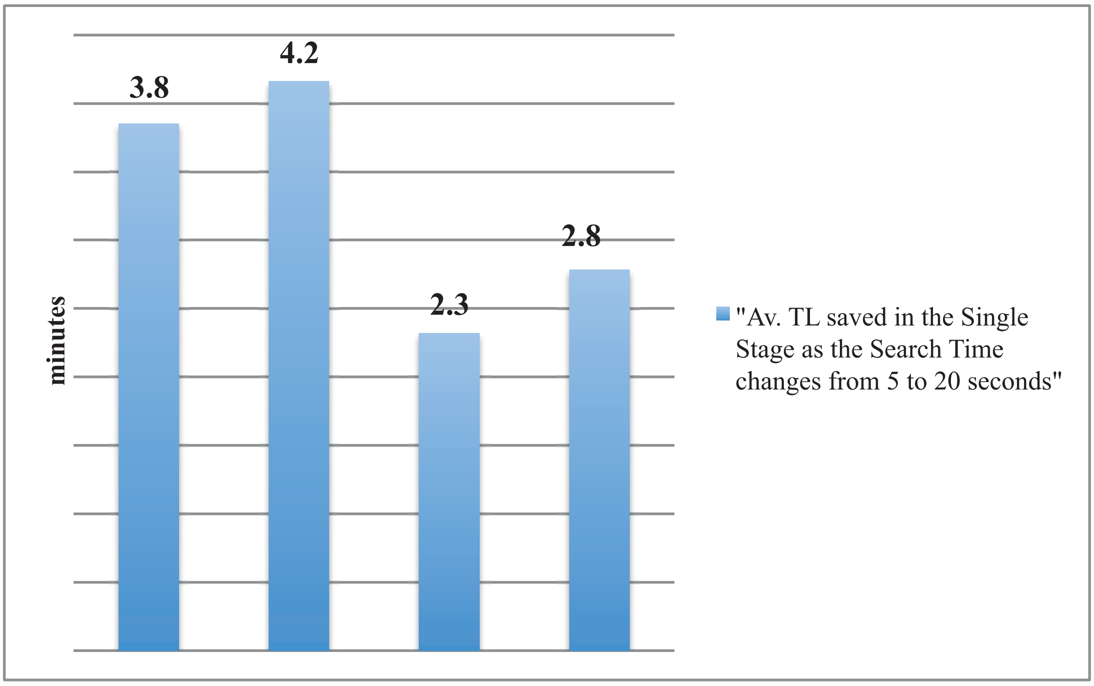
They show (and it is well emphasized by Graph. 4.1) how the sorting process (Two-Stage terminal) does not improve the loading performance in term of time.




Graph. 4.1. Search Time vs. Av. Load Time – "SERIES 1"

The value of the average loading time $T_L$ in the Two-Stage cross dock, in fact, is greater than all the values taken by $T_L$ as the *Search Time* $S_t$ changes in the Single Stage terminal. The latter, in fact, permits to save from a minimum of 2.32 minutes to a maximum of 4.16 minutes in the loading operations compared to the Two-Stage cross dock (as it is shown in Graph. 4.2).

| Search Time (seconds) | Loading Time saved (minutes) |
|---|---|
| 5 | 3.8 |
| 10 | 4.2 |
| 15 | 2.3 |
| 20 | 2.8 |




Graph. 4.2. Av. $T_L$ saved in the Single Stage Cross Dock as the Search Time changes

On the other hand, an extra requirement from one to three forklifts in the shipping area, depending on the value of $S_t$, is necessary to perform in an efficient way the operations in the Single Stage Cross Dock (Tab. 4.1). It surely means a bigger cost in term of resources but it could be justified by better values of all the KPI's chosen for the evaluations of the models.

They are shown in Table 4.3 where, for the Single Stage layout, the averages of the values the KPI's take as the *Search Time* changes are reported.

| | Single Stage layout | Two-Stage layout |
|---|---|---|
| Forklifts receiving area | 3 | 4 |
| Forklifts shipping area | 7 | 5 |
| Av. Transit time $T_T$ | 3.6 + 0.24 min. | 3.6 + 0.35 min. |
| Av. Staging Time $S_T$ | 260,8 min. | 262.2 min. |
| Loading Time $T_L$ | 9.60 min. | 12.88 min. |
| Av. Crossing Time $C_T$ | 267.1 min. | 272.2 min. |
| Receiving Fork. Utilization | 34.5% | 38% |
| Shipping Fork. Utilization | 54.3% | 39.8% |

Tab. 4.3. Single Stage and Two-Stage KPI's – "SERIES 1"

### 4.2. Simulation using Dataset "Series 2"

Simulations are run for both the models using the number of forklifts chosen after the sizing process in Chapter 3. The following tables report the average time a truck takes to be loaded ($T_L$) in the Single Stage and in the Two-Stage terminals respectively, using the dataset "series 2".

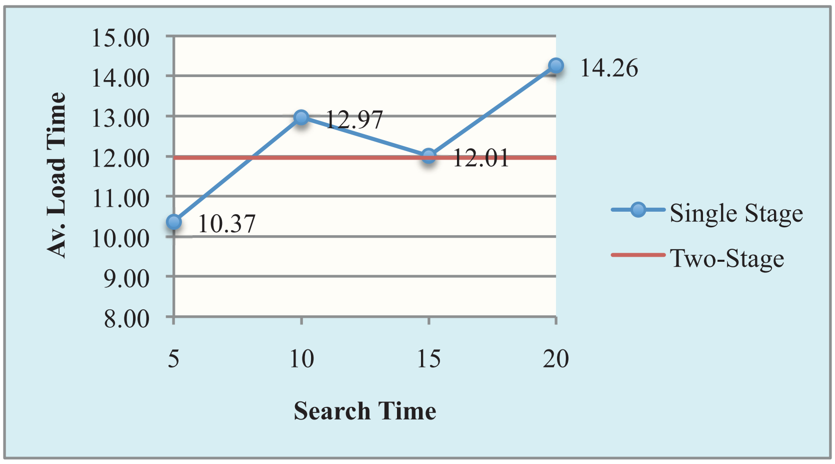
| Forklifts Receiving | Forklifts Shipping | Search Time | Av. Loading Time $T_L$ |
|---|---|---|---|
| 3 | 5 | 5 | 10.37 minutes |
| 3 | 5 | 10 | 12.97 minutes |
| 3 | 6 | 15 | 12.01 minutes |
| 3 | 6 | 20 | 14.26 minutes |

