Master’s degree thesis

LOG950 Logistics

Potential effects of RFID technology on internal RTIs’ supply chain performance: a case study of “Swire Oilfield Services”

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Number of pages including this page: 86

Molde,2015

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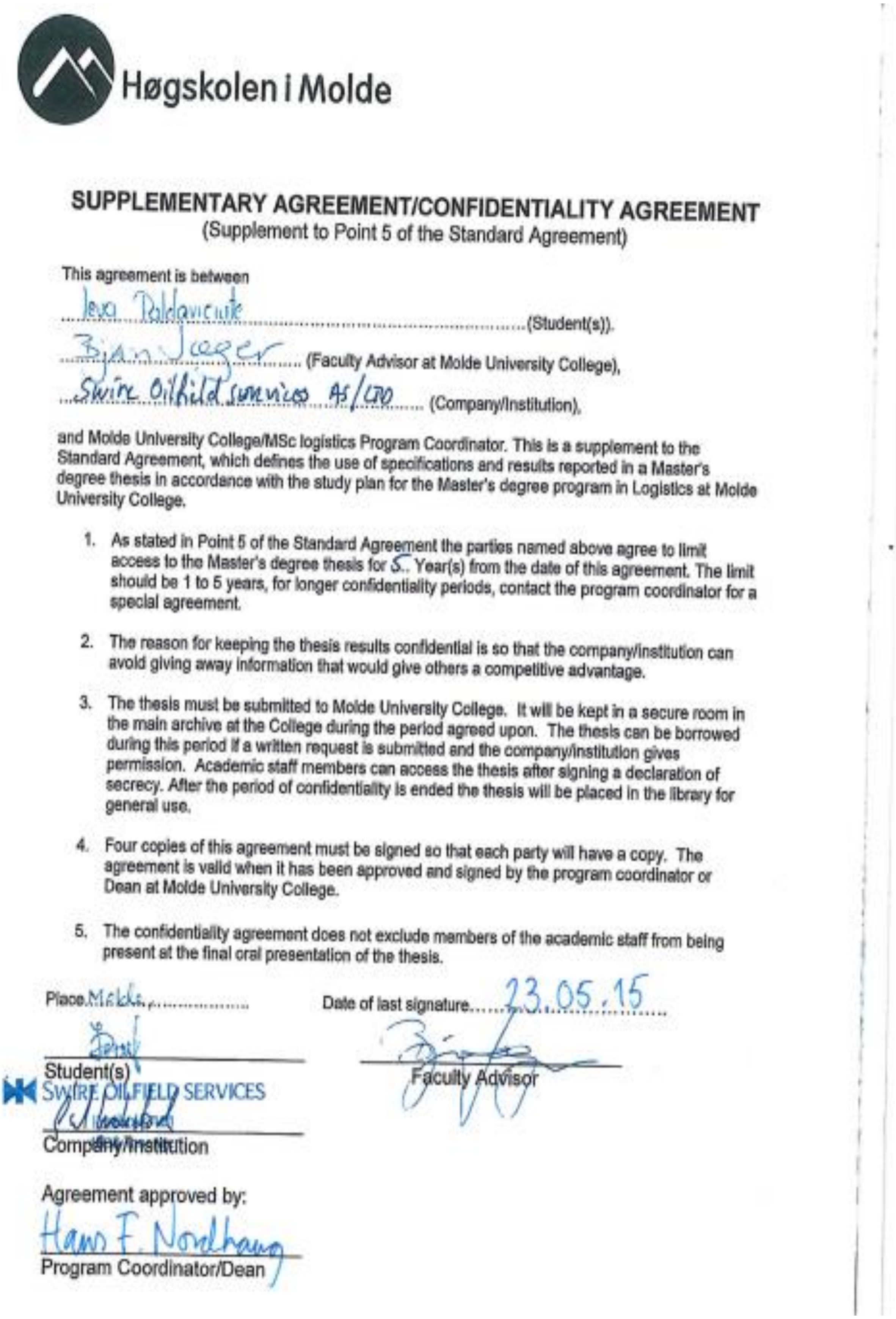

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Acknowledgements

I would like to say a big thank you to all the people who contributed to the writing process of this thesis by their knowledge and experience, as well as to those who supported me through this sometimes difficult 9-month period by simple words of encouragement.

Special thanks to Mr. Åsmund Krokstad from „Swire Oilfield Services“, who never once denied me answers to sometimes difficult or even repetitive questions.

Also big thank you to my supervisor Mr. Bjørn Jæger for guiding me academically until the very end of writing process and answering each and every question I had in a very helpful manner.

Additionally I would like to thank Mr. Ketil Danielsen for consulting me about sometimes complicated (to me) matters of Arena simulation software.

Summary

The aim of this study is to investigate whether and how increased visibility in maintenance processes due to the adoption of Radio Frequency Identification (RFID) technology could improve maintenance performance of “Swire Oilfield Services” in Returnable Transport Items’ (RTIs) management.

RFID technology has been a widely discussed method for increasing visibility in supply chains. Supply chain visibility can be increased by the usage of different kinds of trace and track technologies, however RFID is considered to be the most promising in logistics sector as having superior benefits when compared with such technologies as GPS/GSM tracking or barcoding.

For some closed-loop supply chains operating RTIs the implementation of RFID technology could be more beneficial than for others. Upstream oil and gas supply chain can be a good example of how increased visibility can affect the performance of each actor in the supply chain. This thesis is mostly concerned with one part of the upstream oil and gas supply chain – the owner of RTIs pool, in this case “Swire Oilfield Services” company, and whether/how the adoption of RFID technology could improve the internal processes and create actual benefits for the company.

A study case, based on qualitative and quantitative data received directly from “Swire Oilfield Services”, was composed. The main research question for this study was:

- Whether and how increased visibility in maintenance processes due to RFID technology could improve the performance of “Swire Oilfield Services” in RTI business?

The more detailed research sub-questions were:

- What is current “Swire Oilfield Services” maintenance performance?
- What effects could RFID application and increased visibility have on maintenance performance in “Swire Oilfield Services”?
- Are there any problematic areas in “Swire Oilfield Services” performance that could be improved by the adoption of RFID technology?
- What would be the recommendations to improve the problematic areas of company’s maintenance performance?

To obtain answers to the main research question and its sub-questions, a simulation model of current company’s maintenance processes was created by using Arena simulation software; then, by changing few model parameters, a second simulation model was

created. The results of the first and the second simulation models were compared and conclusions drawn.

The structure of the thesis consists of few chapters:

Chapter 1.0: Presents an overview of scientific literature, relevant to the case study;

Chapter 2.0: Presents main objectives, research questions, data collection methods and preliminary review of the case study of “Swire Oilfield Services”;

Chapter 3.0: Displays the research analysis done for the case; the description of first and second simulation models, the comparison of simulation reports of both simulation models;

Chapter 4.0: Presents recommendations for further improvement of maintenance processes in “Swire Oilfield Services”.

The results indicate that the maintenance system in “Swire Oilfield Services” company has few problematic areas that could be considerably improved by the adoption of RFID technology.

RFID technology could enhance planning and scheduling processes in the system, also, it could improve the overall maintenance system performance and enable collection of accurate data about the actual maintenance performance, which is currently lacking in “Swire Oilfield Services”.

Additionally, the adoption of RFID technology would cause a number of positive effects on overall RTIs’ management in the long run and provide many financial benefits as well.

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Introduction

The interest in Radio Frequency Identification (RFID) technology has been booming in the past few decades. Many academic researchers, scientists and managers from various industries are searching for new ways of profitable adoption of RFID technology into daily business activities.

Increasing visibility in supply chains by tracing and tracking assets with the assistance of RFID technology is a widely discussed topic throughout many industries, oil and gas industry being no exception. The discussion of what are the effects of RFID technology implementation in daily logistics activities is becoming more and more relevant due to technological advancement and increasing need to have real time knowledge about asset whereabouts.

The case of ”Swire Oilfield Services” which is studied in this thesis analyses the internal supply chain of ”Swire Oilfield Services” company, a part of the upstream oil and gas supply chain on the Norwegian Continental Shelf. The study case is mostly concerned with how full adoption of RFID technology could affect maintenance processes and the company’s internal performance indicators.

The qualitative and quantitative data that was used in the case study was directly provided by “Swire Oilfield Services”; a big part of qualitative data was obtained through interviews with “Swire Oilfield Services” management.

The main research question that is asked in the thesis is:

- Whether and how increased visibility in maintenance processes due to RFID technology could improve the performance of “Swire Oilfield Services” in RTI business?

The more detailed research sub-questions are:

- What is current “Swire Oilfield Services” maintenance performance?
- What effects could RFID application and increased visibility have on maintenance performance in “Swire Oilfield Services”?
- Are there any problematic areas in “Swire Oilfield Services” performance that could be improved by the adoption of RFID technology?
- What would be the recommendations to improve the problematic areas of company’s maintenance performance?

To test how potential effects of RFID technology could translate into real logistics processes in “Swire Oilfield Services” a simulation model of current company’s maintenance system was set up; then, a set of assumed changes caused by the adoption of

RFID were implemented in the second simulation model. The performance parameters of both simulation models were compared.

The results indicated that the maintenance system in “Swire Oilfield Services” company has few problematic areas that could be considerably improved by the adoption of RFID technology. RFID technology could enhance planning and scheduling processes in the system, also, it could improve the overall maintenance system performance and enable collection of accurate data about the actual maintenance performance, which is currently lacking in “Swire Oilfield Services”.

Additionally, the adoption of RFID technology would cause a number of positive effects on overall RTIs’ management in the long run and provide many financial benefits as well.

1.0 Literature review

1.1 Supply chain visibility and track and trace technologies

Heaney (2013) states that “supply chain execution and responsiveness require the tight synchronization of supply and demand, as well as the orchestration of the three flows of commerce – the movement of goods, information, and funds – across an increasingly large number of logistics and trading partners spanning wide geographic areas”. Supply chain management of such scale inevitably requires high supply chain visibility, which has been an increasingly discussed topic in scientific literature.

The need for increased supply chain visibility has resulted in a substantial and growing demand for tracking and tracing of goods in the supply chain. The monitoring and management of logistics and supply chain networks are nowadays considered an important issue for global companies (Shamsuzzoha and Helo, 2011).

This chapter presents the principles of track and trace technologies and the ways these technologies can increase visibility in supply chains.

1.1.1 **Supply chain visibility**

As the White Paper of Forrester Consulting (2012) states, supply chain visibility and asset-tracking applications are a key focus for many firms. A survey carried by Aberdeen group indicated that 63% from 149 companies with predominantly global supply chains that participated in the research indicated supply chain visibility as a high priority for improvement (Heaney, 2013).

The notion of visibility in supply chains can be summarised as “visibility is the ability to know exactly where things are at any point in time, or where they have been, and why” (Solanki and Brewster, 2013). It is claimed that supply chain visibility applications help reduce working capital, improve fixed asset utilization, and improve customer service (Forrester Consulting, 2012). In recent years data visibility in supply chains has received considerable attention; information systems are now being designed to facilitate the process of making data available in real time to stakeholders in the supply chain, while keeping access control restrictions in place (Solanki and Brewster, 2013).

Supply chain visibility is also closely related with the Internet of things (IoT) concept, which dates back to the early 1980’s when the first appliance – a Coke machine, was connected to the internet to check its inventory to determine how many drinks were available (Palermo, 2014). The phrase Internet of Things heralds a vision of the future

Internet where connecting physical things through a network will let them take an active part in the Internet, exchanging information about themselves and their surroundings. This will give immediate access to information about the physical world and the objects in it leading to innovative services and increase in efficiency and productivity (Bandyopadhyay and Sen, 2011). According to Gartner (2013), in 2009, there were 2.5 billion connected devices with unique IP addresses to the Internet; most of these were devices people carry - such as cell phones and PCs. In 2020, there will be up to 30 billion devices connected with unique IP addresses, most of which will be products.

Well developed IoT will greatly enhance product visibility in supply chains across many business sectors and raise issues of guaranteed security and privacy of the users and their data (Bandyopadhyay and Sen, 2011). At the same time, in order to fully exploit IoT benefits, there will be a high need for well developed track and trace technologies, integrated with existing information systems.

1.1.2 Principles of track and trace technologies

According to Shamsuzzoha and Helo (2011), there is no universally accepted definition of tracking and tracing in the logistics literature; however many scientists do present quite similar descriptions of track and trace concepts, as presented in tables 1 and 2.

Table 1. Definitions of ”tracing” concept (Source:created by author)

Year	Author(s)	Definition
1985	Porter (quoted in Fritz and Schiefer, 2009)	Tracing capability allows, for any product and from any stage within the value chain, to identify the initial source (backward tracing) and, eventually, its final destination (forward tracing).Tracing is a method of recording and/or having access to information regarding the composition of an object from raw material or sub-components and operations that the object has undergone during its lifetime.
2006	Kelepouris et al.	Tracing is a method of recording and/or having access to information regarding the composition of an object from raw material or sub-components and operations that the object has undergone during its lifetime.
2011	Shamsuzzoha and Helo	Tracing system signifies to storing and retaining the life cycle history of the manufacturing and distribution of product(s) and its components.

Table 2. Definitions of ”tracking” concept (Source:created by author)

Year	Author	Definition
2006	Kelepouris et al	Tracking is a method of determining the ongoing location and state of items during their way through the supply chain.

2009	Fritz and Schiefer	The tracking capability allows, to identify for any product, the actual location at any given time.
2011	Shamsuzzoha and Helo	The term tracking can be identified as the collecting and managing the information of the present location of a product(s) or delivery item(s).

To summarize, the concept of tracking and tracing includes managing the successive links between batches and logistic units throughout the entire supply chain network. (Shamsuzzoha et al, 2013). Figure 1 represents track and trace time dimension.

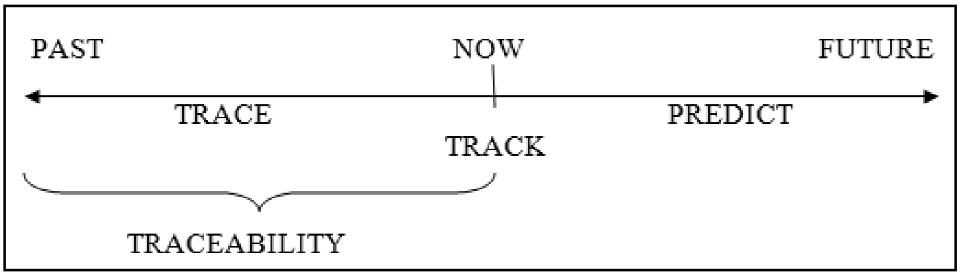


Figure 1. Track and trace time dimension (Source: Zanette et al, 2011)

According to Bechini et al (2007), the term traceability, which is used as an umbrella term for both tracking and tracing, can be defined as the ability to trace the history, application or location of an entity by means of recorded identifications. Zanette et al (2011) states that product traceability is the ability to know exactly the localization of the product in the industry at any time (Track), furthermore, to know where the item has been (Trace) in the past (Figure 1).

Track and trace technologies can be sorted according to its main application types or areas.

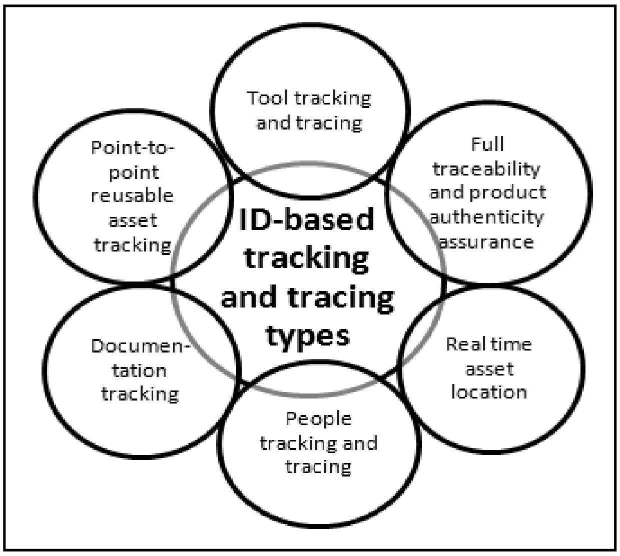


Figure 2. ID-based tracking and tracing types. (Source: adapted by author from Kelepouris et al., 2007)

Kelepouris et al. (2007) divide existing approaches to ID-based tracking and tracing in terms of key application types (Figure 2):

- *Point-to- point reusable asset tracking* application type refers to recording the position of a reusable asset, as it is transferred between critical points in either a maintenance or manufacturing process, or throughout a supply chain.
- *Real time asset location* application type refers to techniques which estimate the position of an asset in a great degree of accuracy within one area.
- *Full traceability and product authenticity assurance* application type refers to tracking and tracing systems that support full traceability, providing a detailed product pedigree for each item and ensuring product authenticity.
- *Tool tracking and tracing.* Tools can be reusable assets that are used on a shared basis among the engineers of the same or different companies. This system is RFID-based.
- *Documentation tracking* application type is mostly related to the aerospace sector and refers to the tracking of the documentation that accompanies aircraft and engine parts and contains part-related information.
- *People tracking and tracing* systems have been used for ensuring that only authorised personnel with the correct training can access certain areas or use certain equipment.

Kandel and Klumpp (2012) distinguishes three kinds of trace and track solutions used in logistics (Figure 3).

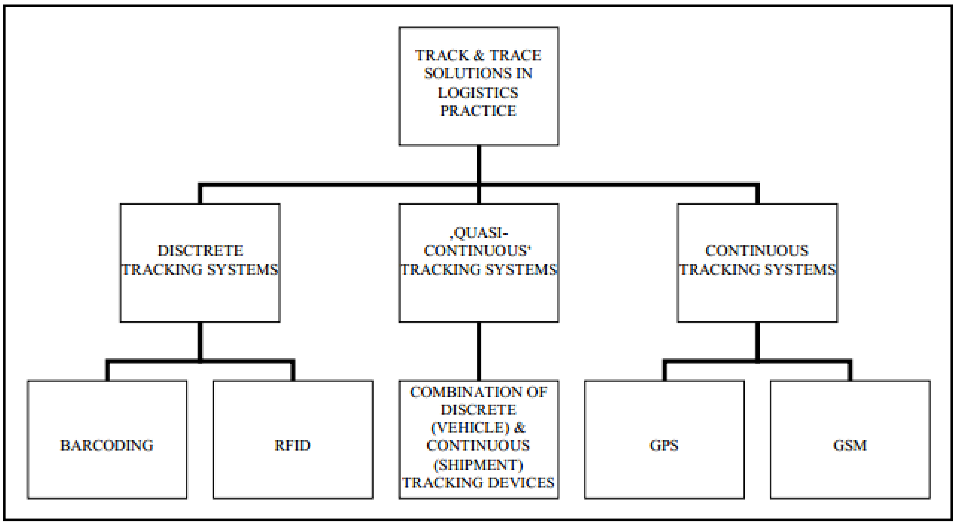


Figure 3. Categorization of tracking solutions in logistics practice (Source: Kandel and Klumpp, 2012)

The first category of distinguished tracking systems is called *discrete* due to the fact that barcoding and RFID technologies only offer geographical positions when the tagged shipments are located near fixed reading installations. It is not clear what is happening to the shipment between two reading points, therefore these both track and trace solutions can only be described as ”event monitoring”.