Tab. 4.4. Single Stage "SERIES 2"- Av. Loading Time $T_L$ as the Search Time changes

| Forklifts Receiving | Forklifts Shipping | Av. Loading Time $T_L$ |
|---|---|---|
| 4 | 5 | 11.96 minutes |

Tab. 4.5. Two-Stage "SERIES 2" – Av. Loading Time $T_L$

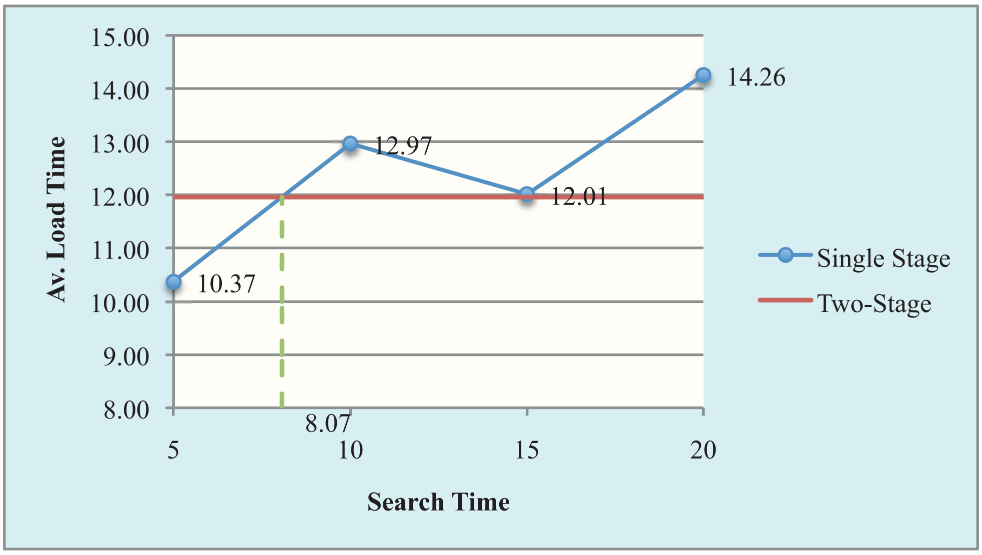
The results show that the cross dock achieves better performances in the loading operations if dedicated lanes are adopted within the terminal. The only exception is when the *Search Time* $S_T$ in the Single Stage model is considered low (5 seconds). It is well shown by the Graph. 4.3.




Graph. 4.3. Comparison between $T_L$ in the different handling strategies – "SERIES 2"

It is possible to state that the sorting process improves the loading activity, in term of time, compared to the Single Stage layout with medium, high, and very high *Search Times*. Moreover, to obtain this improvement in the loading process, not only extra resources are not required in the shipping area but, rather, the pool of forklifts used to load the trucks in the Two-Stage layout is composed by one resource less than the Single Stage when the *Search Time* is considered high or very high. Therefore, remembering the need of one extra forklift in the receiving area, the handling strategy adopted in the Two-Stage terminal positively affects the behaviour of the facilities within the cross dock, at least when the *Search Time* is high or very high, because the total requirement of forklifts (receiving + shipping) is the same.

Finally, in order to quantitatively understand when this strategy starts to improve the loading activity in term of time, the threshold value of the *Search Time* in the Single Stage cross dock is identified in 8.07 seconds, as the following graphic shows.




Graph. 4.4. Threshold value of the *Search Time*

All the results obtained through the simulations are shown in the Table 4.6 where, for the Single Stage layout, the averages of the values the KPI's take as the *Search Time* changes (with the exception of the case with low *Search Time* where the Single Stage cross dock performs better than the Two-Stage) are reported.

| | Single Stage layout | Two-Stage layout |
|---|---|---|
| Forklifts receiving area | 3 | 4 |
| Forklifts shipping area | 5.67 | 5 |
| Av. Transit time $T_T$ | 3.02 + 0.24 min. | 3.39 + 0.35 min. |
| Av. Staging Time $S_T$ | 61.18 min. | 58.37 min. |
| Loading Time $T_L$ | 13.08 min. | 11.96 min. |
| Av. Crossing Time $C_T$ | 69.08 min. | 67.8 min. |
| Receiving Fork. Utilization | 42% | 48.2% |
| Shipping Fork. Utilization | 67.3% | 39.9% |

Tab. 4.6. Single Stage and Two-Stage KPI's – "SERIES 2"

As it is supposed in Section 1.2.1, the Two-Stage cross dock needs one extra forklift in the receiving area and takes more time to carry the goods from the unloading area to the staging lanes. It is shown by the higher value of the *Av. Transit Time* $T_T$, made up by the components *Average Waiting Time For a Free Forklift* and *Average Transportation Time Until the Lane*. However, this time (and also the extra forklift in the case of high or very high *Search Time*) is fully retrieved through the following operations as $S_T$ and $T_L$ show.

Especially, the average time saved in the loading operations is 13.08 – 11.96 = 1.12 minutes per truck. It means that the sorting process in the Two-Stage cross dock permits to save 1.12 * 120 = 134.4 minutes in a day (as the cross dock serves 120 outgoing trucks per day) that implies, on equal other terms, a possible additional capacity of 134.4 / 11.96 = 11 trucks loaded in a day compared with the Single Stage cross docking terminal.

Dealing with the utilization of the resources, the absolute values are clearly quite low and they should be raised. But it is not possible to work in this way. The sizing made in Chapter 3 aims at the certainty that the operations within the cross dock do not fail any orders with the given scheduled arrival times. As it is shown in the previous Chapter, in fact, reducing the number of resources in order to increase their utilization would cause the departure of some trucks without the complete load. Therefore, it is a problem connected to the optimization of the trucks schedule that is outside the target of this work.

Something can be stated comparing the utilization of the forklifts in the different layouts indeed. The results show, in fact, that the utilization of the forklifts is higher in the receiving area of the Two-Stage terminal. This fact confirms that it takes more time than the Single Stage to perform the operations in the receiving area, even though the difference of 6.2% is kept down. On the contrary, in the shipping area, the utilization of the forklifts is much higher in the Single Stage terminal because, as it is shown in Tab. 4.6, the loading operations take more time to be performed. But, in this case, the difference is 27.2 percentage points. It that means that the reservation of one staging lane to each type of freight strongly affects in a good way the behaviour of the facilities within the cross docking.

### 4.3. Simulation using Dataset "Series 3"

Simulations are run for both the models using the number of forklifts chosen after the sizing process in Chapter 3. Tables 4.7 and 4.8 report the average time a truck takes to be loaded ($T_L$) in the Single Stage and in the Two-Stage terminals respectively, using the dataset "series 3".

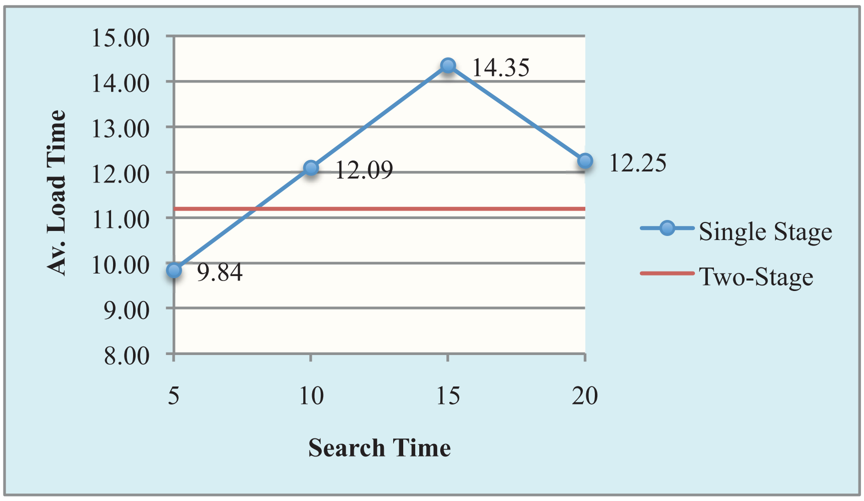
| Forklifts Receiving | Forklifts Shipping | Search Time | Av. Loading Time $T_L$ |
|---|---|---|---|
| 3 | 5 | 5 | 9.84 minutes |
| 3 | 5 | 10 | 12.09 minutes |
| 3 | 5 | 15 | 14.35 minutes |
| 3 | 6 | 20 | 12.25 minutes |

Tab. 4.7. Single Stage "SERIES 3" - Av. Loading Time $T_L$ as the Search Time changes

| Forklifts Receiving | Forklifts Shipping | Av. Loading Time $T_L$ |
|---|---|---|
| 4 | 5 | 11.19 minutes |

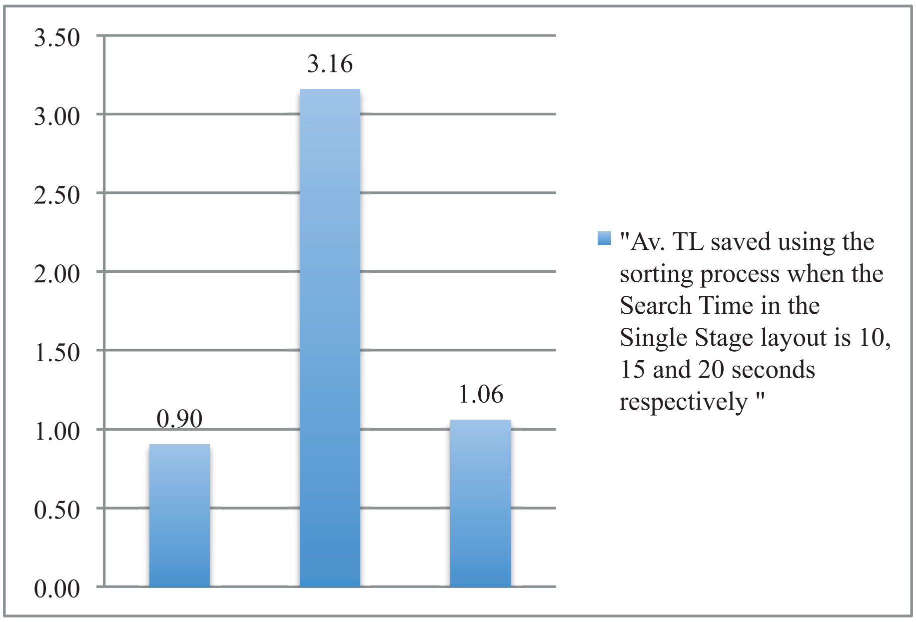
Tab. 4.8. Two-Stage "SERIES 3" – Av. Loading Time $T_L$

As it happens using the dataset "series 2", the results show that the cross dock achieves better performances in the loading operations if dedicated lanes are adopted within the terminal. The only exception is when the *Search Time* $S_T$ in the Single Stage terminal is considered low (5 seconds). It appears evident through the following graphic.




Graph. 4.5. Comparison between $T_L$ in the different handling strategies – "SERIES 3"

The improvement in the loading activities is, first of all, in term of time if compared to the Single Stage layout with medium, high, and very high *Search Times* (Graph. 4.6).