Continuous tracking solutions make it possible to localize shipment positions at any time; however tracking by using the technology of mobile telephone transceiver stations (GSM) is not very common. This technology is not feasible for logistics applications due to high variation in localization accuracy (Kandel and Klumpp, 2012)

When using GPS, the actual position is defined continuously by the use of GPS signals. GPS modules calculate the distances to a number of satellites, for this reason the shipped goods can be localized anytime and with a satisfactory accuracy of a few meters.

Quasi-continuous tracking solution includes combination of a shipment based discrete tracking solution and vehicle based continuous tracking solution. (Kandel and Klumpp, 2012) The disadvantage is that this way a “virtual connection” between vehicle and shipment is necessary and it is not feasible for networks in which different logistics service providers execute the transport, since it has to be guaranteed that all vehicles used in the transport chain are equipped with an on-board telematics system (Hillbrand and Schoch, 2007).

In order to compare advantages and disadvantages of different kinds of tracking solutions, the background and main principles of barcoding, GPS/GSM tracking and RFID technology are presented in following 1.1.3 – 1.1.5 sections.

1.1.3 **Barcodes**

According to GS1 (2015), barcodes are symbols that can be scanned electronically using laser or camera-based systems. They are used to encode information such as product numbers, serial numbers and batch numbers; barcodes play a key role in supply chains enabling to automatically identify and track products as they move through supply chain. According to Roman et al (2013), currently there are three generations of barcodes, as it is displayed in Figure 4.

- *First generation barcodes* (a) are linear or one-dimensional barcodes such as the Universal Product Code (UPC) that are made up of lines and spaces of various widths that create specific patterns.
- *Second generation barcodes* (b) are two-dimensional (2D) barcodes, mostly used for mobile devices. 2D barcodes has more advantages when compared with 1D barcodes: it can contain more information, it is more secure, easy to transmit and easier to read. 2D

barcodes are used in a wide range of industries, from manufacturing and warehousing to logistics and healthcare (GS1, 2014).

- *Third generation barcodes* (c) are called High Capacity Colour Barcode (HCCB) and was just recently developed within Microsoft Research. It assists in identifying commercial audiovisual works such as motion pictures and video games (Microsoft Research, 2015).

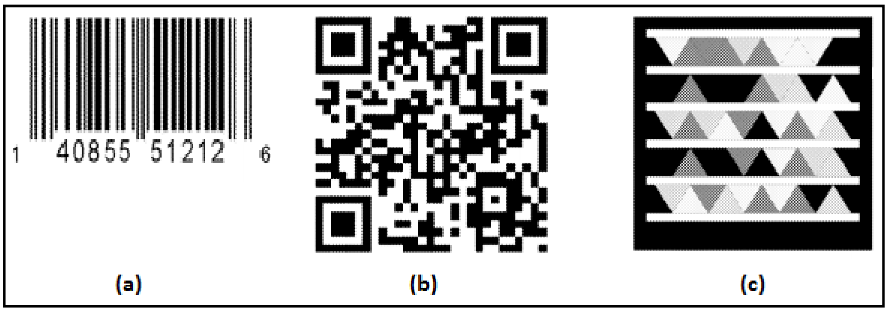


Figure 4. Examples of first (a), second (b) and third (c) generation barcodes (Source: adapted by author from Roman et al, 2013)

The use of barcode technology has proven its effectiveness in a number of industries, such as retail and manufacturing; this is due to ability to assist in organizing, storing, retrieving and making use of huge amount of data in an efficient manner.

1.1.4 **GPS and GSM**

The development of mobile tracking technology focuses on two principal technologies: *global systems for mobile communication* (GSM) and *global positioning systems* (GPS). According to Malladi and Agrawal (2002), GPS is space-based radio positioning system that provides 24-hour, 3-dimensional position, velocity and time information to suitably equipped users anywhere on the surface of the Earth. GPS can provide service to an unlimited number of users since the user receivers operate passively (i.e., receive only) (Kaplan and Hegarty, 2006) The US began the GPS project in 1973; GPS was originally intended for military applications, but in the 1980s the government made the system available for civilian use. There are no subscription fees or setup charges to use GPS (Garmin, 2015).

Two levels of navigational accuracy are provided by the GPS: the *Precise Positioning Service* (PPS) and the *Standard Positioning Service* (SPS). GPS was designed, first and foremost, by the US Department of Defence as a United States military asset; therefore, the PPS is available only to authorized users, mainly the US military and authorized allies.

SPS is available worldwide to anyone possessing a GPS receiver. Therefore PPS provides a more accurate position than does SPS (Bowditch, 2002).

GPS system has been widely used for tracking and monitoring purposes in logistics and in many other industries as well.

Global System for Mobile (GSM) is a second-generation cellular system standard that was developed to solve the fragmentation problems of the first cellular systems. It was first introduced into the European market in 1991 and is now the world's most popular standard for new cellular radio and personal communications equipment throughout the world (Gu and Peng, 2010).

In logistics GSM can be used in combination with GPS as a mobile vehicle tracking system that has two parts: a mobile vehicle unit and a fixed GSM base station. The mobile vehicle unit, attached to the vehicle, has a GPS module through which the vehicle's position is monitored via satellite and GSM technology is used to transmit that information to the base station.

Table 3. Principle differences of GPS/GSM devices (Source: adapted by author from Stopher, 2009)

	GPS	**GSM**
Availability of signals for positioning	Generally requires clear view and no solid objects (buildings, mountains) in sight or tunnels for the signal to pass through.	Works equally well in rural and urban areas.
Positioning accuracy	Provides position information in ±5m accuracy.	Most accurate positioning in dense urban areas; least accurate positioning in remote areas. However, not better than ±40m.

The principle difference between GPS and GSM devices is the accuracy of positioning and the availability of signals for positioning (Stopher, 2009). GPS system is very precise, providing position information in ±5m accuracy; however it requires special conditions for the signal to pass through. GSM is less accurate in determining positions than GSM, it mostly depends on how closely base stations are spaced.

Due to these differences GSM and GPS systems can be used together as each other's supplement to ensure maximum benefits.

1.1.5 RFID

The interest in RFID technology is high and still increasing; the idea and basic technical developments of RFID has been evident ever since the beginning of 20th century; however only in 1960‘s-1970‘s these ideas actually became reality (Landt, 2001) and marked the beginning of RFID diffusion into many commercial areas.

In 1960‘s the electronic article surveillance (EAS) (equipment to counter theft) was developed and it is considered to be the first and most widespread commercial use of RFID (Landt, 2001). In 21st century RFID technology is used in many more industries, even though according to Sarac et al. (2010) it is more beneficial for retail, healthcare, textile, automotive and luxury goods sectors. According to Marino and Merino (2012), RFID is the third evolution on asset tracking by optical reading technology, from Bar Codes in the beginning and Quick Response (QR) codes after it.

Over the time RFID technology has been defined in a similar way by many researchers, as it is displayed in Table 4.

Table 4. Definitions of RFID technology (Source: created by author)

Year	Author(s)	Definition
2003	McCarthy et al (quoted in Domdouzis et al, 2006)	Radio-Frequency Identification (RFID) technology is a wireless sensor technology which is based on the detection of electromagnetic signals.
2003	McFarlane et al, (quoted in Sarac Aysegul and Dauzere-Peres, 2010)	Radio frequency identification (RFID) is an automatic identification and data capture technology which is composed of three elements: a tag formed by a chip connected with an antenna; a reader that emits radio signals and receives in return answers from tags, and finally a middleware that bridges RFID hardware and enterprise applications
2006	Wyld, (quoted in Tajima, 2007)	RFID is an automatic identification (auto-ID) technology, which identify items and gathers data on items without human intervention or data entry.
2009	Gaukler et al.	Radio Frequency Identification (RFID) is a wireless (contactless) identification technology for objects.
2014	Shian-Jong Chuu	A wireless automatic identification, data collection and storage technology which mainly consist of three components: tags, readers, and middleware that bridge RFID hardware and enterprise applications. Through radio waves, RFID technologies provide a real-time communication with numerous objects at the same time at a distance, without contact or direct line of sight.

To summarize, in the 21st century literature RFID is mostly defined as a wireless identification technology that does not require human intervention and consists of three main elements: a tag connected to an antenna, a reader and a middleware system. Figure 5 displays all these components of a RFID system and how they are linked with each other.

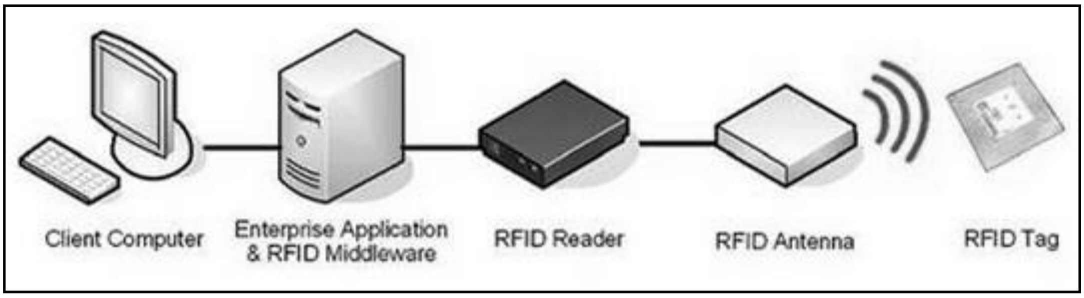


Figure 5. Basic components of an RFID system (Source: Kwok, Tsang & Cheung, 2008)

According to Adgar et al (2007), a RFID tag is a compact and small silicon chip, containing memory, modulator and antenna. Based on reading method there are two kinds of tags: passive and active. Passive tags are powered by reader's magnetic field; this kind of tags is used most widely due to its low cost, long life and small size when compared to active tags. Active tags are self-powered by internal battery and are mostly used when high-speed identification in a long distance area is required.

The second key component of RFID system is RFID reader. It emits low-powered RF signal to activate passive tags, identify tags and transfer information to and from a tag.

The last key component is RFID middleware, which is computing software that connects RFID technology with information distribution systems (Adgar et al, 2007).

RFID technology is based on EPC codes: an Electronic Product Code (EPC) is a universal identifier that gives a unique identity to a specific physical object. This identity is designed to be unique among all physical objects and all categories of physical objects in the world, for all time (EPC information, 2013). In most cases EPC codes are encoded on RFID tags; the structure of an EPC code is displayed in Figure 6.

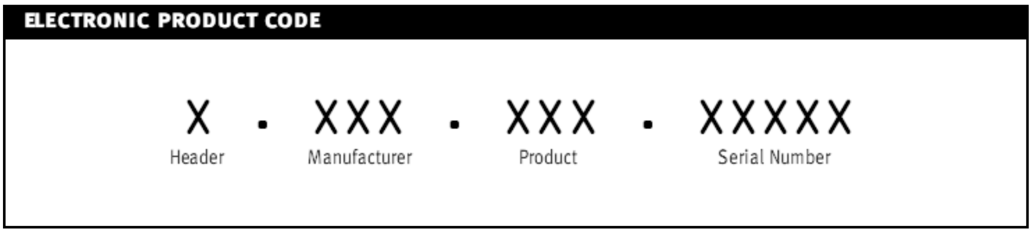


Figure 6. Electronic Product Code structure (Source: Sarma et al., 2001)

The basic format of an EPC code consists of Header (Figure 6 "Header"), which identifies the length, structure, version, and generation of the EPC; EPC Manager Number (Figure 6 "Manufacturer") that identifies the entity responsible for maintaining the subsequent partitions; Object Class (Figure 6 "Product") that identifies a class of objects and also Serial Number (Figure 6 "Serial Number") which allows each tagged item to be uniquely identified (EPC information, 2013).

The application and standardization of EPC use is managed by EPCglobal, a division of GS1 organization. The Header and EPC Manager Number parts of EPC code are assigned by EPCglobal, whereas Object Class and Serial Number are assigned by EPC Manager Owner (EPC information, 2013).

As mentioned before, EPCglobal is also developing RFID-related standards, which define key characteristics of different RFID systems. Lack of internationally unified standards is a well known problem for RFID users; ISO and EPCglobal are developing two complementary initiatives in RFID standardization; however their approaches differ in few aspects.

Table 5. ISO vs. EPCglobal RFID standards (Source: adapted by author from Gerst et al., 2005)

Characteristics	ISO	EPC Global
Approach	High level, generic approach, focusing not on the data itself, but on how to access it.	Specific, focuses on the data itself.
Air interface	Covers the entire range of frequencies.	Only UHV frequency.
Chips	Bigger, smarter, active chips – more expensive.	Smaller chips – cheap enough to make economic sense for the package good industry.

As it can be seen in Table 5 the attempted standardization of RFID technology by ISO and EPCglobal differs in its approach. According to Gerst et al. (2005), ISO RFID standards cover four areas: technology, data content, conformance and performance and application standards: it is also claimed that ISO standards are generic, being able to be supported by any system in any context, irrespective of the data that is being carried. EPCglobal, on the other hand, is more specific than ISO, since EPC standards describe the tag and the air interface depending on the data being carried; these standards are much more limited in their scope (Gerst et al., 2005). EPC offers more specific standards oriented towards the users of RFID technology, whereas ISO is more oriented towards the manufacturers of RFID tags.

One of other concerns that follow RFID technology is also the issue of privacy and security. RFID tags contain vast amount of information about the product handling history, therefore competitors might obtain confidential information about supply chain practices (Hinkkla, 2010). Theoretically it is possible to break the RFID code and receive information, or even change the information of the tag, The ongoing standardization of RFID technology, security threats and unclear benefits of its usage prevents many companies from shifting to this technology when there are other possible alternatives with clearer outcomes.

1.1.6 Barcoding, GPS, GSM and RFID technologies in logistics

As it was presented in 1.1.3-1.1.5 sections, barcoding, GPS, GSM and RFID technologies has different features and different advantages and disadvantages when tracking and tracing of goods is considered. In order to evaluate which track and trace solution is the most promising in logistics sector, a more detail comparison of barcoding, GPS/GSM and RFID technologies will be presented further on.

Table 6 displays a thorough comparison of barcoding and RFID technology.

Table 6. Comparison of Bar Code Labels and RFID Tags (Source: Sheikh, 2013)

Operations	Barcode	RFID EPC Tags
Efficiency	• Reads one tag at a time; • Line of sight required; • Action required by scanner operator.	• Reads multiple tags simultaneously; • No line of sight required; • Action not required by operator, but does accommodate on-demand identification with a handheld reader.
Durability	• Paper labels are easily; damaged or obscured by oil and/or dirt; • Once damaged it cannot be repaired.	• RFID tags can be matched to the application needs, providing the right level of durability for specific environments.
Data Capacity	• Limited amount of data.	• Significantly greater capacity enabling the storage and capture of more detailed and relevant information.
Flexibility	• Static information – Write once; • Tags are not reusable; • Standard technology – with a barcode reader a barcode can be processed anywhere in the world.	• Dynamic information – Ongoing read/write capacity enables creation of continual records; • Tags are re-usable; • RFID might struggle to pick up information when passing through metal or liquid.
Security	• Information is usually printed on the label with the barcode; therefore it can be more easily reproduced/ forged.	• Information is encoded; password protected or set to include a feature that removes data permanently.
Uniqueness	• Barcode can only identify a class of goods.	• RFID tags and their associated serial identification number provide unique serialization.

According to Table 6, the most important differences of barcoding and RFID technology lies in the efficiency, data capacity, flexibility and security of these track and trace solutions; RFID technology seems to have a stronger position when compared with barcoding. The ability to scan without line of sight proved to be the key advantage of RFID over conventional barcode scanning. However, for some SME organisations the capital investment and maintenance cost of RFID can be too much (Mo and Lorchirachoonkul, 2010). These high initial implementation costs of RFID technology stimulated the investigation of alternative track and trace solutions; one of such alternatives is the Global Positioning System (GPS).

Since late 1990’s, it has been a common trend for third party logistics companies to incorporate GPS technologies via mobile data networks such as GSM or GPRS to track vehicles and drivers (Mo and Lorchirachoonkul, 2010). The biggest advantage of GPS system in logistics is its accuracy – where RFID technology can register an event only when a tag passes RFID reader, GPS can trace goods globally with 10+ meters accuracy. However, according to a study by the Pennsylvania University RFID Study Group (2006), the major issue in the use of GPS for goods tracking in supply chains is the difficulty of system interoperability: the only key data being transmitted over the mobile network is the GPS data. Most GPS solutions would incorporate mapping database which allow users to locate the vehicles’ locations. Since the mapping database is proprietary to the GPS software, it is inaccessible to any other applications. This makes it impossible to provide accurate interpretation of the GPS data in the map (Mo and Lorchirachoonkul, 2010).

Additionally, once GPS-tagged goods enter supply base/warehouse/factory GPS does not provide enough precise information anymore to be considered useful, even though this technology is of high value when tracking vehicles with goods in transit. GPS and RFID technologies are to some extent overlapping, but even though GPS main advantage over RFID is that GPS system can provide real time data about item location, whereas RFID can only provide the data where and when the item was last seen in the system, GPS is more likely to be deployed in tracing high cost items, whereas RFID can be used both for cheaper and more expensive items tracking.

To conclude, each of considered track and trace technologies has its own advantages and disadvantages. According to Stackpole (2012), companies are not likely to choose between barcode, RFID or GPS/GSM, but rather come up with a new trace and track strategy that incorporates a mix of these technologies. However whereas barcodes can provide accurate information about inventory levels and GPS/GSM technology allows to trace and track vehicles with goods in transit in real time, RFID technology due to its efficiency, security and flexibility can provide information about goods both inside supply bases/factories/warehouses and out in transit; additionally, as the research of White et al. (2007) confirms, when compared with barcoding "RFID can deliver measurable operational benefits: shorter cycle times result in more throughput, productivity benefits and lower product search times". These considerable benefits make RFID technology superior when compared with barcoding and GPS systems.

1.2 The management of Returnable Transport Items (RTIs) in supply chains by using RFID technology

Returnable transport items (RTIs) stands for a variety of reusable packages, such as containers, bins, pallets and etc. used for goods transportation throughout the supply chain (Ostman, 2013). RTIs have an increasing importance for daily logistics operations: it has been introduced in many different industries due to the advantages RTIs offer over traditional single-use packaging (Hellström and Johansson, 2010). RTIs do not only protect the goods and facilitate handling and storage operations, but also increase the efficiency of the whole supply chain.