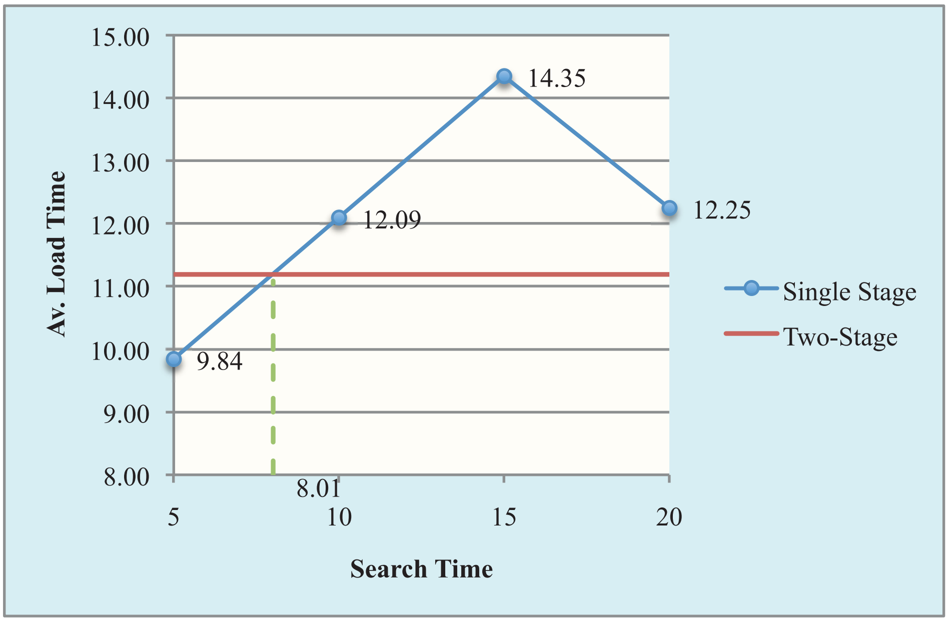



Graph. 4.6. Two-Stage Cross Dock - Saved $T_L$ compared to the Single Stage terminal

Moreover, to obtain this improvement in the loading process, not only extra resources are not required in the shipping area but, rather, the pool of forklifts used to load the truck in the Two-Stage terminal is composed by one resource less than the Single Stage when the *Search Time* $S_T$ is very high.

Therefore, it is possible to state that the handling strategy utilized in the Two-Stage terminal positively affects the behaviour of the facilities within the cross dock, at least when the *Search Time* $S_T$ in the Single Stage terminal is very high, because the total requirement of forklifts (receiving + shipping) is the same.

Finally, in order to quantitatively understand when this handling strategy starts to improve the loading activity in term of time, the threshold value of the *Search Time* $S_T$ in the Single Stage cross dock is identified in 8.01 seconds, as the following graphic shows.




Graph. 4.7. Threshold value of the *Search Time*

All the other performance indicators are shown in the following table where, for the Single Stage layout, the averages of the values the KPI's take as the *Search Time* $S_T$ changes (with the exception of the case with low $S_T$ where the Single Stage cross dock performs better than the Two Stage one) are reported.

| | Single Stage layout | Two-Stage layout |
|---|---|---|
| Forklifts receiving area | 3 | 4 |
| Forklifts shipping area | 5.33 | 5 |
| Av. Transit time $T_T$ | 2.95 + 0.24 min. | 2,94 + 0.35 min. |
| Av. Staging Time $S_T$ | 94.6 min. | 92 min. |
| Loading Time $T_L$ | 13.07 min. | 11.19 min. |
| Av. Crossing Time $C_T$ | 102.11 min. | 101 min. |
| Receiving Fork. Utilization | 31.9% | 35.35% |
| Shipping Fork. Utilization | 50.1% | 27.48% |

Tab. 4.9. Single Stage and Two-Stage KPI's – "SERIES 3"

As it happens using the dataset “series 2”, the Two-Stage cross dock needs one extra forklift in the receiving area but, in this case, the *Average Waiting Time For a Free Forklift* is the same as in the Single Stage terminal. Anyway, the value of the *Av. Transit Time* $T_T$ is higher because of its *Average Transportation Time Until the Lane* component. The handling strategy in the Two-Stage terminal takes more time to carry the goods from the unloading area to the staging lanes indeed, because the forklifts do not have just to carry the goods to the lane corresponding to the receiving door, as it is in the Single Stage Cross Dock. However, this time (and also the extra forklift in the case of very high *Search Time* in the Single Stage) is fully retrieved through the following operations as $S_T$ and $T_L$ show.

Especially, the average time saved in the loading operations is 13.07 – 11.19 = 1.88 minutes per truck. It means that the Two-Stage cross dock permits to save 1.88 * 120 = 225.6 minutes in a day (as the cross dock serves 120 outgoing trucks per day) that implies, on equal other terms, a possible additional capacity of 225.6 / 11.19 = 20 trucks loaded in a day compared with the Single Stage cross docking terminal.

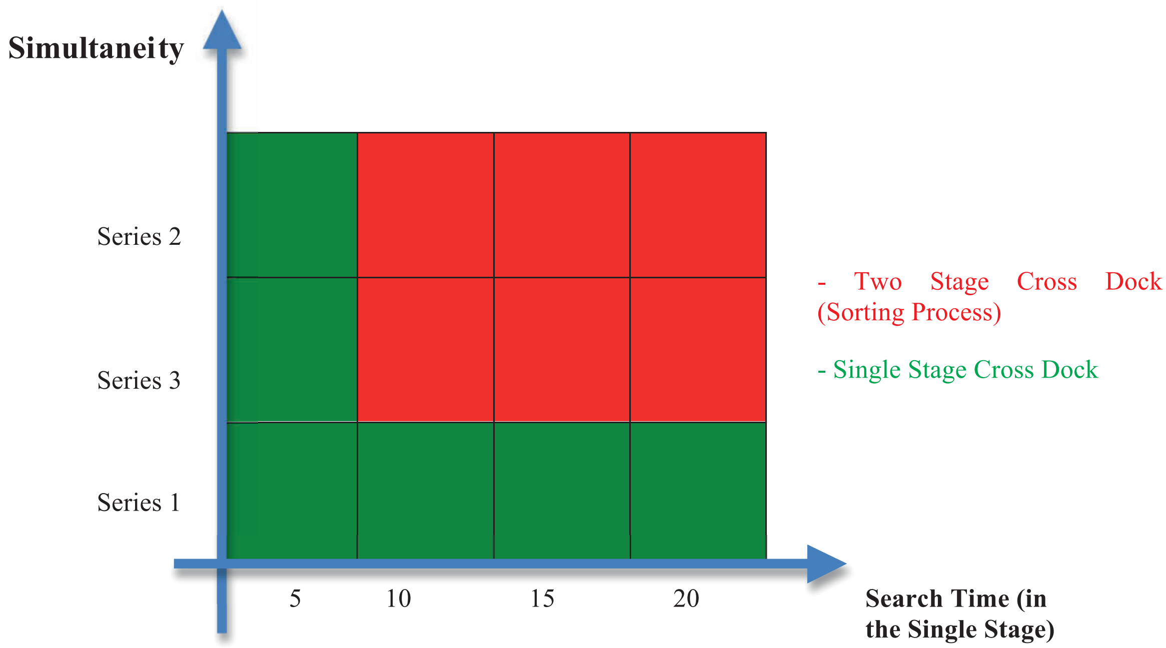
Finally, comparing the values of the utilization of the forklifts, it is possible to notice it is higher in the receiving area of the Two-Stage terminal. This fact confirms it takes more time, even though the difference of 3.45% is very kept down. On the contrary, in the shipping area, the utilization of the forklifts is much higher in the Single Stage terminal because the loading operations take more time to be performed. But, in this case, the difference of 22.62 percentage points between the two levels of utilization means that the reservation of one staging lane to each type of freight strongly affects in a good way the behaviour of the facilities within the cross docking terminal.