An increasing issue in RTIs management is the lack of visibility of RTIs-related operations, which results in more complicated decision making and responsibility allocation among involved parties and emerging costs from high loss rates, breakages and unavailability of RTIs (Ilic et al., 2009).

To increased visibility in supply chains RTI pool owners are using RFID technology to trace and track (mostly) high-value RTIs. Nevertheless, RFID is becoming more and more popular in low-value and high-volume RTIs tracking too (Ostman, 2013).

The following sections will overview the role of RTIs in logistics, the adoption of RFID technology in managing RTI pools and its usage in RTIs maintenance processes. Following sections are meant to give an idea what are the challenges that RTI pool owners face and how can RFID technology increase the efficiency of operations by increasing the visibility of processes throughout the supply chain.

1.2.1 **Returnable transport items (RTIs) in logistics**

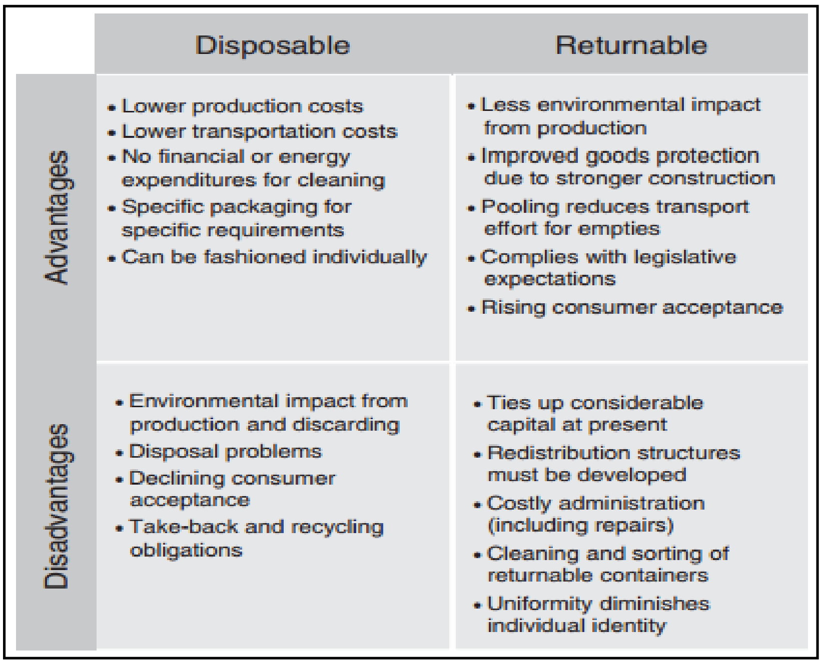
ISO standards (2005) define RTIs as: "all means to assemble goods for transportation, storage, handling and product protection in the supply chain which are returned for further usage, including for example pallets with and without cash deposits as well as all forms of reusable crates, trays, boxes, roll pallets, barrels, trolleys, pallet collars and lids.”

RTIs flow in so called ”closed loop supply chain” (CLSC), which is a combination of forward supply chain, where the RTIs flow from manufacturer to supplier to distributors and consumers; and reverse supply chain, where used RTIs are returned to manufacturers, where they go through a variety of maintenance processes and are returned to the supply chain for the further usage.

According to GS1 (2007), there are three kinds of processes for RTIs:

1. The supplier owns the RTIs and there are no special markings that make them specific to the supplier nor the RTIs are made to fit defined products. In this case, RTIs are exchanged one for one between all the actors of the supply chain.
2. The supplier owns the RTIs that are specific to the supplier of the contained goods. In this case, RTIs are to be returned to the supplier.
3. A pool operator owns the RTIs. A pool operator is a company that provides RTIs to suppliers and make sure that the quality and quantity of these RTIs match the supplier requirements. The pooling process includes getting the RTIs back from the delivery location and reconditioning before new use.

Hansen et al (2008) compares RTIs with disposable packaging systems in Figure 7.



	Disposable	Returnable
Advantages	• Lower production costs • Lower transportation costs • No financial or energy expenditures for cleaning • Specific packaging for specific requirements • Can be fashioned individually	• Less environmental impact from production • Improved goods protection due to stronger construction • Pooling reduces transport effort for empties • Complies with legislative expectations • Rising consumer acceptance
Disadvantages	• Environmental impact from production and discarding • Disposal problems • Declining consumer acceptance • Take-back and recycling obligations	• Ties up considerable capital at present • Redistribution structures must be developed • Costly administration (including repairs) • Cleaning and sorting of returnable containers • Uniformity diminishes individual identity

Figure 7. Advantages and disadvantages of RTI relative to disposable packaging systems (Hansen et al, 2008)

As the management of disposable packaging systems is getting more and more complicated, the importance of RTIs' management is increasing, especially considering lower environmental impact of RTIs compared with disposables.

However despite the fact that RTIs are considered greener and more cost efficient solution compared with so called single-use or one-way assets, RTIs management still faces few key problems. As Hellström and Johansson (2010) states, s single RTI can cost from as little as 10 euros, to as much as thousands of euros a piece; therefore it is not uncommon for the value of the RTI to exceed that of the goods it holds. Hence, an RTI fleet, which often represents a significant initial capital investment, may also represent a considerable operating cost for shrinkage.

Ostman (2013) states that with average annual shrinkage rate of anywhere from 3% to 9% and a breakage rate of 9%, RTI pools can cause large expenses. To solve this, companies spend money requiring additional logistics assets and hiring adequate labour to manage them. It is often not known, at any specific point in time, where the individual RTIs are and in what condition they are in. This limited visibility creates the tendency for people and organisations to feel less responsible for the proper management of RTIs. As a consequence, unnecessary costs resulting from high loss rates, breakages and unavailability of RTIs are generated which have a negative impact on the overall performance of the whole supply chain (Ilic et al., 2009).

Additionally, another problem related to the return of RTIs is that return flows are often difficult to estimate and therefore varies a lot (Kim and Glock, 2013). High return flow variation and uncertain timing complicates the planning of maintenance processes and purchasing of new items. Reasons for variations in return quantities could be damage, misplacement or theft; in addition, uncertain return times and return quantities may lead to stockout situations that may damage the reputation of the company (Kim et al., 2014).

Returnable transport items plays a significant role in supply chain management, however there are some important issues to be solved for each RTI pool manager in order for the business to be efficient and profitable. Increased supply chain visibility can considerably enhance RTI management and it is believed that RFID technology can prrovide many advanatages in this area.

1.2.2 The benefits of RFID technology in RTI supply chains

According to Hellström and Johansson (2010), the management of RTI pools would suffer without information systems which keep track of individual RTIs and present timely, relevant information on their whereabouts. RFID technology is considered to be a good tool for enhancing visibility throughout a supply chain and creating great benefits for the main stakeholders, displayed in Figure 8.

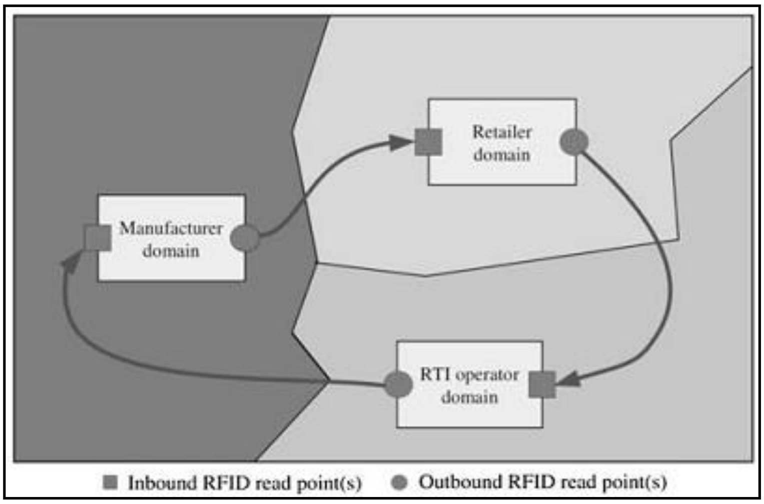


Figure 8. The three domains of responsibility and interest for RTI management (Source: Ilic et al., 2009)

According to Figure 8, main stakeholders in RTI management are Manufacturer, Retailer and RTI operator. As the figure implies, there are boundaries of responsibility between them, therefore with the implementation of RFID technology it is possible to establish accountability for each of the stakeholders. As it is displayed in Figure 7, a minimum of six RFID read points (three inbound and three outbound) should be established for all the stakeholders to successfully share information (Ilic et al., 2009) and trace and track RTIs.

Hansen et al (2008) proposes three RTI management task areas that can be supported by RFID (Table 7).

Table 7. RTI management task areas, supported by RFID (Source: adapted by author from Hansen et al, 2008)

Inventory management	Maintenance management	Circulation management
▪ maintaining master data (container type, manufacturer, volume, etc.); ▪ procurement (replenishment and expansion); ▪ reassessment as part of asset valuation; ▪ disposal; ▪ storage, sorting and supply.	▪ container cleaning; ▪ repair; ▪ modifications; ▪ life cycle documentation.	▪ circulation figure and rate; ▪ dwell time at each destination; ▪ availability of specific containers at each storage location.

According to Ostman (2013) and Ilic (2009) the implementation of RFID technology into supply chain brings benefits to all involved actors, however pool owners do experience the highest benefits. All these benefits are listed in Table 9.

Table 8. Benefits of RFID technology adoption into supply chain (Source: adapted by author from Ostman, 2013, and Ilic, 2009)

	RTI's pool owner-specific benefits	**Supply chain actor-specific benefits**
1.	The reduction in RTI pool size due to reduced shrinkage and optimized management, which can bring significant cost savings;	Faster authentication and counting of items since RFID does not require line of sight and multiple tags can be scanned simultaneously;
2.	Timely information of actual RTI stock;	Cost reduction;
3.	Reduced risk of non-availability of RTIs;	Easier evaluation of the number of RTIs held by each stakeholder;
4.	Optimisation RTI collection route;	RTI cycle time reduction;
5.	Decreased RTI losses;	Greater transparency in operations;
6.	More precise maintenance process es;	Greater predictability of the RTI flows in supply chain;
7.	Decreased damages of RTIs, since with RFID it is possible to pinpoint exactly what has happened with a RTI at each stop of the journey.	Decreased labour costs due to the automatic operations;
8.		Less human errors due to more accurate and automated processes;
9.		Information asymmetry between parties can be avoided;
10.		More accurate invoicing and improved customer service.

For some closed-loop supply chains that uses RTIs the implementation of RFID technology might be more beneficial than for others. Upstream oil and gas supply chain can be a good example of how logistics can influence overall business costs.

According to ATKearney (2012), the upstream oil and gas businesses are facing new logistics challenges with the move of oil and gas production sites to more remote and more difficult locations, such as ultra-deepwater or Arctic. Any unplanned downtime in the platforms due to lack of needed equipment can result in major losses and have grave consequences for the business. The shipments to oil and gas production sites are made daily and their types vary a lot, therefore Chima (2007) claims that very few other industries can benefit from maximizing supply chain efficiencies more than the oil and gas industry.

Even though historically primary focus of oil and gas companies has been on the availability of materials rather than costs, this trend was driven by risk aversion, lack of tracing systems, and complicated supply chains. Considering that logistics costs for upstream oil and gas supply chains typically represent up to 15% of total operating expenditures and can be as high as 30% (ATKearney, 2012), managing to reduce these costs even by few percents might mean considerable savings for the company, and that can be reached with the implementation of RFID technology in the supply chain.

Figure 9 displays the upstream oil and gas supply chain on the Norwegian continental shelf.

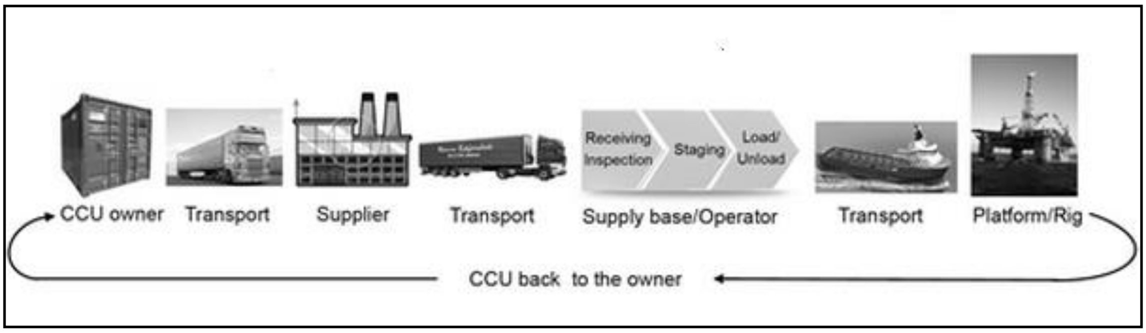


Figure 9. The upstream oil and gas supply chain on the Norwegian Continental Shelf (Source:Hodgson, 2014)

Figure 9 illustrates the movement of CCU thorough the upstream oil and gas supply chain: the CCU is transported to the supplier from the CCU owner, and then it is again transported to the supply base where it is inspected/staged/loaded/unloaded and transported to the platform/rig. Then CCU is returned to the CCU owner for maintenance processes and is ready to start new cycle.

With the assistance of RFID technology a CCU can be traced and tracked throughout the whole cycle. It does not only provide valuable information about the whereabouts of the CCU to CCU owner at any moment of time, but also enables all the other actors in the supply chain to track the movement of CCU and therefore facilitates planning.

To conclude, returnable transport items are being introduced in increasing number of industries; the integration of RFID technology in RTI supply chains creates many different advantages. For the upstream oil and gas business precision is a critical factor when considering the supply of RTIs to platforms/rigs, therefore RFID technology does have a huge potential in facilitating planning processes and increasing the level of transparency and visibility in the supply chain.

1.2.3 Maintenance of RTIs by using RFID technology

RFID technology can not only be used for the forward part of a closed-loop supply chain management, but it can also be applied in the internal movement of goods in the company, particularly in the maintenance processes.

According to Muller, Richter and Plate (2008), there are two key factors that are identifiably driving the adoption of RFID in maintenance:

- Maintenance drivers (e.g lack of transparency in maintenance processes, lack of information to determine a proper maintenance strategy, maintenance costs);
- Information technology innovations (e.g. mobile terminals, tablet computers, wireless communication, component miniaturization, embedded systems with sensors).

Ilic et al. (2009) claims that RFID application in maintenance is most valuable in counting, grading and sorting returned RTIs upon receipt and determining corresponding repair actions accordingly. Since current processes are manual, time consuming and error prone, the application of RFID could considerably improve it; with the usage of RFID it would be possible to count returned RTIs automatically and make grading and sorting processes semi-automatic. Complete maintenance history files on maintenance assets could be kept automatically, starting with procurement or storage, commissioning, concrete utilization and its intensity. RTIs, based on their previous usage and age could be quickly identified and maintenance facilities could systematically plan and schedule future maintenance processes.

These and other functionalities of RFID usage in maintenance processes were summarised by Muller, Richter and Plate (2008):

- Identification of maintenance assets or components;
- Storage of information on maintenance assets;
- Determination of the condition of maintenance assets over time and thorough processes;
- Localization of mobile assets;
- Automated data acquisition and exchange with other information systems.

The main overall benefits of RFID technology in maintenance processes are:

- Increased maintenance staff productivity;
- Reduced manual (multiple/repeated) data acquisition activities and the associated error sources;
- Automated knowledge management about asset condition by automatically acquiring data directly on assets;

- Reduced error sources in processes;
- Elimination of paper documents, printing costs and format changes;
- Options of integrating third parties and data exchange with them. (Muller, Richter and Plate, 2008)

As it was discussed, RFID usage in maintenance can create valuable benefits for RTI pool owners, making maintenance processes more efficient and transparent. The ability to track and trace individual RTIs through their life cycle and see where and how RTIs were utilised also enables RTI pool owner predict and plan maintenance processes in advance, what can shorten time period that RTIs need to spend in maintenance.

2.0 Research methodology

This section presents the company that agreed to collaborate on this research, "Swire Oilfield Services", and to describe what kind of problems company currently faces in RTIs' management. Detailed research problem and main objectives of this study will also be presented, as well as the relevance of this study, data collection methods and main methodologies that will be used.

2.1 Case study

2.2 Company presentation

"Swire Oilfield Services" is a part of the Swire Group; it was established in 1979 and is currently the world's largest supplier of special offshore cargo carrying units (CCUs) to the global energy industry and is a leading supplier of modular systems, offshore aviation services and fluid management (Swire Oilfield Services, 2015).

The company has a presence in all major oil and gas regions with large operations in Northern Europe, North America, West Africa, Asia Pacific and Brazil; it is operating in 31 country and has 36 bases around the globe. "Swire Oilfield Services" offer its customers the possibility to use track and trace technologies based on both GPS and RFID systems through their innovative system OverVu®. Customers are offered to monitor the location and compliance status of both rented and customer owned assets. Currently "Swire Oilfield Services" owns a pool of over 60 000 rental assets.

In Norway "Swire Oilfield Services" provide a range of modular systems for rent or sale, chemical handling and offshore aviation services. The company has established 8 bases in different locations in Norway that employs 240 staff members and operates 16 000 cargo carrying units, from which 3 000 units are tagged with RFID tags. The product fleet covers all major product areas of containers, tanks and baskets.

The Tananger base outside Stavanger is the head office for "Swire Oilfield Services" in Norway. The base employs 180 staff members and all company's project activities are located there together with the main chemical handling facility. All major repair and testing facilities are also located in Stavanger.

2.2.1 External visibility

As it was previously mentioned, “Swire Oilfield Services” has a strong presence in all major oil and gas regions and is an important supplier or cargo carrying units for many oil and gas companies. The company has generated around 600mln. NOK revenue in 2014, from which around 65% was generated by rental operations; therefore it is clear that successful management of RTIs is a crucial part of company’s business.

In order for “Swire Oilfield Services” to enhance the management of RTIs it is important to have visibility and transparency of the whole supply chain. External supply chain visibility in “Swire Oilfield Services” is provided by a software application platform called “OverVu®”, which provides end-users with the ability to identify, locate and track equipment, viewing asset location and status. The platform provides built-in support for a range of identification and data capture technologies, from barcodes to GPS (Swire Oilfield Services, 2015). “OverVu®” enables users to:

- Create a customised dashboard for specific needs;
- Query asset location, history and status;
- Receive alerts on asset movements;
- Flexibly define alert conditions;
- Create geo-fencing boundaries using an intuitive point and click, stringing technique;
- Simply hover over an area or individual asset to expose pertinent information;
- Access asset certification documents and contents information;
- Create structured reports, including graphical representations of key performance indicators such as asset utilisation (Swire Oilfield Services, 2015).

“OverVu®” system was launched in 2014 and is the first full-service track and trace solution in the industry; in Norway “OverVu®” tracks around 3000 assets on Norwegian Continental Shelf (NCS) by Auto ID.