### 4.4. Summary of the results

The analysis of the results made in the previous sections of Chapter 4 shows that the strategy of reserving a staging lane to each type of freight adopted introducing the sorting process in the Two-Stage cross dock can improve or worsen the operations within the terminal depending on

- the simultaneity of the unloading/loading activities (the different datasets utilized as input)
- the value of the *Search Time* $S_T$ in the Single Stage terminal

The following graphic summarizes which cross dock performs better as these factors change.




Graph. 4.8. More performing strategy as Dataset and *Search Time* change

It is possible to notice that the strategy of staging different type of freight in different lanes does not improve the loading operations when the unloading and the loading activities mostly take place in different moments of the day (dataset "series 1"). It is caused by the lag between the arrivals and the departures of freights, thanks to that every staging lane can be considerably filled with all the mix of products. Therefore, the forklifts can find all of them in the staging lane corresponding to the shipping door. In this way, the distances that forklifts have to drive are much smaller than distances in the Two-Stage. It causes shorter times to perform the loading activity, even though the *Search Time* is very high.

On the contrary, as the simultaneity in the unloading and loading activities increases (the warm up time is only 1 hour), both in series2 and series3, the probability not to find the right good in the staging lane corresponding to the shipping door is higher, and forklifts have to look for it into the other lanes (according to the algorithm explained in Section 2.1.3). In this way, simulations show that the Sorting process, eliminating the *Search Time* and using an accurate and orderly management of freight, leads to better performance in the loading activity. The only exception is associated to low *Search Times*. Its threshold value can be identified in 8 seconds: with higher values it is demonstrated that the Two-Stage terminal permits to obtain better performances of the operations.

To test the robustness of the results, the two different strategies are tested in the case of unexpected disruptions in the following Section.

## 4.5. Disrupted scenarios

In order to evaluate the robustness of the layouts and of the strategies, both the models are tested in the case of unexpected disruptions.

The main target of this project is the evaluation of possible advantages that the adoption of staging lanes dedicated to different type of freights can give to the operations within a cross docking terminal.

Therefore, one brake in the pool of forklifts used in the receiving area is simulated in the next sections, in order to test how the models perform if the requirement of resources differs from the one chosen according to the sizing criteria (Chapter 3).

### 4.5.1. Dataset "Series 1" – Disrupted Model

For both the models, one simulation is run decreasing of one unit (compared to the requirement chosen after the sizing in Chapter 3) the number of available forklifts in the receiving area, in order to simulate the brake of one of them.

A medium *Search Time* (10 seconds) is chosen to test the disrupted scenario in the Single Stage layout.

The following table summarizes the number of forklifts utilised to test the disruption in the models.

| Number of Forklifts | Single Stage layout | Two-Stage layout |
|---|---|---|
| Receiving Area | 2 | 3 |
| Shipping Area | 7 | 5 |

Tab. 4.11. Disrupted scenario "Series 1" - Number of Forklifts

The results are shown in the table below (in red colour are reported the values of the KPI's in the undisrupted scenario).

| | Single Stage [min] | | Two-Stage [min] | |
|---|---|---|---|---|
| KPI | Basic | Disrupted | Basic | Disrupted |
| $T_T$ | 3.6+0.24 | 15.9 + 0.24 | 3.6+0.35 | 7.18+0.35 |
| $S_T$ | 260 | 249 | 262.18 | 258.57 |
| $T_L$ | 8.72 | 9.72 | 12.88 | 12.88 |
| $C_T$ | 267.10 | 268.65 | 272 | 272.16 |
| Rec. Fork. Utiliz. | 33.99% | 69.21% | 37.9% | 48.2% |
| Shipp. Fork. Utiliz. | 50.6% | 50.02% | 39.9% | 39.84% |
| Av. Truck. Waiting | 0.07 | 0.6 | 0.891 | 0.893 |
| Failed Orders | 0 | 0 | 0 | 0 |

Tab. 4.12. KPI's in the undisrupted and disrupted models – "SERIES 1"

How it was presumable, the unavailability of one resource in the receiving area increases the value of the component *Average Waiting Time For a Free Forklift* of the transit time $T_T$. According to the increase of $T_T$ the average staging time $S_T$ decreases but not in a sufficient way to maintain the average crossing time $C_T$ the same as in the undisrupted scenarios. Anyway, the growth of $C_T$ is kept down in both the models. The utilization of the forklifts used in the receiving area obviously increases. Thanks to the 6 hours warm up time in the dataset "series 1", that permits to conspicuously fill up the staging lanes before the arrival of the first outgoing truck, no orders are classified as "failed" introducing the disruption in the models. Therefore the operations in the receiving area efficiently support the loading operations also when a forklift brakes down.