Additionally, “Swire Oilfield Services” in Norway is also participating in EPIM Logistics Hub (EHL) project that will connect oil companies operating on the Norwegian Continental Shelf and automatically track goods in the supply chain for offshore facilities by using RFID technology. EHL will enable sharing tracking information of cargo carrying units and their content during transportation; contribute to higher efficiency and quality of the logistics operations (EPIM, 2015).

EPIM Logistics Hub will enable such improvements:

- Simplified management of the CCU pool on hire;

- More effective search for lost and delayed goods;
- Less waste of time and resources;
- More predictable planning and better plans;
- Improved HSE: fewer unnecessary lifts, fewer critical delays (Bjordal, 2014).

EHL will enhance “Swire Oilfield Services” visibility over external part of supply chain in Norway; companies participating in EHL will share only external events, such as “entering” or “leaving” of RTIs from the base; such knowledge will improve planning possibilities for the company.

The joint usage of “OverVu®” and EPIM Logistics Hub for “Swire Oilfield Services” in Norway will provide visibility over external processes of RTIs’ management in both global and national perspectives; however it will still lack visibility over company’s internal processes. Having visibility over processes that happens to RTIs inside “Swire Oilfield Services” base from the moment RTI is returned to the base until the moment it is leaving the base again, has many potential benefits for the company.

2.2.2 Internal visibility

In the reverse supply chain part of a closed-loop supply chain, RTIs are returned to the pool owner for maintenance processes, done in internal supply chain of the company. In “Swire Oilfield Services” case the company does not have enough visibility over the internal part of the supply chain.

When RTIs are returned to the base they must go through return inspection (RI), during which it is determined what kind of (if any) maintenance processes a unit requires. It is not possible to determine in advance what kind of processes will be required before unit physically reaches the base; additionally, it is not possible to determine how long one unit will need to spend in any of maintenance processes; it might take one hour or one day to be processed through one or through all maintenance processes.

Another complicated issue in “Swire Oilfield Services” is the different nature of supply agreements between the company and its clients. Supply agreements in “Swire Oilfield Services” differ in their time management; some clients are renting units for a long term periods (up to few years), and some clients might request units on short notice, when RTIs must be prepared for delivery to the client in few hours period. Such short-notice deliveries complicate company’s ability to plan in advance what kind of units must be prepared for shipment. Additionally, as a result of short-notice hiring requests “Swire Oilfield Services” faces a problem when requested units must be delivered to the client, but there are no available units in the base to ship out, since suitable units are either being rented to other clients or are going through maintenance processes and cannot be used. In these situations “Swire Oilfield Services” has two options:

- To locate required units in other bases in Norway and have them delivered to the client;
- To rent required units from competing companies and deliver them to the client.

The first option is complicated due to considerably large distances between company’s bases is Norway and the landscape of the country, which prevents fast delivery of required units. “Swire Oilfield Services” is developing new solutions for joint RTIs’ management throughout all bases in Norway, but the development it is still in progress.

The second option is used much more often due to close location of competitor’s supply bases; however this option is very costly, since in this case “Swire Oilfield Services” not only loses money for renting the unit from the competitor, but it usually also costs more than what company gets from its client, since long term clients pay a discounted price for RTIs, but competitors rent RTIs for the market price.

Neither of these two solutions is perfect, but it is not possible to avoid short-notice hire in oil and gas industry, where emergency shipments do occur very often. For “Swire Oilfield Services” it is important to stay competitive and therefore flexible in the market in order to satisfy clients; improved management of RTIs through maintenance processes is also one of the solutions how the company could improve their customer service and not lose money.

2.3 Research problem, objectives, and unit of analysis

The main research question of this study is to investigate:

- Whether and how increased visibility in maintenance processes due to RFID technology could improve the performance of “Swire Oilfield Services” in RTI business?

The more detailed research sub-questions are:

- What is current “Swire Oilfield Services” maintenance performance?
- What effects could RFID application and increased visibility have on maintenance performance in “Swire Oilfield Services”?
- Are there any problematic areas in “Swire Oilfield Services” performance that could be improved by the adoption of RFID technology?

- What would be the recommendations to improve the problematic areas of company's maintenance performance?

The answers to these research questions will give an insight how maintenance processes in the company are done currently and what are the main problems/bottlenecks that occur during these processes; it will also present potential effects of RFID technology adoption in the system and suggest a possible action plan for the improvement of company's performance.

Objectives that were established for the research:

- To simulate current "Swire Oilfield Services" maintenance performance using "Arena" simulation software;
- To simulate possible "Swire Oilfield Services" maintenance performance using "Arena" simulation software;
- To estimate and evaluate how the adoption of RFID technology in maintenance processes could influence maintenance performance of the company;
- To identify whether assumed benefits of RFID technology for the management of RTIs can be justified.

The unit of analysis in this research is the company "Swire Oilfield Services". Company's inner and (to some extent) external processes will be discussed, simulated and compared, then conclusions about company's performance will be made.

2.4 Relevance of the research

The relevance of this research is partly considered in the literature review at the beginning of this paper. As it was previously mentioned, the scientific interest in RFID technology has been increasing for the past few decades and is only increasing nowadays due to the advancing adoption of the technology in various industries.

However despite this booming interest in RFID, there is still quite a lot of scepticism regarding this technology. Even if RFID industry experts and academic researchers argue that the RFID technology is a disruptive technology to transform supply chains into more efficient systems, skepticism remains that the RFID technology is an upgraded barcode system with a huge cost and little benefit (Shin and Eksioglu, 2014; Collins et al., 2010).

Moreover, there are not so many researches made on what effects RFID adoption might have on maintenance processes and whether it can improve company's performance this way. Such research angle is especially relevant for the upstream oil and gas industry, considering its business model, where efficiently managed RTIs are an inevitable part of company’s operational and financial success.

”Swire Oilfield Services” is a very suitable company for this case study, since it already has accumulated some experience by using RFID technologies in day-to-day business, and at the same time is also on the verge of adopting RFID on a wider scope in the business.

To conclude, studying the effects of RFID technology in maintenance processes might present possibilities for overall improvement of company’s performance that might as well be adaptable in other companies that operate pools of RTIs.

2.5 Data collection

Data that is used in the analytical part of this research was received directly from “Swire Oilfield Services”; the company provided both quantitative and qualitative data, regarding internal company’s processes, costs, key performance indicators and etc.

General qualitative data about “Swire Oilfield Services” business processes was acquired during an interview with Åsmund Krokstad, Solution Delivery Manager for Trace and Track Solutions and Manfred Vonlanthen, General Manager of “Swire Oilfield Services” in Norway. Åsmund Krokstad also provided deeper insights into company’s internal operations when it was needed.

Other data collection options were rejected due to various reasons:

- Collecting data by making questionnaires and surveying many companies in the industry was rejected due to the type of this research, since it requires to have very detailed information about inner processes in the companies, which are often kept confidential. Additionally, not many companies have sufficiently detailed data to be provided for this research.
- Making an experiment was also not an option, since reactions to a specific event would not give enough insight and data for answering the main research question of this research.
- A possibility to use only secondary data was also rejected since it would not provide sufficient amount and detailed enough data to make relevant conclusions.

2.6 Used software and theoretical background

All acquired data was processed either by Microsoft Excel (for general calculations), “Arena” simulation software (for simulating maintenance processes in the company with and without RFID technology), or by using Factory Physics formulas (for calculating company’s performance indicators).

“Arena” simulation software is used for discrete event simulations. Discrete event simulations allow quickly analyzing a process or system’s behaviour over time, ask “why” or "what if" questions, and design or change processes or systems without any financial implications (Arena simulation, 2015). Main advantages of ”Arena” simulation software are:

- Improving visibility into the effect of a system or process change;
- Exploring opportunities for new procedures or methods without disrupting the current system;
- Diagnosing and fixing problems;
- Reducing or eliminating bottlenecks;
- Reducing operating costs;
- Improving financial forecasting;
- Better assessment of hardware and software requirements;
- Reducing delivery times;
- Better management of inventory levels, personnel, communications systems, and equipment;
- Increasing profitability through overall improved operations (Arena simulation, 2015).

”Arena” simulation software is a valuable tool in replicating real life processes in companies. Simulations make it possible to look into possible outcomes of different scenarios and draw assumptions from these observations; therefore it is a very suitable tool for this research.

According to Hopp and Spearman (1996), factory physics is a systematic description of the underlying behaviour of manufacturing systems. Even though factory physics is targeted towards manufacturing companies, the main principles to some extent can be adopted to service industry as well. Hopp and Spearman (1996) also states that factory physics enables managers and engineers to:

- Identify opportunities for improving existing systems;
- Design effective new systems with control that are consistent with, not contrary to, their natural tendencies;
- Make the tradeoffs needed to coordinate policies from disparate areas into an environment of continual improvement.

Therefore factory physics can not only identify current system problems, but also suggest improvement possibilities. Factory physics is also a valuable tool in this paper in measuring and comparing ”Swire Oilfield Services” performance with and without RFID technology.

3.0 Research analysis

This chapter is meant to present the analytical part of this paper. It will present theoretical simplifications that were made in the case and an overview of company’s current maintenance processes. Moreover, this chapter will display and explain simulation models that were used to obtain results, and calculations using factory physics. All relevant comparisons of obtained results will also be discussed in this chapter, as well as recommendations for company’s future action plan.

3.1 Detailed description of the case study and its simplifications

3.1.1 **„Swire Oilfield Services“ internal processes and problems**

As it was discussed in previous chapter, the main problem that “Swire Oilfield Services“ face is the lack of internal supply chain visibility. This lack of visibility created a number of problems for the company, such as :

- RTIs in “Swire Oilfield Services“ are registered manually, by punching unit ID into a hand-held unit, what sometimes leads to wrong input, especially if a handled unit is out of coverage and the staff needs to write the unit ID on a piece of paper – the note is sometimes lost in the process and as a result the unit is left unregistered. Also, it happens that a unit is picked up by a customer out of the yard without being registered or a unit is stacked in the wrong order (Swire Oilfield Services operational presentation, 2014).
- Personnel have little visibility over the location of units in the yard, what leads to time consuming manual search. At the same time personnel has also no idea about what units are on the way to the base, being returned from the customers, or where a particular unit is in the system in real time.
- The maintenance process is also complicated, since fixed asset hires are prioritized, therefore when a big order comes it can disrupt standardized procedures and make a queue in some of the stations (Swire Oilfield Services operational presentation, 2014).
- Currently “Swire Oilfield Services“ is using Enterprise Resource Planning (ERP) system, however the staff of the company does not trust the system, therefore finished units are re-counted in order to confirm that the number of containers ready to be hired

is correct. Also, ERP does not give the user reports or any statistical analysis of the units and the processes the units are going through.

- Company’s management has a hard time evaluating company’s performance, since performance reports are difficult to export. There is no information on inventory turnaround being generated, as well as unit utilization level (Swire Oilfield Services operational presentation, 2014). Also, the management sets daily efficiency goals which could have a better foundation if historical statistics are used; however currently there is no way to generate it; therefore there is a clear need for an automated reporting system with a daily/weekly/monthly/quarterly data summary.
- There are issues with the inventory management as well. Currently inventory count in the company is done manually, 4 times a year. One such count costs 600 000 NOK, therefore the inventory count costs 2 400 000 NOK/year for “Swire Oilfield Services”, whereas with RFID technology these counts could be done instantly and with no costs.

All these problems for “Swire Oilfield Services” results into:

- Stock out situations due to the inefficient data capturing methods;
- Lost sales (and the need of cross-hire) due to the erroneous data and lack of traceability of the units in the yard;
- Lower utilization rate of the units due to lack of overview of the units;
- Excess buffer inventory;
- Billing delays;
- Lost revenue;
- Lost profit.

The recent launch of “OverVu” platform in 2014 did bring some benefits for “Swire Oilfield Services”, the company’s subsidiary in Norway is now able to track 3000 assets on Norwegian Continental Shore by using Auto ID technology, however it still did not create sufficient visibility over company’s supply chain. It can be expected that the benefits of “OverVu” system will be exploited in the future and more assets will be tracked and traced in Norway.

The current fleet of RTIs in “Swire Oilfield Services” in Norway consists of four main groups of items: Containers, Tanks, Baskets and Skips. The fleet is on average renewed by 10% every year.

Ideally around 85% of all units in the company are being utilised all the time; the rest ~15% can be considered as a buffer stock, even though the majority of these units are usually going through maintenance processes. The usual buffer stock contains 10% of Containers, 5% of Tanks and 2% of Baskets. There is no buffer stock for Skips kept.

Maintenance processes in “Swire Oilfield Services” are performed during a normal work day, from 8:00 till 16:00, five days per week. There is a number or workers performing different tasks.

One of the simplifications made in this research is that only Tananger base in Norway will be discussed; this base is the headquarters of “Swire Oilfield Services” in Norway and it also has the highest activity in terms of RTIs management in the country.

The current “Swire Oilfield Services” maintenance process map in Tananger base is displayed in Figure 10.

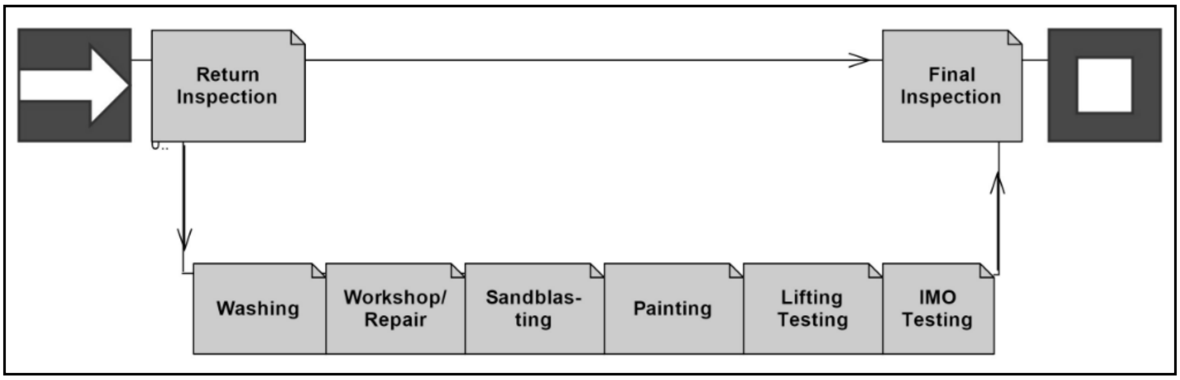


Figure 10. Maintenance process map in ”Swire Oilfield Services” Tananger base (Source: created by author)

Figure 10 displays company’s internal maintenance processes done for RTIs. The ➡ marks the unit return point to the base, based on the records provided by “Swire Oilfield Services” management one unit is returned to the base every 7.5 minutes, even though it can fluctuate from 1 unit/5.5 minutes till 1 unit/11 minutes.

The overall maintenance process consists of 8 stations: Return Inspection, Washing, Workshop/Repair, Sandblasting, Painting, Lifting Testing and IMO Testing.

Return Inspection is done to all units that are returned to the supply base; it takes 5-15 minutes for an inspector to visually evaluate a unit and decide what processes are needed to be performed on it, if any. Around 50% of units do need some maintenance processes done; the other 50% of returned units get Final Inspection and are ready to be rehired.

Washing is done for approximately 44% of units that needs maintenance. Before Washing units are checked for waste; if there is any waste inside a unit they are sorted and cleaned. The unit is then washed and dried, and sent for further maintenance process if needed. It takes from 30 minutes to 1 hour and 30 minutes to wash a unit, depending on the amount of waste inside it.

Workshop/Repair is done for around 80% of units that needs maintenance; after the workshop or repair the unit is sent to further maintenance processes if needed. It takes from 1 to 5 hours, 3 hours being the most common value to repair a unit or do a workshop on it.

Sandblasting and Painting are both required for approximately 5% of returned items that needs maintenance. It takes from 1 hour to 1 hour and 20 minutes for one unit to be painted; it takes from 1 hour 45 minutes to 3 hours for a unit to be sandblasted.

Lifting Testing is done for around 50% of units that require maintenance, and IMO testing is done for around 2.8% of units that require maintenance. It takes around 40 minutes to perform Lifting Testing on a unit; IMO Testing requires 5 hours for each unit.

Final Inspection is not a maintenance station on its own; it must be performed at the end of maintenance processes, therefore if Lifting Testing is the last maintenance station for the unit, then Final Inspection will be performed in Lifting Testing station, if Painting is the last station – it will be performed at that station and so on. It takes from 5 to 15 minutes to perform Final Inspection; after a unit is approved it is marked as “available” and put in the yard, what in Figure 9 is marked by ▣ sign.

As it was mentioned in previous chapter, unit might need only one of maintenance processes done, a few or all of them; it cannot be determined earlier than when a unit is going through Return Inspection.

Only one worker is required to perform a specific maintenance task on one unit in each maintenance station; nevertheless there are a number of workers working in each of the stations in Tananger base. In Washing station there are 16 workers, 2 workers in Sandblasting, 22 in Repair/Workshop, 3 in Painting, 25 in Lifting Testing and 8 in IMO Testing. Final Inspection is done by one of these workers, depending on which maintenance station is the last for the unit before being ready for hire again.

Tananger base owns 6 different trucks/forklifts meant to transport units within the base. The forklifts have different characteristics, from speed to tonnage, age and fuel consumption and etc. The way maintenance stations and RTIs are placed in Tananger base is also a concern for “Swire Oilfield Services”, since current arrangement interferes with efficient forklift activities.

3.1.2 Case simplifications

There are a number of simplifications and assumptions made in order to make it easier to translate this case study into a simulation model with “Arena” simulation software, and to make the model more comprehensible. These simplifications and assumptions are:

- From eight possible “Swire Oilfield Services” bases in Norway only the Tananger base in Stavanger will be considered in this research. This base has the highest activity in RTIs’ rental operations and is strategically the most important base in Norway.
- It is assumed that once a unit enters the maintenance process it does not leave it until it is fully repaired and prepared to be hired again.
- It is assumed that a normal work day lasts 8 hours (8:00-16:00) without breaks; a normal work week is Monday to Friday.
- It is assumed that units are returned to Tananger base only during normal work hours.
- All the forklifts/trucks in the base are similar and can lift/transport only one unit at a time.
- The statistical data that is used in simulation models are derived from other statistical data provided by “Swire Oilfield Services” management; only data from October, November and December of 2014 is used.
- Even though there are some RTIs tagged with RFID in Tananger base, in the first simulation model it is assumed that there are zero units tagged with RFID. It does not distort the results of first simulation model.

3.1.3 Potential RFID effects on “Swire Oilfield Services“ performance

Wider adoption of RFID technology in this particular “Swire Oilfield Services” case could have various potential effects on company’s operational characteristics and logistics processes. Such effects are listed in Table 9.

Table 9. Potential effects of RFID technology on ”Swire Oilfield Services” operational characteristics and business processes (Source: created by author)

Improvement	Effect	Outcome
• Real time information about RTIs stock levels	• Improved visibility and management of RTIs stock	• Decrease in inventory levels; • Increase in RTIs’ availability; • Decrease in stock-out situations; • Reduced number of cross-hire situations; • Increase in vehicle utilization.
• Increased visibility	• More predictable RTI	• Improved planning and scheduling of

of RTIs being returned to the base	return flows	maintenance processes; • Decrease in inventory levels; • Increase in RTIs' availability; • Decrease in stock-out situations; • Reduced number of cross-hire situations.
• Unique identification of individual RTIs	• Decrease in inventory discrepancies; • Improved accountability of stocks; • Improved visibility over maintenance processes; • Improved tracing of damage sources;	• Reduced errors in inventory count; • Improved order management; • Improved identification of excessive holding areas; • Decreased number of damaged RTIs; • Reduced maintenance cycle time;
• Storing and tracing of RTIs maintenance history	• Better overview of RTIs' damage history;	• Improved scheduling and planning of maintenance processes; • Reduced maintenance cycle time; • Increased useful lifetime of RTIs.
• Automatic read and count of RTIs	• Elimination of manual inventory count procedure	• Improved inventory count procedure; • Decreased labour costs.

Table 9 displays potential effects of RFID adoption in "Swire Oilfield Services" supply chain from an internal perspective. With the adoption of RFID technology all these effects can become visible, some might appear instantly and some might take time, and some might be more visible than others. Nevertheless, all these effects can create positive change in the company and its supply chains.

3.2 First simulation model

To get some statistical data about "Swire Oilfield Services" maintenance processes a simulation model using "Arena" simulation software was created. The model was created based on real company's activities and resources; therefore it does correspond to company's real life maintenance processes. The statistics that are included in the model were provided by "Swire Oilfield Services"; RFID technology is not used in this model.

Running this model provides various statistical data that will be presented further on; this data will be analysed in the context of Factory Physics.

3.2.1 **Model overview**

The overall image of the first simulation model is presented in Figure 11. The model is separated into five different areas, marked by different colours – green, pink, yellow, blue and grey. Each of these areas will be discussed separately; additionally an overview of transportation system in the simulation will be presented.

3.2.1.1 Model areas

Green area

The model starts with a CREATE model, which marks container (entity) returns to the base. CREATE module is set to "create" returns according to a triangular probability distribution, in which three time values are set – minimum, mode (most likely) and maximum. These time values were derived from a set of service orders in "Swire Oilfield services", generated from company's ERP system. The newest data was used from company's service orders set, which at the time of starting this research was from October, November and December 2014. The average daily amount of units returned to the base was counted, as well as standard deviation; it appeared that on average a unit is returned to the base every 7.5 minutes, with minimum value of 5.5 and maximum of 11.5 minutes. CREATE module is followed by DECIDE module called "Keep containers?" that has a derived DISPOSE 2 module from it. The DECIDE module is created for scheduling purpose – all containers that arrive not during the normal work hours (8:00-16:00) are removed from the system and only the ones that arrive on "correct" time are allowed to enter the further model. DECIDE module is followed by a PROCESS module called "Return Inspection", which is a standard process imitating the Return Inspection done on returned items. This process is marked as non-value added; the unit is seized-delayed-released. Processing one unit requires 1 inspector; there are two inspectors available. After Return Inspection units are directed into STATION called "Starting station", from where units are distributed according to their need for maintenance processes. "Starting station" is followed by DECIDE module called "Unit needs maintenance?"; in this module there is a 2-way by chance possibility that a unit will need some maintenance process done. Such possibility is 50%, therefore a half of all returned items is directed into the maintenance area. The rest 50% of units leave Return Inspection through LEAVE module called "Leave Return Inspection"; their further path will be discussed later on.

Pink and yellow areas

Pink area is a continuation of green area; this part of the module is closely connected with yellow area, therefore they will be discussed together.

Units that in "Unit needs maintenance?" DECIDE module in green area were decided to require maintenance are directed to another DECIDE module called "Unit needs washing?" in pink area; there is a 44% probability that a unit does need washing. In this case, a unit is directed to LEAVE module called "Leave Starting Station". In reality this is the first case where a unit needs to be transported from the return point to the washing station. Therefore LEAVE module requests a transporter – a forklift, based on the shortest distance to starting station that lifts the unit (lifting operation takes 15 seconds) and transports it to the STATION called "Enter Washing".

In yellow area there is a STATION called "Enter Washing", where units needing washing procedure are transported to. The forklift puts down the unit (again, this operation takes 15 seconds) and the forklift is "released" from this operation and is free to go where it is requested next. "Enter Washing" is followed by a PROCESS module called "Washing", which seizes-delays-releases the unit; washing procedure requires 1 washer for one unit. After this procedure the unit is directed to LEAVE module called "Leave Washing". Here, a forklift is again requested, the unit is lifted and it is artificially transported to a STATION in pink area, called "Re-enter 1". The distance between LEAVE module "Leave Washing" and STATION "Re-enter 1" is marked to be 0, since in reality the unit is not transported anywhere from yellow area until it is decided which station should be next on its path. As it was mentioned before, a unit might need one or few/all maintenance processes, therefore in the simulation model it has to be decided each time before leaving one process whether a unit needs the following process, since otherwise the model will not properly reflect real transportation of units in maintenance processes in "Swire Oilfield Services".

The unit is artificially transported to STATION "Re-enter 1" and the forklift is released. The unit then enters a DECIDE module called "Unit needs repair or workshop?", where the probability of a unit requiring repair or workshop is equal to 80%. Additionally, this DECIDE module also has a second stream of incoming units from the previous DECIDE module called "Unit needs washing?"; units that were not sent to washing procedure were directed to this module. This way all units independently from maintenance procedures performed on them previously has a 2-way chance (which are predetermined in DECIDE modules) on having all (or none) maintenance processes performed on them.

The DECIDE module “Unit needs repair or workshop?” is different from other DECIDE modules, since in “Swire Oilfield Services” base there are not one but three repair stations, where units are repaired depending on their kind; therefore DECIDE module is N-way by chance type. 80% of units requiring repair or workshop are separated into four unit types: 19.2% tanks and freezers; 17.3% SMS; 18.2% baskets; 25.3% containers. These percentages were obtained from “Swire Oilfield Services” Service Orders sheet taken from ERP system, by counting the number of Return Inspections of each unit type in October-December 2014, and deriving the average percentage of each unit group in total number of Return Inspection. Further on, units are directed in different LEAVE stations from where units are transported into different Repair/Workshop stations based on their types. From LEAVE modules called “Leave Repair or Workshop (1/2/3)” units again are artificially resent to ENTER module called “Re-enter 2” and previously described procedure is repeated.

Those units that were only artificially transported to STATION “Re-enter 1” (but were actually left in “Leave Washing”), are waiting to be directed by one of the following DECIDE modules to another maintenance procedure; then they are transported to a required station.

The rest of pink and yellow areas are designed in the same way as it was described; only the last line is somewhat different. Units that are decided as non requiring IMO Testing in DECIDE module called “Unit needs IMO Testing?” at the end of pink area, are directed to the blue area. The same rule is valid for units that did have IMO testing performed and are leaving from LEAVE module called “Leave IMO Testing” at the end of yellow area.

Blue area

Following the path of units from pink area, since they are directed from a DECIDE module they go directly to the PROCESS module called “Final Inspection”. Final Inspection is done on every single unit that has finished all maintenance processes and is ready to be shipped again to the customer.

Units from the yellow area are leaving from LEAVING module, therefore they cannot go straight to the DECIDE module, but rather needs to be transported to a STATION module first. Since Final Inspection is actually not done on a separate station, but rather it is performed on a unit after its last maintenance process, the distance between LEAVE module called “Leave IMO Testing” and STATION called “Enter Final Inspection” is again 0.

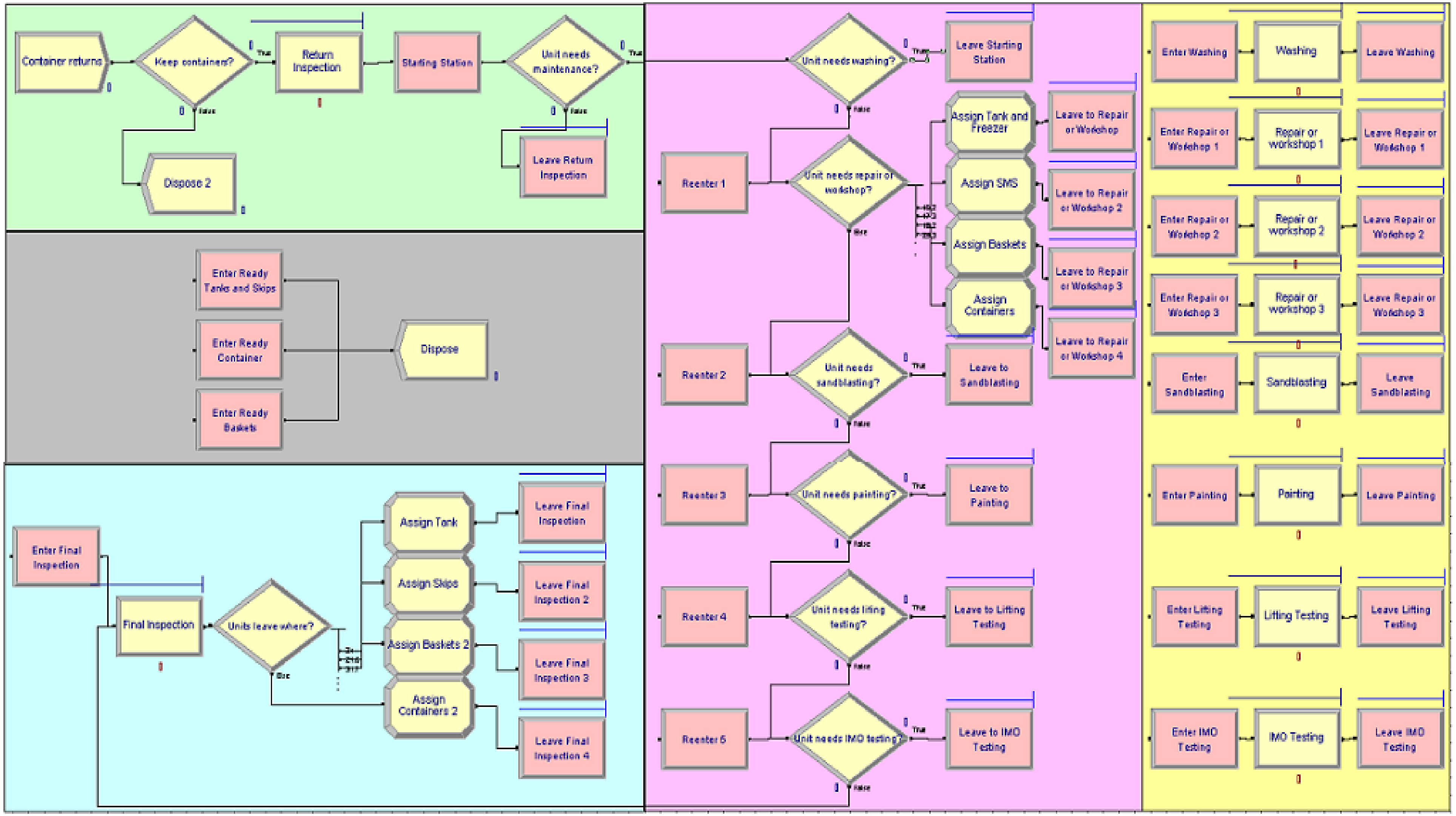


Figure 11. Simulation model of current "Swire Oilfield Services" maintenance processes (Source: created by author)

STATION called “Enter Final Inspection” in blue area also has a second incoming flow of units; units that are decided not to need any of the maintenance processes in green area, DECIDE module called “Unit needs maintenance?” are moved from STATION “Starting station” to LEAVE module “Leave Return Inspection”, where a forklift is requested and units artificially transported to STATION called “Enter Final Inspection”.

Here 100% of units that had Final Inspection need to be sorted into different groups and transported to three different yards where they wait to be shipped to the customers. The division is following: 24% Tanks; 21.6% Skips; 31.7% Baskets; 2.7% Containers.

Grey area

Grey area is the final area of the simulation model. Different kinds of units (which were sorted in blue area) are transported into three different STATION modules, imitating three yards where units are stored after maintenance processes are finished. One such yard is meant for Skips and Tanks, second is for Containers and third is for Baskets.

The DISPOSE module marks the end of the simulation model, where units “leave” the system.

3.2.1.2 Transportation in the model

The model also includes 6 forklifts moving on a free path; at the beginning of the simulation forklifts are stationed in Starting Station, Enter Ready Station, Enter Painting Station, Enter Sandblasting Station, and Enter Lifting testing Station.

The velocity of a forklift is 1/minute; the ”1” refers to a specific distance that forklift moves in 1 minute. In this case it is assumed that the average forklift speed is 7 km/hour, therefore 1=120m, i.e. actual forklift speed in the model is 120m/min.

The distances between different maintenance stations were assumed according to the current base map, displayed in Figure 12.

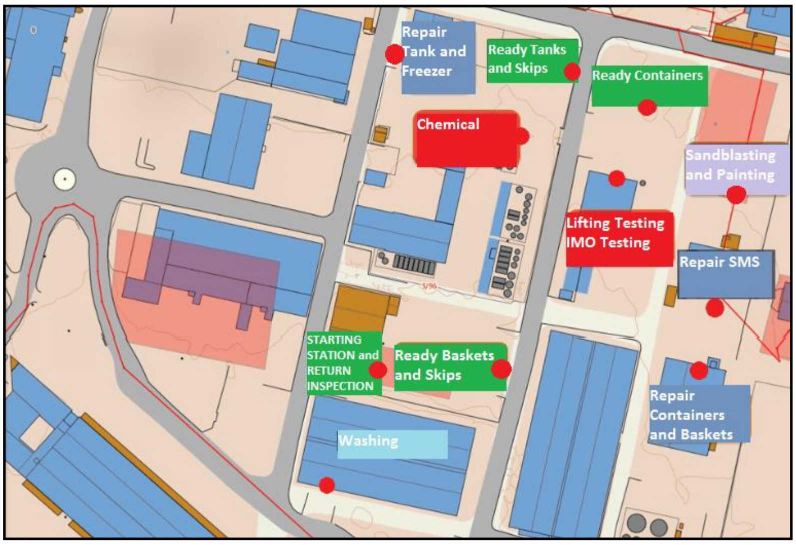


Figure 12. Current base map of "Swire Oilfield Services" (Source: created by author)

The map in Figure 12 displays locations of all different maintenance stations in "Swire Oilfield Services" base; red dots mark the "entrance" from which distances to each station were measured. The scale of the map is 1cm: 20m.

3.2.2 First simulation model report

The model is set up to run for 480 hours 6 times; 480 hours were chosen because this is the amount of hours in one month's workdays. As calculation *(1)* assumes, there are 20 workdays in a month and 24 hours in the workday.

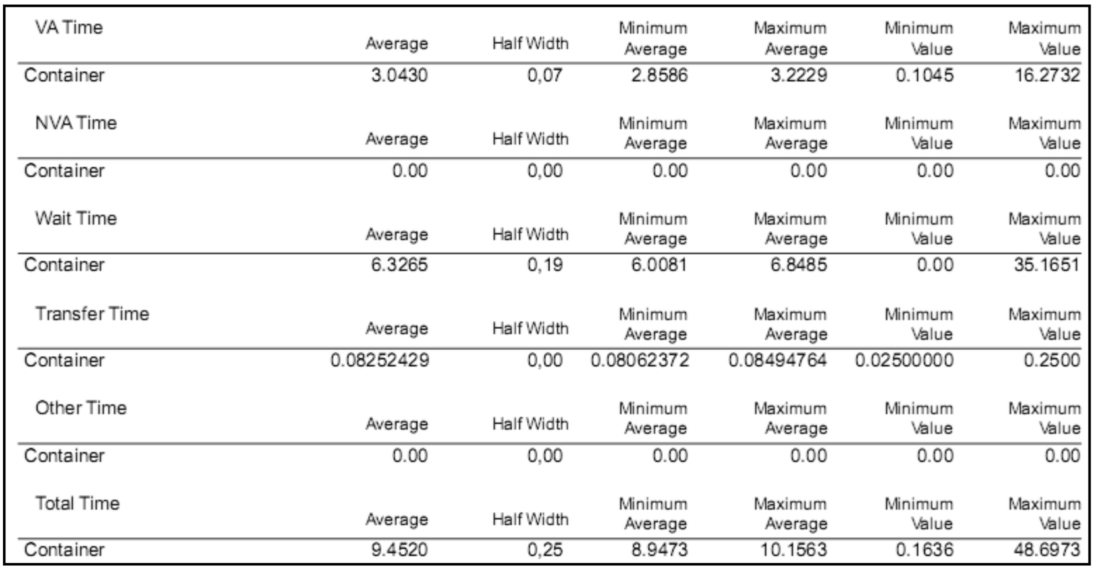
$$(1) \quad 20 \times 24 = 480 \text{ hours}$$

Even though there are only 8 work hours in a real workday, there are 24 hours in a workday in the model, because the simulation for the scheduling purposes is set up in a way that only RTIs arriving in the base during timeframe of 08:00-16:00 are allowed to enter the model.

The simulation is run 6 times; therefore the whole simulation period adds up to 6 months of work. To check whether simulation provides reliable parameters, the simulation was also run with a longer simulation length (100*480 hours); the results were the same as with shorter time frame.

Running first simulation model that was discussed in the previous section produced a simulation report which provided statistical data about maintenance processes that will be presented further on.

Figure 13 displays a part of simulation report which presents general model parameters.



VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	3.0430	0,07	2.8586	3.2229	0.1045	16.2732

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	0.00	0,00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	6.3265	0,19	6.0081	6.8485	0.00	35.1651

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	0.08252429	0,00	0.08062372	0.08494764	0.02500000	0.2500

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	0.00	0,00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	9.4520	0,25	8.9473	10.1563	0.1636	48.6973

Figure 13. General parameters of 1st simulation model (Source: Arena simulation))

„VA Time“ is the time unit spends in the maintenance system while going through Value Added processes, which in this case are all maintenance processes (Return Inspection, Washing, Repair or Workshop, Sandblasting, Painting, Lifting Testing, IMO Testing and Final Inspection).

In Lean manufacturing theory processes are defined as Value Added or Non-Value Added depending on the customers perspective to the process (Nave, 2002); even though such maintenance processes as Return Inspection, Lifting Testing, IMO Testing and Final Inspection does not actually change product‘s (unit‘s) characteristics, these are essential processes without which product (unit) would not be available for usage and therefore would have no use for the customer; therefore these processes are marked as Value Added in the simulation.