Comparing the behaviour of the models, it is possible to state that the Single Stage layout continues to perform better when subjected to disruptions. Even if the *Average Waiting Time For a Free Forklift* increases much more in the Single Stage than in the Two-Stage (its value is 15.9 minutes against 7.18 minutes), the time saved thanks to the smaller distances the forklifts have to drive without the sorting process allows the goods to be in the staging lanes when they have to be loaded onto the outbound trucks in any case. The increases of 1 minute in the loading time $T_L$ and 0.53 minutes in the *Average Outgoing Trucks Waiting Time* (compared to the undisrupted scenario) mean that, because of the higher $T_T$, the goods are not always found in the lane closest to the shipping door and, therefore, the forklifts take more time to carry them from the other staging lanes. No trucks, in fact, have to wait 10 minutes at the door for a second search in the lanes. Despite of this increase in the loading time $T_L$, it remains 3.161 minutes smaller than the value of $T_L$ in the Two-Stage layouts. It confirms, also supported by better values of the other KPI's, the uselessness of lanes dedicated to different kind of freight when the unloading and the loading operations mostly take place in different moments of the day.

### 4.5.2. Dataset "Series 2" – Disrupted Model

For both the models, one simulation is run decreasing of one unit (compared to the requirement chosen after the sizing in Chapter 3) the number of available forklifts in the receiving area, in order to simulate the brake of one of them.

As it is explained in the Section 4.2, the Single Stage layout always performs the operations worse than the Two-Stage layout, except when the *Search Time* $S_T$ is considered low.

Therefore it is interesting to test the disruption in this case, when the $S_T$ = 5 seconds. The following table summarizes the number of forklifts utilised to test the disruption in the models.

| Number of Forklifts | Single Stage layout | Two-Stage layout |
|---|---|---|
| Receiving Area | 2 | 5 |
| Shipping Area | 3 | 5 |

Tab. 4.13. Disrupted scenario "Series 2" - Number of Forklifts

The results are shown in the table below (in red colour are reported the values of the KPI's in the undisrupted scenario).

| | Single Stage [min] | | Two-Stage [min] | |
|---|---|---|---|---|
| KPI | Basic | Disrupted | Basic | Disrupted |
| $T_T$ | 3.02+0.24 | 38.3+0.24 | 3.39+0.35 | 11.8+0.35 |
| $S_T$ | 60.62 | 32.13 | 58.38 | 49.4 |
| $T_L$ | 10.3718 | 13.85 | 11.96 | 11.96 |
| $C_T$ | 69.077 | 75.65 | 67.82 | 67.82 |
| Rec. Fork. Utiliz. | 41.63% | 62.24% | 48.2% | 65.08% |
| Shipp. Fork. Utiliz. | 66.21% | 65.95% | 39.9% | 39.84% |
| Av. Truck. Waiting | 0.161 | 0.72 | 0.311 | 0.32 |
| Failed Orders | 0 | 141 | 0 | 0 |

Tab. 4.14. KPI's in the undisrupted and disrupted models – "SERIES 2"

How it was presumable, the unavailability of one resource in the receiving area increases the value of the component *Average Waiting Time For a Free Forklift* of the transit time $T_T$. According to the increase of $T_T$ the average staging time $S_T$ decreases.

Concerning the average crossing time $C_T$ and the average load time $T_L$, they increase in the Single Stage model while they remain the same in the Two-Stage terminal, compared to the undisrupted scenario. It means that the unavailability of one forklift in the receiving area strongly affects the operations in the Single Stage model, as the 141 failed orders confirm.

On the contrary, despite of a bigger *Average Waiting Time For a Free Forklift* compared to the basic scenario, the Two-Stage terminal performs the operations achieving the same efficiency as when disruptions do not occur. With the exception of the utilization of the forklifts in the receiving area (that obviously increases reducing the number of resources) and the transit time $T_T$ (directly connected to the number of resources), the values of all the KPI's do not change from the undisrupted scenario indeed.

Therefore, even if an extra forklift is required, the adoption of staging lanes dedicated to the different kind of freight is strongly advised also when the $S_T$ is considered low, because even if it performs the loading operations worse (in term of time) it is not subjected to the disruption analysed.

4.5.3. Dataset "Series 3" – Disrupted Model

For both the models, one simulation is run decreasing of one unit (compared to the requirement chose through sizing) the number of available forklifts in the receiving area, in order to simulate the brake of one of them. As for the dataset "series 2", it is interesting to test the disruption in the case of *Search Time* = 5 seconds. The following table summarizes the number of forklifts utilised to test the disruption in the models.

| Number of Forklifts | Single Stage layout | Two-Stage layout |
|---|---|---|
| Receiving Area | 2 | 5 |
| Shipping Area | 3 | 5 |

Tab. 4.15. Disrupted scenario "Series 3" - Number of Forklifts

The results are shown in the table below (in red colour are reported the values of the KPI's in the undisrupted scenario).

| | Single Stage [min] | | Two-Stage [min] | |
|---|---|---|---|---|
| KPI | Basic | Disrupted | Basic | Disrupted |
| $T_T$ | 3.02+0.24 | 6.01+0.24 | 2.94+0.35 | 4.78+0.35 |
| $S_T$ | 91.62 | 89.36 | 92 | 90.34 |
| $T_L$ | 9.841 | 9.962 | 11.19 | 11.19 |
| $C_T$ | 99.7 | 99.78 | 101.02 | 101.05 |
| Rec. Fork. Utiliz. | 41.63% | 44.69% | 35.35% | 47.16% |
| Shipp. Fork. Utiliz. | 39.3% | 39,43% | 27.47% | 27.5% |
| Av. Truck. Waiting | 0.161 | 0.054 | 0.07 | 0.07 |
| Failed Orders | 0 | 0 | 0 | 0 |

Tab. 4.16. KPI's in the undisrupted and disrupted models – "SERIES 3"

The unavailability of one resource in the receiving area increases the value of the component *Average Waiting Time For a Free Forklift* of the transit time $T_T$, especially in the Single Stage layout where the growth is bigger compared to the Two-Stage. According to the increase of $T_T$ the average staging time $S_T$ decreases but the average loading time $T_L$ and the average crossing time $C_T$ remain almost the same as the undisrupted scenario in both the models. It means that both the layouts can perform operations achieving the same efficiency also when disruptions occur. With the exception of the utilization of the forklifts in the receiving area (that obviously increases reducing the number of resources) and the transit time $T_T$ (directly connected to the number of resources), the values of all the KPI's do not change from the undisrupted scenarios indeed.