Value Added time in simulation report on average is 3.0430 hours, what indicates that on average a unit spends around 3 hours going through maintenance processes. The „Half Width“ of Value Added time is 0.07, which indicates that the variation of Value Added time is ±0.07/2. Since the simulation was run 6 times, ”Minimum Average” and ”Maximum Average” indicates minimum and maximum average values of the Value Added time among these replications. ”Minimum Value” and ”Maximum Value” indicates minimum and maximum values of Value Added time among all replications. The difference between minimum value (0.1045) and maximum value (16.2732) seems to be extremely high, however since the Half Width is only 0.07 it indicates that the variation in the system is not high.

None of the processes in the model are defined as ”NVA Time” – Non-Value Added time, therefore the numbers in the report are all 0.00.

”Wait Time” indicates the average time between the arrival of two units in one station, which in this case is 6.3265 hours.

”Transfer Time” indicates the time unit spends by being transported from one maintenance station to another; the average Transfer Time value is – 0.08252429 hours and it does not vary, since Half Width is 0.00. Non existing variation might be the result of relatively similar distances between different maintenance stations (Figure 11). Nevertheless, considering that on average the accumulated time of one unit being transported between maintenance stations is 0.08252429 hours, and as it was assumed previously that forklift speed in the simulation is 7 km/hour, it turns out that:

$$(2)\quad 0.08252429 \text{ hours} \times 7 \text{ km/hour} = 0.57767003 \text{ km}$$

Therefore the average distance that one unit is being transported within the base adds up to 578 meters.

No processes are defined as ”Other Time” in the simulation; therefore the report displays 0.00 values for this parameter.

”Total Time” is the sum of all above parameters; 9.4520 hours is the time a unit spends in the system on average. The maximum value of total time indicates that the longest period one unit spent in maintenance facilities was 48.6973 hours.

3.2.3 **Factory physics calculations**

As Hopp and Spearman (1996) states, “factory physics is a systematic description of the underlying behaviour of manufacturing systems”. Even though factory physics is meant to improve performance of manufacturing companies, it can also be adapted to service companies to some extent. Such processes as maintenance procedures in “Swire Oilfield Services” can be easily compared to a standard manufacturing procedures, since many factory physics parameters are relevant in this case.

3.2.3.1 Factory Physics parameters that will be used

Factory physics parameters that will be used in this paper are (definitions by Hopp and Spearman, 1996):

- **Throughput** (**TH**): The average output of a process per unit time.

- **Capacity**: An upper limit on the throughput of a production process.
- **Raw process time** (**T_0**): The raw process time of the line, T_0, is the sum of the long-term average process times of each workstation in the line
- **Work in process** (**WIP**): The inventory between the start and end points of a product routing.
- **Cycle time** (**CT**): The cycle time of a given routing is the average time from release of a job at the beginning of the routing until it reaches an inventory point at the end of the routing.
- **Utilization**: We can compute utilization as a ratio of Arrival rate and Effective production rate; where the Effective production rate is defined as the maximum average rate at which the workstation can process parts, considering the effects of failures, setups, and all other detractors that are relevant over the planning period of interest.
- **Bottleneck rate** (**r_b**): The bottleneck rate of the line, r_b, is the rate (jobs per unit time) of the workstation having the highest long-term utilization.

These Factory Physics parameters can be calculated by using statistical numbers from the simulation report produced by Arena simulation software; or, alternatively, some of these parameters are already stated in the simulation report.

3.2.3.2 Factory Physics parameters

Throughput (**TH**): The simulation report indicates that the average amount of units that finished maintenance processes in one replication (or in other words in one month) was 1 152 (Figure 14).

System

	Average
Number Out	1,152

Figure 14. Average monthly system throughput (Source: Arena simulation)

According to calculations based on real service orders in “Swire Oilfield Services”, the average number of units that finished maintenance processes (had Final Inspection performed) during timeframe of October-December 2014 were 966, as it is displayed in Figure 15.

October	November	December	Average
1210	849	838	966

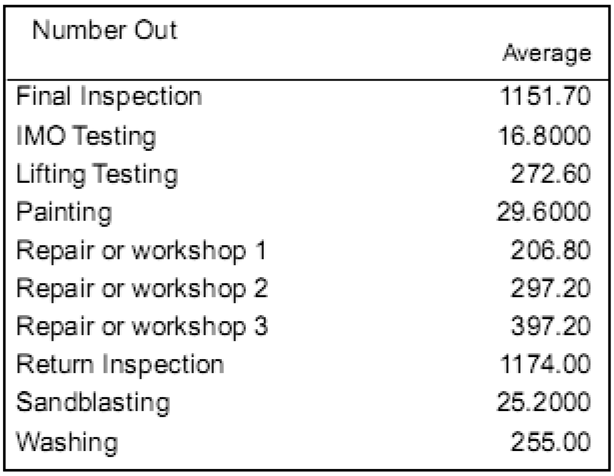
Figure 15. Number of units that had Final Inspection performed in October-December 2014 (Source: created by author)

The difference between number of units in the model (1 152) and in reality (966) can be considered to be caused by two reasons:

- model error, since the simulation model is based on average statistics and the actual variation of the amount of units arriving in the base is high;
- or to some extent it can be considered that in real company's maintenance processes there are some bottlenecks that causes such mismatch of numbers, such as unplanned downtime of some maintenance stations, lower than usual number of workers working on a particular day/week/month, unit registration errors due to manual work and etc..

Both of these reasons may have influenced throughput to some extent.

Separate maintenance stations, however, had their own average throughput, since the time needed to perform different maintenance processes highly differed.



Number Out	Average
Final Inspection	1151.70
IMO Testing	16.8000
Lifting Testing	272.60
Painting	29.6000
Repair or workshop 1	206.80
Repair or workshop 2	297.20
Repair or workshop 3	397.20
Return Inspection	1174.00
Sandblasting	25.2000
Washing	255.00

Figure 16. Average throughput of different maintenance stations (Source: Arena simulation)

As it can be seen from Figure 16, IMO Testing process had the lowest average throughput of 16 units per month, whereas Return Inspection had the highest average throughput rate, followed by Final Inspection and Repair or Workshop. These numbers does not reflect actual possible throughput (capacity) of the stations, since the model only allows a particular number of units to enter each station, even though some stations might be able to perform required services on more units.

Capacity: The capacity of separate maintenance stations differs depending on the amount of time required for a specific process to be performed. Assuming (as previously) that each maintenance station works:

(3)   20 days x 8 work hours = 160 hours/month

and taking the “most likely” time values for process performance, and number of workers performing these processes, the hourly/monthly capacity of each maintenance station can be calculated as it is done in Table 10.

Table 10. Hourly and monthly capacity of each maintenance station (Source: Created by author)

Station	Number of Workers	Process time (hours)	Station Capacity (units per hour)	Station Capacity (units per month)
Return Inspection	2	0.1	20	3200
Washing	16	1	16	2560
Repair or workshop	22	3	7.3	1168
Sandblasting	2	2.5	0.8	128
Painting	3	1.8	1.7	407
IMO Testing	8	5	1.6	256
Lifting Testing	25	0.7	35.7	5714
Final Inspection	2	0.1	20	3200
Raw process time		∑ 14.2		

The formula used in Table 8 for calculating hourly Station Capacity was:

(4) Station Capacity = Number of Workers / Process Time

The formula used in Table 8 for calculating monthly Station Capacity was:

*(5) Station Capacity =(Number of Workers / Process Time)*160*

The possible monthly capacity of each maintenance station considerably differs from actual throughput. Units move from one maintenance station to another by predetermined sequence, based on probability that a unit requires specific maintenance processes performed, therefore at most cases the capacity of each station can hardly be reached; however some of the stations might have a capacity that might never be reached, therefore the number of workers in such maintenance stations should be revised (reduced).

Raw process time (**T_0**): Raw process time can be calculated from Table 8, by summing up process times of all maintenance stations. In this case T_0= 14.2 hours, what means that if a unit requires all maintenance processes to be performed, including only the processing time (without transportation), it would take 14.2 hours for one unit to be processed.

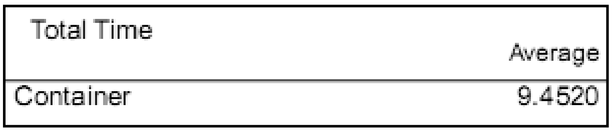
Work in process (**WIP**): The average number of units in whole maintenance system at any time during work hours is approximately 23.

WIP

	Average
Container	23.2902

Figure 17. Average number of units in maintenance system (Source: Arena simulation)

Cycle time (CT): The average time a unit spends in the maintenance system (including transportation time) is 9.4520 hours.



Total Time	Average
Container	9.4520

Figure 18. Total time a unit spends in maintenance system (Source: Arena simulation)

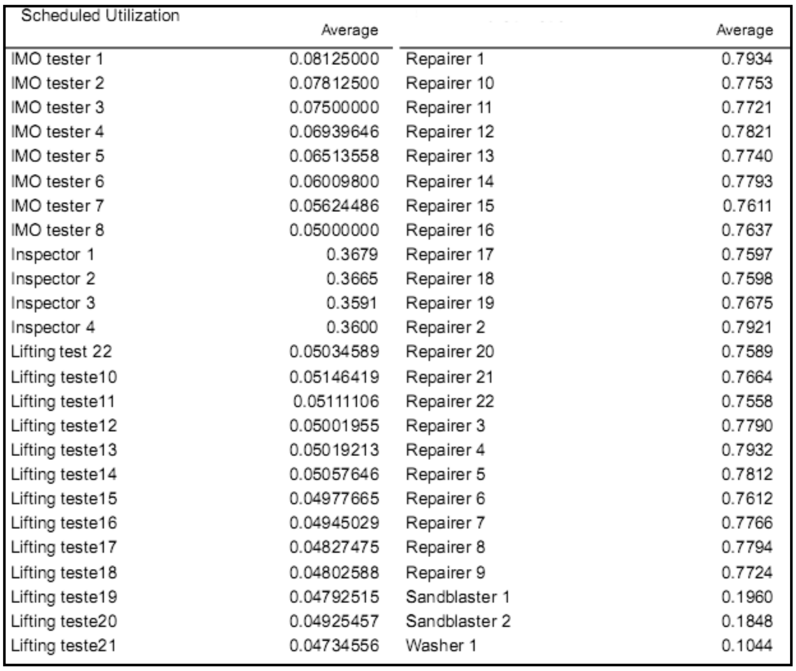
Utilization: The utilization rate regarding employees in the maintenance system is the most relevant kind of utilization in this case. The simulation report provides a detailed utilization analysis of employees; there are two main kinds of such utilization in Arena software: "Instantaneous Utilization" and "Scheduled Utilization". "Scheduled Utilization" is more relevant in this case, since it presents cumulative utilization rates, whereas "Instantaneous Utilization" is more useful when the aim is to track utilization rates over time.

(7) Displays the formula for "Scheduled Utilization" calculation:

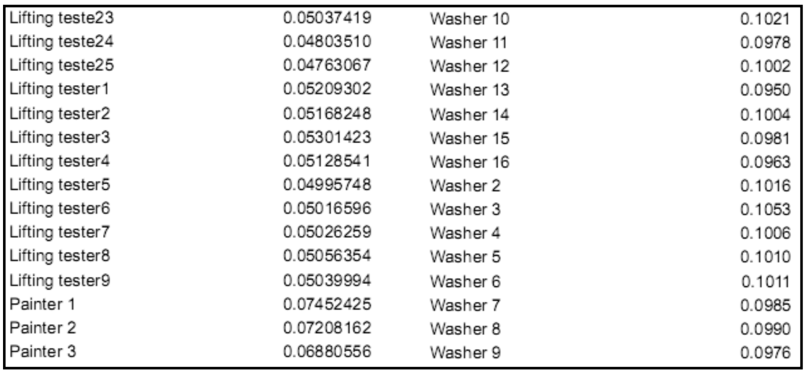
$$\text{(6)} \quad \textit{Scheduled Utilization} = \sum \textit{Busy} \, / \sum \textit{Scheduled}$$

"Scheduled Utilization" is the ratio of cumulative "Busy" workers and cumulative "Scheduled" workers ("Number busy" and "Number scheduled" statistics parts of the first simulation report are displayed in Appendices A and B).

Figure 19 displays "Scheduled Utilization" rates in "Swire Oilfield Services".



Scheduled Utilization	Average		Average
IMO tester 1	0.08125000	Repairer 1	0.7934
IMO tester 2	0.07812500	Repairer 10	0.7753
IMO tester 3	0.07500000	Repairer 11	0.7721
IMO tester 4	0.06939646	Repairer 12	0.7821
IMO tester 5	0.06513558	Repairer 13	0.7740
IMO tester 6	0.06009800	Repairer 14	0.7793
IMO tester 7	0.05624486	Repairer 15	0.7611
IMO tester 8	0.05000000	Repairer 16	0.7637
Inspector 1	0.3679	Repairer 17	0.7597
Inspector 2	0.3665	Repairer 18	0.7598
Inspector 3	0.3591	Repairer 19	0.7675
Inspector 4	0.3600	Repairer 2	0.7921
Lifting test 22	0.05034589	Repairer 20	0.7589
Lifting teste10	0.05146419	Repairer 21	0.7664
Lifting teste11	0.05111106	Repairer 22	0.7558
Lifting teste12	0.05001955	Repairer 3	0.7790
Lifting teste13	0.05019213	Repairer 4	0.7932
Lifting teste14	0.05057646	Repairer 5	0.7812
Lifting teste15	0.04977665	Repairer 6	0.7612
Lifting teste16	0.04945029	Repairer 7	0.7766
Lifting teste17	0.04827475	Repairer 8	0.7794
Lifting teste18	0.04802588	Repairer 9	0.7724
Lifting teste19	0.04792515	Sandblaster 1	0.1960
Lifting teste20	0.04925457	Sandblaster 2	0.1848
Lifting teste21	0.04734556	Washer 1	0.1044

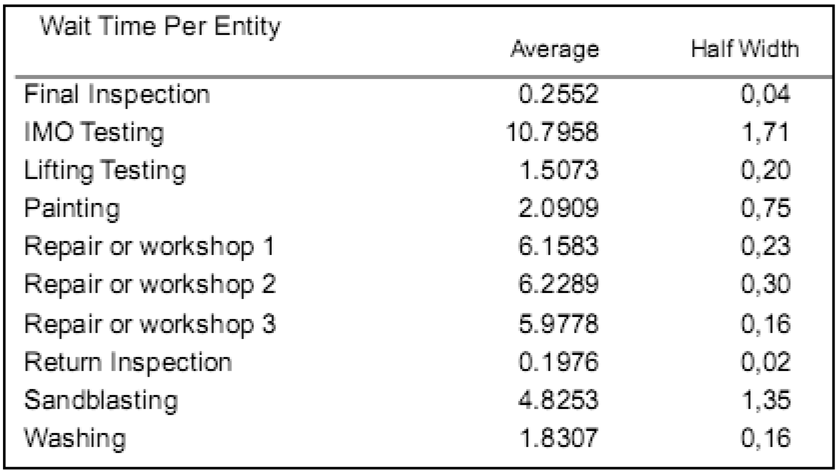


Lifting teste23	0.05037419	Washer 10	0.1021
Lifting teste24	0.04803510	Washer 11	0.0978
Lifting teste25	0.04763067	Washer 12	0.1002
Lifting tester1	0.05209302	Washer 13	0.0950
Lifting tester2	0.05168248	Washer 14	0.1004
Lifting tester3	0.05301423	Washer 15	0.0981
Lifting tester4	0.05128541	Washer 16	0.0963
Lifting tester5	0.04995748	Washer 2	0.1016
Lifting tester6	0.05016596	Washer 3	0.1053
Lifting tester7	0.05026259	Washer 4	0.1006
Lifting tester8	0.05056354	Washer 5	0.1010
Lifting tester9	0.05039994	Washer 6	0.1011
Painter 1	0.07452425	Washer 7	0.0985
Painter 2	0.07208162	Washer 8	0.0990
Painter 3	0.06880556	Washer 9	0.0976

Figure 19. Scheduled utilization rates of workers in maintenance processes (Source: Arena simulation)

From Figure 19 it can be seen that most of the employees are not fully utilised during a workday. The utilization rates of Repairers are the highest, reaching 75-79%, whereas Lifting Testers are utilized the least, by only ~5%. Such large differences between different kinds of employees can be explained by varying number of units that need particular maintenance processes they perform; however, the monthly capacity of different maintenance stations is much higher than actual number of units processed, therefore it might be that there are too many employees in some of the stations as well.

Bottleneck rate (r_b): Since in this case maintenance process line consists of more than one routing, the arrival rate to every workstation differs; therefore the bottleneck may not be at the slowest workstation. In this case "bottleneck" is the time that employees need to wait for a unit to arrive in their maintenance station, since while waiting employees are not being utilised. The simulation report displays average waiting time in each maintenance station (Figure 20).



Wait Time Per Entity	Average	Half Width
Final Inspection	0.2552	0,04
IMO Testing	10.7958	1,71
Lifting Testing	1.5073	0,20
Painting	2.0909	0,75
Repair or workshop 1	6.1583	0,23
Repair or workshop 2	6.2289	0,30
Repair or workshop 3	5.9778	0,16
Return Inspection	0.1976	0,02
Sandblasting	4.8253	1,35
Washing	1.8307	0,16

Figure 20. Waiting time for units in different maintenance stations (Source: Created by author)

According to Figure 20, the longest period of time that employees are waiting for a unit to arrive into the maintenance station is in IMO Testing; a unit arrives to this station on average every 10.8 hours (variation ±1.71/2 hours (Half Width). There is a low percentage of units that require IMO Testing, therefore as a result the utilisation rate of employees in IMO Testing station reaches only 6-7%; a more detailed look into processes in this station should be taked, since there is a possibility that there are too many employees working in this station.

Other stations has a varying level of wait time, e.g. Repair or Workshop station also has a high wait time of 6 hours, however the processing time of one unit in this station is also quite high (triangular distribution of (1;3;5) hours), therefore the utilization rate of employees in this station is very high. Additionally, Lifting Testing has a wait time of 1.5 hours, whereas processing of one unit in this station barely takes around 40 minutes, therefore the utilization rate of employees is so low in this station (what again can mean too many employees in this station). .

Return Inspection station has the shortest waiting time of 0.1976 hours and variation of ±0.02/2, what indicates that units come into Return Inspection on a very steady rate in this simulation; however with the real statistical data about intervals between RTIs' returns it would be possible to measure this parameter more accurately for this station.

All the Factory Physics parameters that were calculated in this section will be compared with the parameters of second simulation model, where the usage of RFID technology will be included in the maintenance processes in 3.3.2 part of this paper.

3.3 Second simulation model

The essential difference between the first and the second simulation models is the adoption of RFID: the first model replicated real life maintenance processes in "Swire Oilfield Services" without usage of RFID; whereas the second model assumes that every unit in the company is tagged with RFID tag.