Even if the *Average Waiting Time For a Free Forklift* is more than one minute higher in the Single Stage layout, the other component of the transit time $T_T$ called *Average Transportation Time Until the Lane* is smaller compared to the Two-Stage. The reason of this is the smaller distances the forklifts have to drive in the receiving area without the sorting process (Section 2.1.1). Thanks to that the goods can be in the lanes when they have to be loaded onto the outgoing trucks that do not have to wait for some orders at the door: it happens only one time among 120 trucks (as it is also understandable by the value of the average loading time $T_L$ that change of 0.12 minutes compared to the undisrupted scenario). This fact allows the Single Stage cross dock to better perform in operations also when the *Search Time* is 5 seconds and disruptions occur.

Therefore, in the case the unloading and the loading activities are nearly concurrent and the terminal is subjected to different peaks during the day, the Single Stage Cross dock is preferable if the *Search Time* is considered low because the KPI's show that it works better than the Two-Stage layout and it is not subjected to the disruption analysed at the same time. If the value of the *Search Time* increases the strategy of staging different kinds of freight in different lanes allows the terminal to achieve better performances (as it is shown in the Section 4.3). Moreover, they are not affected by the disruption treated, as the KPI's in Table 4.16 show.

4.5.4. Disrupted scenarios: summary of the results

The analysis made in the previous sections aims to test the robustness of the models introducing the disruption of the unavailability of one forklift in the receiving area of the cross docks. The results show important information in order to complete the evaluation of the different strategies in handling and staging freights adopted by the Single Stage and the Two-Stage cross docks.

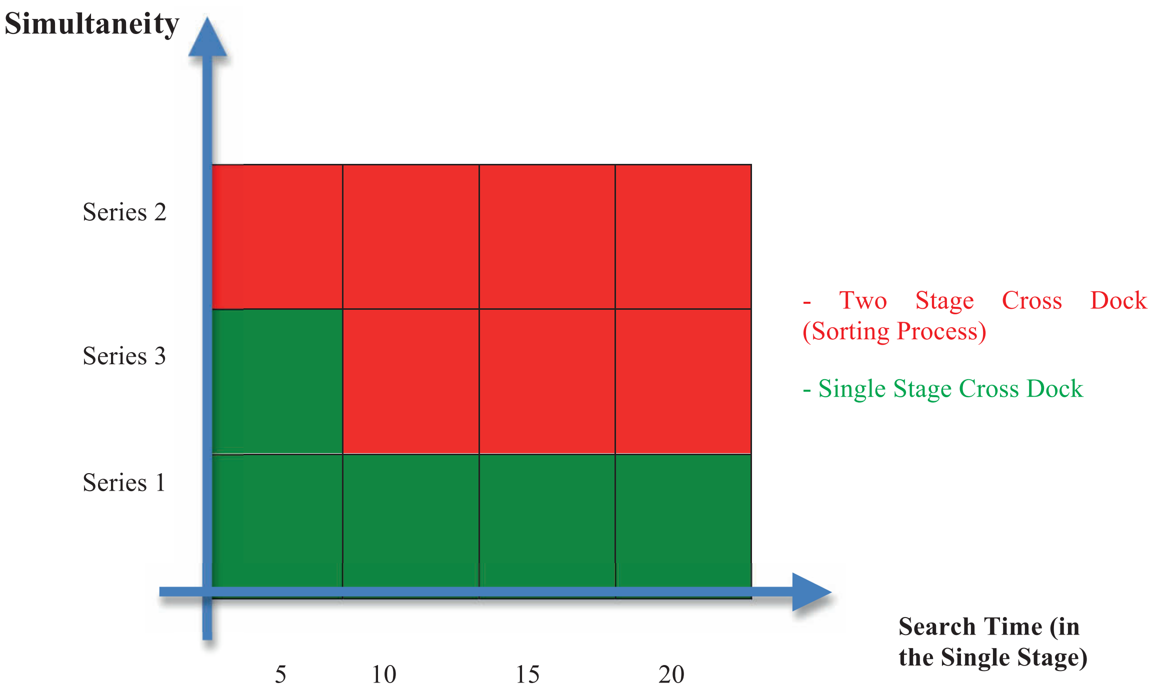
They confirm, supported by the values of all the KPI's, the uselessness of lanes dedicated to different kind of freight when the unloading and the loading operations mostly take place in different moments of the day (dataset "series 1"). Therefore, the Single Stage cross dock is preferred in this case, because its operations perform better than the Two-Stage cross dock also when the disruption is introduced into the models (as it is shown in Table 4.12).

Dealing with dataset "series 2", the analysis in Section 4.2 shows that the Two-Stage cross dock always achieves better performances than the Single Stage terminal, with the exception of the case the *Search Time* is considered low. But in Section 4.5.2 it is possible to notice how the performance of the operations within the Single Stage cross dock is strongly affected in a bad way introducing the disruption in the model, as the 141 failed orders confirm. On the contrary, despite of a bigger *Average Waiting Time For a Free Forklift* compared to the basic scenario (that is obvious using one forklift less in the receiving area), the Two-Stage terminal performs the operations achieving the same efficiency as when disruptions do not occur (as it is shown in Table 4.14). Therefore, even if an extra forklift is required, the adoption of staging lanes dedicated to the different kind of freight is strongly advised also when the $S_T$ is considered low. In fact, even though it performs the loading operations worse than the Single Stage in the undisrupted scenario (in term of time) it is not subjected to the disruption analysed.

Finally, looking at "series3", the introduction of the disruption do not affect both the models. In fact, as it is shown in Table 4.16, the values of the KPI's are the same as the undisrupted scenarios, with the only exception of a bigger *Average Waiting Time For a Free Forklift*, caused by the breaking of one forklift in the receiving area. Therefore, the analysis made in Section 4.5.3 confirms that the Single Stage cross dock is preferable if the *Search Time* is considered low because the KPI's show that it works better than the Two-Stage terminal and it is not subjected to the disruption analysed at the same time.

If the value of the *Search Time* increases the strategy of staging different kinds of freight in different lanes allows the terminal to achieve better performances. Moreover, they are not affected by the disruption treated.

Graph. 4.9 summarizes which strategy in handling and staging freights reaches better performances in the different situations analysed in this work, considering the information obtained through the analysis of the disrupted models too.




Graph. 4.9. More performing strategy as Dataset and *Search Time* change after testing the disrupted models

# CHAPTER 5: CONCLUSIONS

This chapter presents concluding comments on this thesis and suggests directions for future research. Section 5.1 summarizes the contributions and conclusions of this research and Section 5.2 points out some possible extensions for future research.

## 5.1. Summary of the work

In today's logistical environment where small orders and frequent deliveries are expected, cross docking offers an important advantage. Cross docking is a logistical activity that consolidates shipments from inbound trailers to outbound trailers in buildings known as cross docks. Here, incoming deliveries of inbound trucks are unloaded, sorted, moved across the dock and finally loaded onto outbound trucks, which immediately leave the terminal towards their next destination in the distribution chain. In particular, in the sorting process there are different handling strategies connected to the method of staging freights. An overview of the different types of existing cross docks and of the problems connected to them is given in Chapter 1.

This thesis focuses on two different strategies in handling and staging freights within a cross docking terminal to test how they perform in operations. It aims to understand if a sorting process that stages freights in lanes dedicated to the kind of product, as it happens in a Two-Stage cross dock, positively affects the behaviour of the facilities provided by a Single Stage cross dock, especially, the loading process.

After explaining the different logics (that mainly depend on the strategy in handling and staging freights) adopted in the Single Stage and in the Two-Stage cross docking models (Chapter 2), the availability of the data and the different dataset tested are presented. In Chapter 3 the requirement of forklifts is sized for the models as the input dataset changes, because an efficient performance of the operations within the cross docks in serving the scheduled trucks is the starting point for the analysis and it is necessary in order to compare the performances of the two different strategies in handling and staging freights.

In Chapter 4 the performance measurements (KPI's) to evaluate the operations in the cross docking terminals are defined. According to those, an analysis of the behaviour of the facilities within the models is carried out in order to compare the different strategies in handling and staging freights. The results show that there is not one best strategy but the performance of the operations depends on both the distribution of the number of trucks served per hour by the cross dock and the *Search Time* $S_T$ a forklift takes to find the right freight in the staging lanes of the Single Stage terminal (as it is shown in Table 4.10).

Finally, in the last part of Chapter 4, the robustness of the different strategies in handling and staging freights is tested in case of unexpected disruption (Table 4.17).

### 5.2. Summary of the results

This project develops the models of two different strategies in handling and staging freights within a cross docking terminal to test how they perform in operations. It aims to understand if a sorting process that stages freights in lanes dedicated to the kind of product positively affects the behaviour of the facilities provided by the cross dock and, especially, the loading process. The requirement of resources is considered at the same time, in order to provide useful information about the necessity of extra resources.

The analysis of the results obtained through simulations leads to the following conclusions:

- The Two-Stage Cross Dock is more versatile than the Single Stage. After being sized, in fact, it can efficiently perform the operations using the same number of resources, even though the management of the incoming/outgoing trailers changes (Graph. 3.3).
- The strategy of staging different type of freight in different lanes does not improve the loading operations when the unloading and the loading activities mostly take place in different moments of the day. It is caused by the lag between the arrivals and the departures of freights, thanks to that every staging lane can be considerably filled with all the mix of products. Therefore, the forklifts can find all the goods in the staging lane corresponding to the shipping door. In this way, the distances that forklifts have to drive are much smaller than

distances in the Two-Stage. It makes possible to obtain shorter times to perform the loading activity, even though the *Search Time* is very high.

On the contrary, as the simultaneity in the unloading and loading activities increases, the probability not to find the right good in the staging lane corresponding to the shipping door is higher, and forklifts have to look for it into the other lanes (according to the algorithm explained in Section 2.1.3). In this way, eliminating the *Search Time* and using an accurate and orderly management of freight, the Sorting process leads to better performance in the loading activity (Graph. 4.9).

### 5.2. Future works

There are several potential directions for future research on this thesis. First, in this project the assumption that the given cross docks can serve the scheduled incoming trucks without waiting time is taken. The requested resources, the right number of doors and all the optimization problems to make it possible are not treated in this work. Therefore, future research might address to solve all the optimization problems connected to these variables, in order to make an analysis of the different handling and staging strategies treated in this project in a realistic situation, without the adoption of simplifying hypothesis. As it is reported in Section 1.2.4 a vast literature is available in this fields.

Second, since the research is based on the problems in the real world, then it is useful in real application. It could help people to manage the cross dock well by adopting the best performing handling and staging strategy as the situation changes. To make it real, the evaluation of the costs connected to the benefits coming from the adoption of the best performing strategy should be done, in order to calculate the return on investment. The estimation of costs, in fact, is basic to understand the real applicability in the industry.

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## Acknowledgments

It is a pleasure to thank the many people who made this thesis possible. First, I wish to express my sincere gratitude to my supervisor, Prof. Allan Larsen, and my co-supervisor, Allan Olsen, for their kindness, constant support and patient help in my research with the Technical University of Denmark.

I wish to thank my advisor at the University of Padua, Ing. Daria Battini, that made possible the development of this project abroad and for providing insightful suggestions on this thesis.

I am grateful to all my Erasmus friends, for the long time spent together working at "our" table in the corner of the DTU library and for all the moments shared during this experience. I'm sure they will last till the end as our friendships.

I want to thank my Italian great friends that I felt close even though there were many kilometers between us.

Finally I would like to express my deepest appreciation and gratitude to my parents and my sister, for their consistent supports and encouragements during my life.