It is assumed that all data received from RFID tags is transformed into useful information and it is used to identify sources of RTIs' damages, areas of RTIs' losses and bottlenecks in the system. Additionally it is assumed that adequate actions are taken in "Swire Oilfield Services" to eliminate the causes of such problems.

3.3.1 **Changes in the model**

There are a few changes in the second model due to assumed usage of RFID technology and company's actions to improve problematic areas, which directly affects the parameters used in the simulation. The changes in parameters are based on scientific literature, where the effects of adopting RFID technology in the activities of companies were measured, or changes in parameters are assumed based on assumptions considering current "Swire Oilfield Services" performance. A more comprehensive explanation of why particular parameters were changed by particular values and what is it based on will be discussed further on.

1. The adoption of RFID technology in "Swire Oilfield Services" would highly affect the shrinkage of RTIs fleet. According to Hansen et al (2008), in the "Silverstroke AG" pilot project of adopting RFID the shrinkage level of RTIs[1] was reduced by 3%. Current shrinkage level in "Swire Oilfield Services" is 10% (this is the percentage of units that are procured each year to renew the fleet after scrapping old units and to substitute units that were lost in the field). After the adoption of RFID it can be expected that the shrinkage would be reduced to 7%.

   Table 11 represents the RTIs' fleet profile in Tananger base over the period of August-December 2014.

Table 11. "Swire Oilfield Services" fleet profile Aug-Dec 2014(Source: created by author)

	Fleet	**No. Units On Hire**	**No. Units Off Hire**	**No. Units Available for Hire**	**Work In Progress**	**No. Units in Qurantine**	**Dead Stock**
August	8.365	6.310	2.055	1.141	745	15	154
September	8.332	6.180	2.152	1.118	563	14	457
October	8.365	6.175	2.190	1.023	689	21	457
November	8.243	6.146	2.097	1.091	554	17	435
December	8.130	6.122	2.008	1.010	840	17	141
Average	**8.287**	**6.187**	**2.100**	**1077**	**678**	**17**	**329**

329

On average Tananger base operates around 8 287 units per month, from which around 6 187 units are on hire and 2 100 off hire. Units that are off hire are either available for hire (on average 1 077 units), going through maintenance processes (on average 678 units), in quarantine (on average 17 units) or are assigned to dead stock (on average 329 units).

The average number of units in work in progress differs from average number of units that on average finishes going through maintenance processes (966 units) because one unit can

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[1] The type of RTI's used in "Silverstroke AG" pilot project was pallets, therefore considering the difference between containers and pallets the reduced shrinkage level might vary.

be re-rented a number of times in one month and therefore go through maintenance processes more than once in one month.

If there are on average 8 287 units in Tananger base, than the annual shrinkage rate is:

$$(7)\quad 8287 \times 10\% = 828.7 \sim 829 \text{ units}$$

The reduced annual shrinkage rate after the adoption of RFID is:

$$(8)\quad 8287 \times 7\% = 580.09 \sim 580 \text{ units}$$

The difference between initial and reduced shrinkage rate in the company would result in:

$$(9)\quad 829 - 580 = 249 \text{ units}$$

As a result of reduced shrinkage, the RTIs' pool would increase by 249 units.

Such increase in RTIs pool would add up to excessive inventory; however "Swire Oilfield Services" has a cross-hire problem, since the company is usually cross-renting some units from the competitors to cover shortage of available units in the base.

Table 12 represents weekly numbers of units that were cross-hired in Norway in October-December 2014.

Table 12. Number of cross-hired units in Norway in October-December 2014 (Source: created by author)

Date:	Number of units:	Cross-hired units:
2014.12.28	12.592	62
2014.12.22	12.411	45
2014.12.15	11.876	45
2014.12.08	12.161	57
2014.12.01	12.027	34
2014.11.25	12.080	35
2014.11.17	12.099	34
2014.11.10	12.217	40
2014.11.03	12.311	41
2014.10.27	12.363	45
2014.10.20	12.243	52
2014.10.13	12.181	49
2014.10.06	12.151	52

The average monthly number of assets cross-hired in Norway is 182 units. The average number of total fleet in Norway is presented in Table 13.

Table 13. Total RTIs fleet in Norway (Source: created by author)

	October	**November**	**December**	**Average**
Total fleet in Norway	16661	16354	15912	16309

Average number of RTIs in Tananger base is 8536 units and the average number of total RTIs fleet in Norway is 16309, the Tananger base on average operates 52.3% of total RTIs fleet in the country. Therefore it is assumed that also 52.3% of units cross-hired in the country are hired in Tananger base, what consists of :

$$(10) \quad 182 \times 52.3\% = 95.2 \sim 95 \text{ units}$$

In order to level out the number of available units in Tananger base, 95 units from 249 extra units are kept to cover the cross-hire need, and the rest 154 units are sold. The company also saves rental costs of 95 units that it would have been required to rent monthly.

With increased number of RTIs fleet in Tananger base, the return rate of units returned to the base would increase by 1.15%.

2. The adoption of RFID technology into the system would also improve planning and scheduling activities. With the ability to trace and track units on hire it would be possible to anticipate more exactly what units and when exactly are going to be returned to the base.

   Current unit Return Inspection process includes such actions:

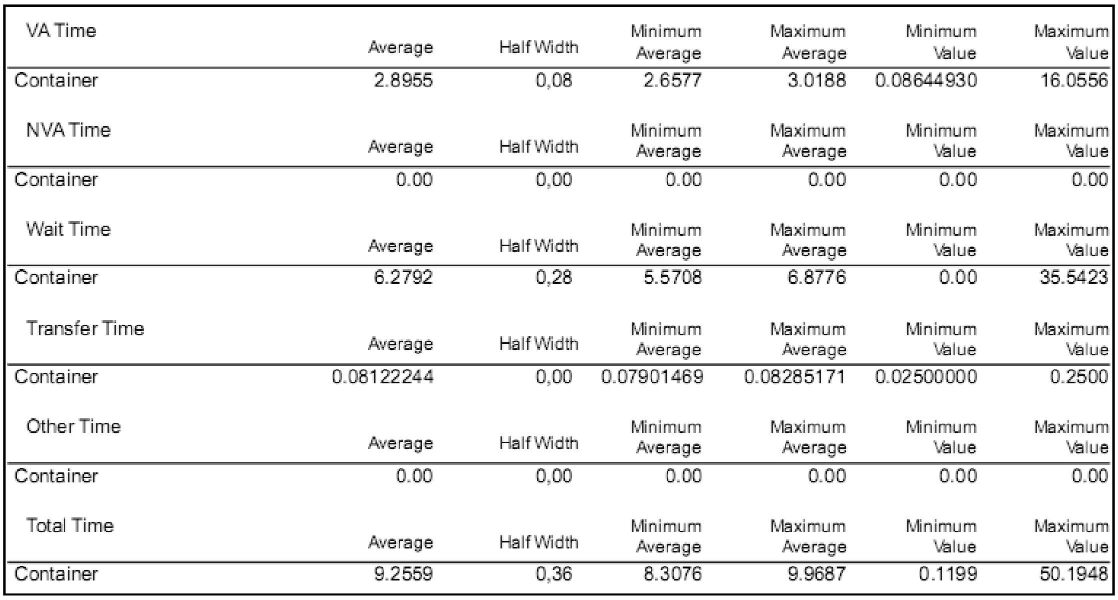
- Documentation is checked;
- Unit is lifted by the truck;
- Unit status is checked manually;
- ID and service needs are put into a handheld unit;
- Service needs are written on a note that is put on the unit;
- Unit is set into a queue based on need.

With RFID technology it would become unnecessary to check its documentation, since it would be done automatically when a unit is returned to the base; as well as service needs would be included into the system and there would be no need to manually put service needs on a note that is attached to the unit. Once a unit's RFID tag is scanned it should display all the information about the unit. It can be assumed that such knowledge would reduce the time it is required to perform Return Inspection by at least 50%. Such change will be caused by the automatic scanning of RFID-tagged units that are returned to the base and in-advance knowledge about where the unit was during its rental period and how long it has been on hire; it would allow anticipating the possible level of damages in advance. Additionally, reduction of manual registration would reduce the number of errors in the inventory count and overall registration system, what would also save time.

3. RFID adoption also enables the unique identification of RTIs. With the ability to trace and track each individual unit it becomes possible to collect historical data about unit's previous maintenance processes, level of damages and most importantly, the locations and customers that have rented the unit previously. With the adoption of RFID RTIs tend to be damaged less, due to more careful handling of units, since customers become aware that all the damages can be traced back to them. Therefore it can be expected that the percentage of units requiring maintenance would drop by at least 2%, from 50% to 48%.

3.3.2 **Second simulation model report**

Second simulation model includes all the changes in the system discussed in the previous section due to the assumed adoption of RFID technology. The general second model parameters are presented in Figure 21 and it will be compared with the results of first simulation model parameters.



VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	2.8955	0,08	2.6577	3.0188	0.08644930	16.0556

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	0.00	0,00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	6.2792	0,28	5.5708	6.8776	0.00	35.5423

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	0.08122244	0,00	0.07901469	0.08285171	0.02500000	0.2500

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	0.00	0,00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	9.2559	0,36	8.3076	9.9687	0.1199	50.1948

Figure 21. General parameters of second simulation model (Source: Arena simulation)

Value Added time in second simulation model on average is 2.8955 hours, which is by 0.1475 hours shorter than in the first simulation model (3.0430 hours).The Half Width is 0.08 which indicates very low variation in Value Added time.

The average value of Wait Time is 6.2792 hours, which is by 0.0473 hours shorter than in 1st simulation model (6.3265 hours). The actual difference is 2.8 minutes between 1st simulation model and second simulation model.

The average Transfer Time value in second simulation model is 0.08122244 hours, compared with 0.08252429 hours in 1st simulation model, therefore they are very similar.

The Total Time is shorter in second simulation model compared to first simulation model, 9.2559 hours compared with 9.4520 hours respectively; such difference indicates that a unit spends 2.1% less time in the system in second simulation model than in 1st simulation model.

Factory Physics calculations, based on second simulation model report, are presented further on.

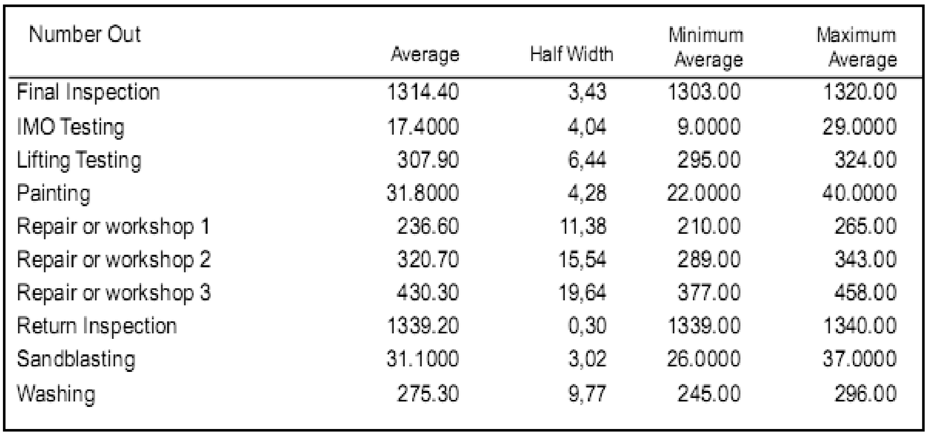
Throughput (**TH**): The simulation report indicates that the average amount of units that finished maintenance processes in one replication (or in other words in one month) in second simulation model was 1 314 (Figure 22).

System	Average
Number Out	1,314

Figure 22. Average monthly system throughput in second model (Source: Arena simulation)

Comparing the results of second simulation to 1st simulation model, the throughput of RTIs in second model was 14 % higher.

Consequently, separate maintenance stations also increased their throughput rates as it is shown in Figure 23.



Number Out	Average	Half Width	Minimum Average	Maximum Average
Final Inspection	1314.40	3,43	1303.00	1320.00
IMO Testing	17.4000	4,04	9.0000	29.0000
Lifting Testing	307.90	6,44	295.00	324.00
Painting	31.8000	4,28	22.0000	40.0000
Repair or workshop 1	236.60	11,38	210.00	265.00
Repair or workshop 2	320.70	15,54	289.00	343.00
Repair or workshop 3	430.30	19,64	377.00	458.00
Return Inspection	1339.20	0,30	1339.00	1340.00
Sandblasting	31.1000	3,02	26.0000	37.0000
Washing	275.30	9,77	245.00	296.00

Figure 23. Average throughput of different maintenance stations in second simulation model (Source: Arena simulation)

The average increase in throughput rates in each maintenance station are displayed in Table 14.

Table 14. The average increase in throughput rates in each maintenance station (Source: created by author)

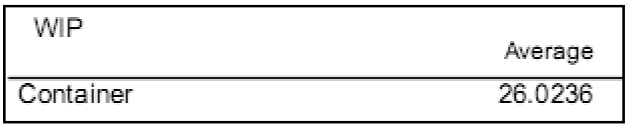
Maintenance station	**1st Simulation Model (units)**	**2nd simulation model (units)**	**Difference 2nd to 1st simulation model (%)**
Final Inspection	1151,7	1314,4	**14.1**
IMO Testing	16,8	17,4	**3.6**
Lifting Testing	272,6	307,9	**12.9**
Painting	29,6	31,8	**7.4**
Repair or Workshop	901,2	987,6	**9.6**
Return Inspection	1174	1339,2	**14**
Sandblasting	25,2	31,1	**23.4**
Washing	255	275,3	**8**

Table 14 indicates that the highest change in throughput increase in second simulation model was in Sandblasting station - 23.4%; throughputs of all the other maintenance stations increased as well. The Half Width indicates that there is a low variation of the number of units processed in different maintenance stations.

Capacity: The capacity of maintenance stations in second simulation model remained the same as in first simulation model, since the number of workers and the required time for one unit to be processed did not change in the second simulation model.

Raw process time (T_0**)**: The raw process time in second simulation model remained the same as in first simulation model.

Work in process (WIP): The average number of units in whole maintenance system at any time during work hours was approximately 25.9728 units in second simulation model, as Figure 25 displays.

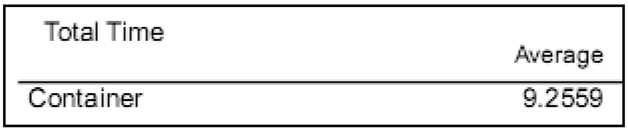


WIP	Average
Container	26.0236

Figure 24. Average number of WIP containers in second simulation model (Source: Arena simulation)

Comparing this number with 1st simulation model it can be stated that there are on average 2.7 more units in the second model's maintenance system than in the first model; it is a positive change, indicating that the system is processing a higher number of units at the same time.

Cycle time (CT): The average time a unit spends in the maintenance system (including transportation time) is 9.2559 hours in second simulation model as it is displayed in Figure 25; it is 2.1% shorter than in 1st simulation model (9.4520 hours).

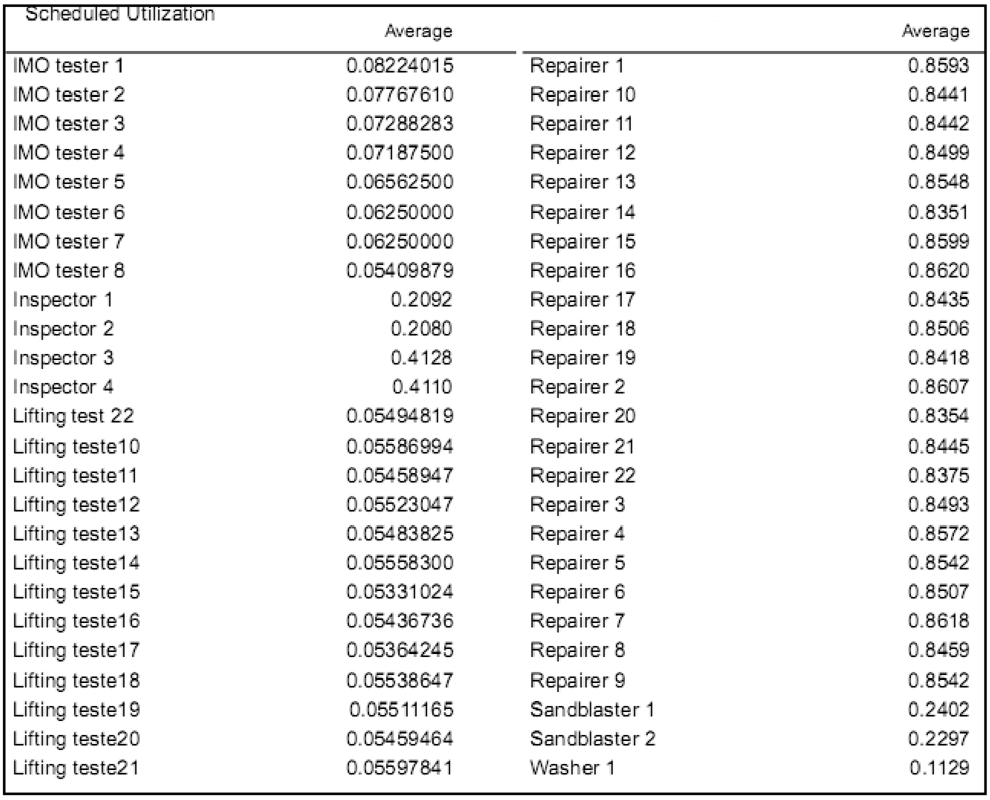


Total Time	Average
Container	9.2559

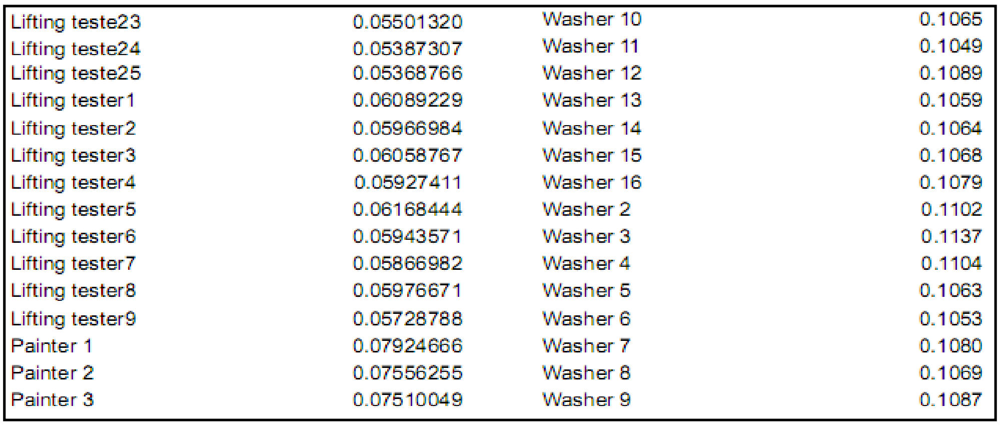
Figure 25. Total time a unit spends in maintenance system in second model (Source: Arena simulation)

Even minor changes in the system causes the change in maintenance cycle time, as this example implicates. In the long term with the adoption of RFID the cycle time should decrease even more, as a result the number of units ready to be rented to the customers should increase and at the same time the number of units in RTIs pool should decrease, causing large financial savings for „Swire Oilfield Services".

Utilization: Figure 27 displays Scheduled Utilization rates in second simulation model ("Number busy" and "Number scheduled" statistics parts of the second simulation report are displayed in Appendices C and D). The scheduled utilization rates in second simulation model have increased for IMO testers (~2%), Repairers (~8% increase), Painters (~5%), Sandblasters (~5%). Very minor increase in scheduled utilization can also be noticed for Washers and Lifting Testers. Inspectors experienced a decrease in utilization rate of ~5%.



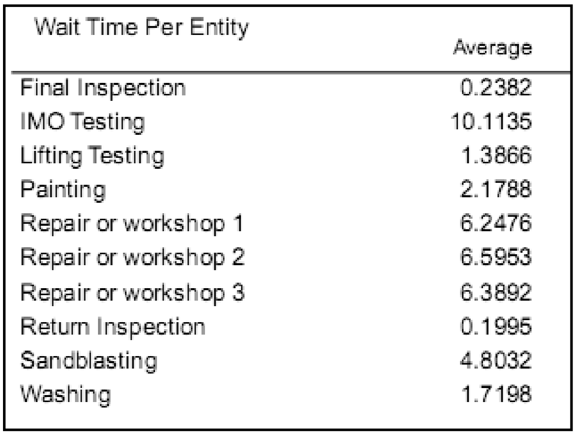
Scheduled Utilization	Average		Average
IMO tester 1	0.08224015	Repairer 1	0.8593
IMO tester 2	0.07767610	Repairer 10	0.8441
IMO tester 3	0.07288283	Repairer 11	0.8442
IMO tester 4	0.07187500	Repairer 12	0.8499
IMO tester 5	0.06562500	Repairer 13	0.8548
IMO tester 6	0.06250000	Repairer 14	0.8351
IMO tester 7	0.06250000	Repairer 15	0.8599
IMO tester 8	0.05409879	Repairer 16	0.8620
Inspector 1	0.2092	Repairer 17	0.8435
Inspector 2	0.2080	Repairer 18	0.8506
Inspector 3	0.4128	Repairer 19	0.8418
Inspector 4	0.4110	Repairer 2	0.8607
Lifting test 22	0.05494819	Repairer 20	0.8354
Lifting teste10	0.05586994	Repairer 21	0.8445
Lifting teste11	0.05458947	Repairer 22	0.8375
Lifting teste12	0.05523047	Repairer 3	0.8493
Lifting teste13	0.05483825	Repairer 4	0.8572
Lifting teste14	0.05558300	Repairer 5	0.8542
Lifting teste15	0.05331024	Repairer 6	0.8507
Lifting teste16	0.05436736	Repairer 7	0.8618
Lifting teste17	0.05364245	Repairer 8	0.8459
Lifting teste18	0.05538647	Repairer 9	0.8542
Lifting teste19	0.05511165	Sandblaster 1	0.2402
Lifting teste20	0.05459464	Sandblaster 2	0.2297
Lifting teste21	0.05597841	Washer 1	0.1129



Lifting teste23	0.05501320	Washer 10	0.1065
Lifting teste24	0.05387307	Washer 11	0.1049
Lifting teste25	0.05368766	Washer 12	0.1089
Lifting tester1	0.06089229	Washer 13	0.1059
Lifting tester2	0.05966984	Washer 14	0.1064
Lifting tester3	0.06058767	Washer 15	0.1068
Lifting tester4	0.05927411	Washer 16	0.1079
Lifting tester5	0.06168444	Washer 2	0.1102
Lifting tester6	0.05943571	Washer 3	0.1137
Lifting tester7	0.05866982	Washer 4	0.1104
Lifting tester8	0.05976671	Washer 5	0.1063
Lifting tester9	0.05728788	Washer 6	0.1053
Painter 1	0.07924666	Washer 7	0.1080
Painter 2	0.07556255	Washer 8	0.1069
Painter 3	0.07510049	Washer 9	0.1087

Figure 26. Scheduled utilization rates of workers in maintenance processes in second model (Source: Arena simulation)

Bottleneck rate (r_b):



Wait Time Per Entity	Average
Final Inspection	0.2382
IMO Testing	10.1135
Lifting Testing	1.3866
Painting	2.1788
Repair or workshop 1	6.2476
Repair or workshop 2	6.5953
Repair or workshop 3	6.3892
Return Inspection	0.1995
Sandblasting	4.8032
Washing	1.7198

Figure 27. Waiting time for the units in different maintenance stations in second model (Source: Arena simulation)

According to Figure 27, IMO Testing still has the longest waiting queue in second simulation model (10.1135 hours); however it is reduced by 0.6 hours when compared with 1st simulation model. It is a positive change, since if units are coming to the maintenance station, the employees are better utilised. Waiting time has also decreased in Final Inspection, Lifting Testing, Sandblasting and Washing, causing a higher utilization rate of employees in these maintenance stations.

However wait time increased in Painting, Return Inspection and Sandblasting stations.

To summarize the results of second simulation model it can be noted that the throughput of overall maintenance system has increased, whereas waiting time has decreased as well as the time unit spend in value added processes. The overall cycle time has decreased; as a result more units are being processed at the same time in maintenance facilities. The transportation time remained nearly the same in second simulation model, even with the slightly increased number of RTIs available. The scheduled utilization rate of the employees working in most maintenance stations had increased; however they still remain very low in general and the number of employees required in each maintenance station should be revised by “Swire Oilfield Services”.

The suggested changes in maintenance system are very minor compared to actual benefits that RFID technology can bring to „Swire Oilfield Services“. At the very least, such minor changes affected the company in a way that it supposedly experiences some financial benefits, listed in Table 15.

Table 15. Preliminar financial benefits from RFID adoption (Source: created by author)

	Reason	Value	Notes
1.	Eliminated risk of losing RTIs	16* units x 67 000 NOK (yearly)	*According to “Swire Oilfield Services”, 16 units went missing in 2012; the number is only used as a guideline.
2.	Reduced shrinkage by 3%	154 units x 67 000 NOK (yearly)	Additional benefits: elimination of costs related with the purchase of new RTIs (Administration costs, customs, transportation and etc.)
3.	Eliminated need of cross-hiring units	95* units x Unit renting price from competitors (monthly)	*95 is an assumed average number of RTIs rented from competitors in Tananger base per month.
4.	Automated inventory count	4 x 600000 NOK (yearly)	

Financial benefits listed in Table 15 are very preliminary, yet in spite of that considerably high. Even though the costs of implementing RFID technology are as well high, in the long run it should be definitively outweighed by financial benefits.

It can be concluded that the assumed minor changes in maintenance system had an instant positive effect and in long term such changes could give many benefits, both from operational and financial perspective, such as decrease in inventory levels. Even though many scientific researchers are dedicated to examine the effects of RFID adoption, not many of such researches suggest numerical proof of how it affects maintenance processes; therefore it can hardly be measured before RFID is actually adopted in the system.

3.3.3 Unmeasurable changes in the system

The adoption of RFID technology also causes few changes in the RTIs’ management that can hardly be measured by numerical values that could be put into the simulation models; such changes are listed below:

- First and possibly most important change is the improved planning system of maintenance activities due to increased visibility over the return schedule of RTIs. According to “Swire Oilfield Services”, it is difficult to anticipate the return rates of RTIs to the base since even though the company knows for how long a unit is rented, there is no visibility over the process of units being transported back – after usage RTIs might need to wait on the oil platforms to be transported to the shore and it is not know when it can be done, since it depends on the schedules of supply vessels and whether it has enough space for the RTIs.

  With the adoption of RFID technology real time information about each rented unit’s whereabouts would be available in Tananger base; the uncertainty about quantity and timing of returns would be decreased and it would make planning and scheduling operations for maintenance procedures in the base much easier.
- Also, tagging units with RFID tags would not only create benefits for tracking and tracing assets while they are outside the base, but also inside the base as well. As of now, employees need to search for units in the yard manually, since it is impossible to track it to its current location. The adoption of RFID in this case would mean saving the time it takes for the employees to manually search for particular units.
- Another immeasurable advantage of RFID adoption into the system is the reduction of manual work due to real time visibility. Such costly procedures as manual inventory counts could be done instantly and save large amounts of money for the company. At the same time automation of such procedures would decrease the risk of manual errors and improve order management.

4.0 Recommendations

The “Swire Oilfield Services” case suggests that full RFID adoption in the system could bring many positive changes in both operational and financial aspects.

However, “Swire Oilfield Services” does not have accurate historical data about the maintenance processes performed on RTIs. With the lack of accurate statistics and the usage of average numbers, the simulation models created for this study to some extent might have erroneous assumptions or results.

In order to improve company’s maintenance performance, a stable and manual-error free data collection system should be implemented. RFID technology, with integrated software solutions for tracking the movements of RTIs inside the base, could collect reliable statistical information about:

- The cycle time each kind of units on average takes to go through maintenance processes; such information together with accurate tracing of RTIs outside the base would improve planning possibilities for maintenance processes (knowing what amount of units is arriving in the base and how long it takes to process it enables forecasting the level of busyness of facilities, scheduling and an adequate number of employees);
- The segmentation of unit damages according to unit kind and the customer it has been rented to. It is possible that a specific kind of units is damaged more often (or more severely) or that a particular customer returns more damaged units to the base than the others. Such data would allow a justified allocation of different renting prices of different kinds of units, or different prices for customers that return highly damaged units.

Data collection system would also provide a lot of other statistical information that could be used for “Swire Oilfield Services” performance improvements.

Full RFID technology adoption in company’s system would also eliminate the risk of errors caused by manual work. It can be seen in current “Swire Oilfield Services” data collection, that the records in ERP system has misleading statistics which can distort any calculations based on such data.

Further on, the planning of the current company’s maintenance facilities is not the most efficient. According to the simulation models the transportation time of units from one maintenance station to another is moderately low, however since maintenance facilities are very scattered, redesigning it could have a very positive effect on the time units spend being transported.

Finally, “Swire Oilfield Services” should revise the number of employees required in each maintenance station, since current simulation model indicates that many employees are not fully utilized.

Conclusions

Theoretical conclusions:

- In past few decades **the need for data visibility in supply chains** has received a lot of attention; as a consequence the need for increased supply chain visibility has been stimulating the development of asset tracking and tracing solutions in logistics. Various tracking and tracing systems are being developed in order to satisfy growing need for asset traceability; not only the information of asset current whereabouts is now accessible, but also the historical data of where the asset has been in the past too. At the same time high emphasis is put on developing safe, authorised access of such information.
- There are few main **kinds of tracking solutions** that are widely used among industries; most common are **GPS/GSM, barcoding and RFID technologies**. Each tracking solution has its advantages and disadvantages that make a particular system more suitable for some industries than others. RFID technology is superior over barcoding in such areas as efficiency, data capacity, flexibility and security, and it surpasses GPS/GSM technologies in its accuracy and price. However due to such differences between tracking technologies, some scientists believe that companies are not likely to choose between barcode, RFID or GPS/GSM, but rather come up with a new trace and track strategy that incorporates a mix of these technologies.
- As the management of disposable packaging systems is getting more and more complicated, **the importance of Returnable Transport Items'** (RTIs) management is increasing, especially considering lower environmental impact of RTIs compared with disposables. However, an increasing issue in RTIs management is the lack of visibility of RTIs-related operations, which can be solved by usage of tracking systems, such as RFID technology. RFID technology can enhance RTIs management in such areas as inventory, maintenance and circulation management and has many benefits for the overall supply chain.
- **RFID technology** is also highly useful **in maintenance processes of RTIs**; it can create valuable benefits for RTI pool owners, making maintenance processes more efficient and transparent. The ability to track and trace individual RTIs through their life cycle and see where and how RTIs were utilised also enables RTIs pool owner predict and plan maintenance processes in advance, what can shorten time period that RTIs need to spend in maintenance.

Conclusions from the analysis:

- **"Swire Oilfield Services"** has a strong presence in all major oil and gas regions and is an important supplier or cargo carrying units for many oil and gas companies. Rental operations is a crucial part of the business, therefore "Swire Oilfield Services" needs to optimize its internal processes to be more efficient in the supply chain. Despite partial usage of "OverVu®" system, the company **does not have sufficient data about RTIs** whereabouts in real time and it creates many problems in internal company's processes.
- **A simulation model** that was built up to replicate current maintenance processes in "Swire Oilfield Services" Tanager base without the usage of RFID technology indicated that either the model has some erroneous statistics built in, or the maintenance system in "Swire Oilfield Services" is underperforming. **The mismatch of numbers** in the model and in reality confirms the assumption that the company needs well developed data collection software to be integrated in the system to collect accurate historical and real time data about maintenance processes in order to further investigate and optimize these processes.
- **The parameters** of the maintenance system **in first simulation model** indicated not only that theoretically the system throughput should be higher than it is in reality, but also that on average a unit spends 9.45 hours in the maintenance processes. From those 9.45 hours only 3 hours are spent in value added processes whereas 6 hours are spent waiting, however for the company it would be more beneficial if these numbers were vice versa. Additionally, the utilization rate of employees in some maintenance stations is very low; therefore a deeper look into this part of maintenance processes should be taken.
- In the **second simulation model** it was assumed that due to adoption of RFID technology the annual shrinkage rate of RTIs pool would decrease by 3%; as a result the RTIs fleet would increase and solve the problem of cross-hiring units from competitors; a problem that "Swire Oilfield Services" faces very often would be eliminated. Also, reduction in the number of units requiring maintenance processes was assumed due to more careful handling of the units; and a reduction of time required to perform Return Inspection was assumed due to partial automation of the process and enhanced planning possibilities.
- **The results of second simulation model** revealed that it is possible to improve most of the general model parameters, from cycle time to employee utilization rates. The

throughput of overall maintenance system has increased, whereas waiting time has decreased as well as the time unit spend in value added processes. The overall cycle time has decreased; as a result more units are being processed at the same time in maintenance facilities. The transportation time remained nearly the same in second simulation model, even with the slightly increased number of RTIs available. The scheduled utilization rate of the employees working in most maintenance stations had increased; however they still remain very low in general.

- It can be concluded that the assumed **minor changes** in maintenance system **had an instant positive effect** on the system; full adoption of RFID technology in long term would give many benefits for the company, both from operational and financial perspective, therefore the benefits of RFID technology for the management of RTIs can be justified.
- There is **a number of effects** caused by assumed RFID adoption on maintenance (and overall system) processes in “Swire Oilfield Services” **that cannot be measured by numerical values**. Such effects include better planning and scheduling possibilities, reduced uncertainty of RTIs whereabouts, and reduced number of manual errors and so on. The value of these effects can be more or less measured only after RFID technology is adopted into the system.

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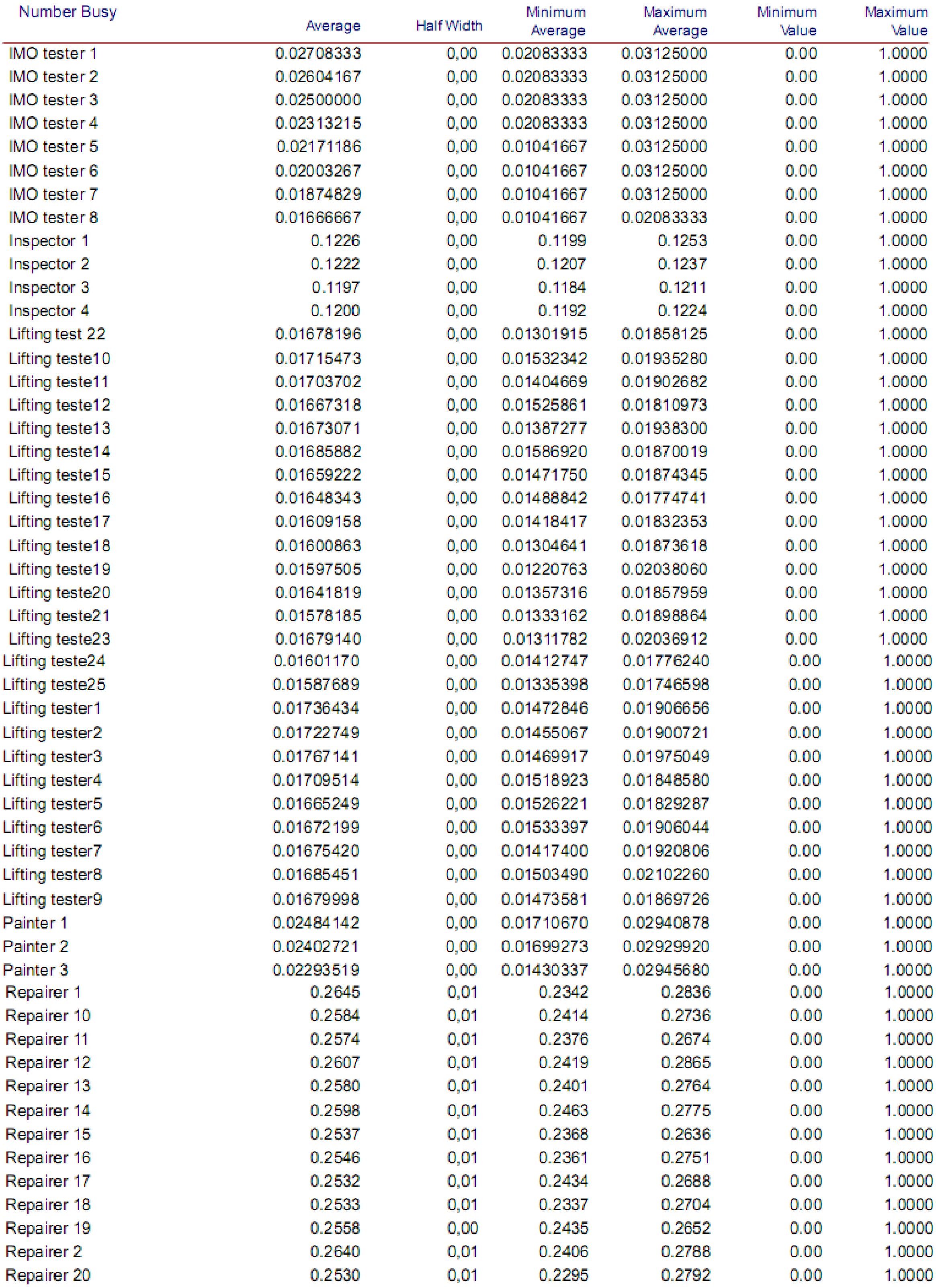
Appendices

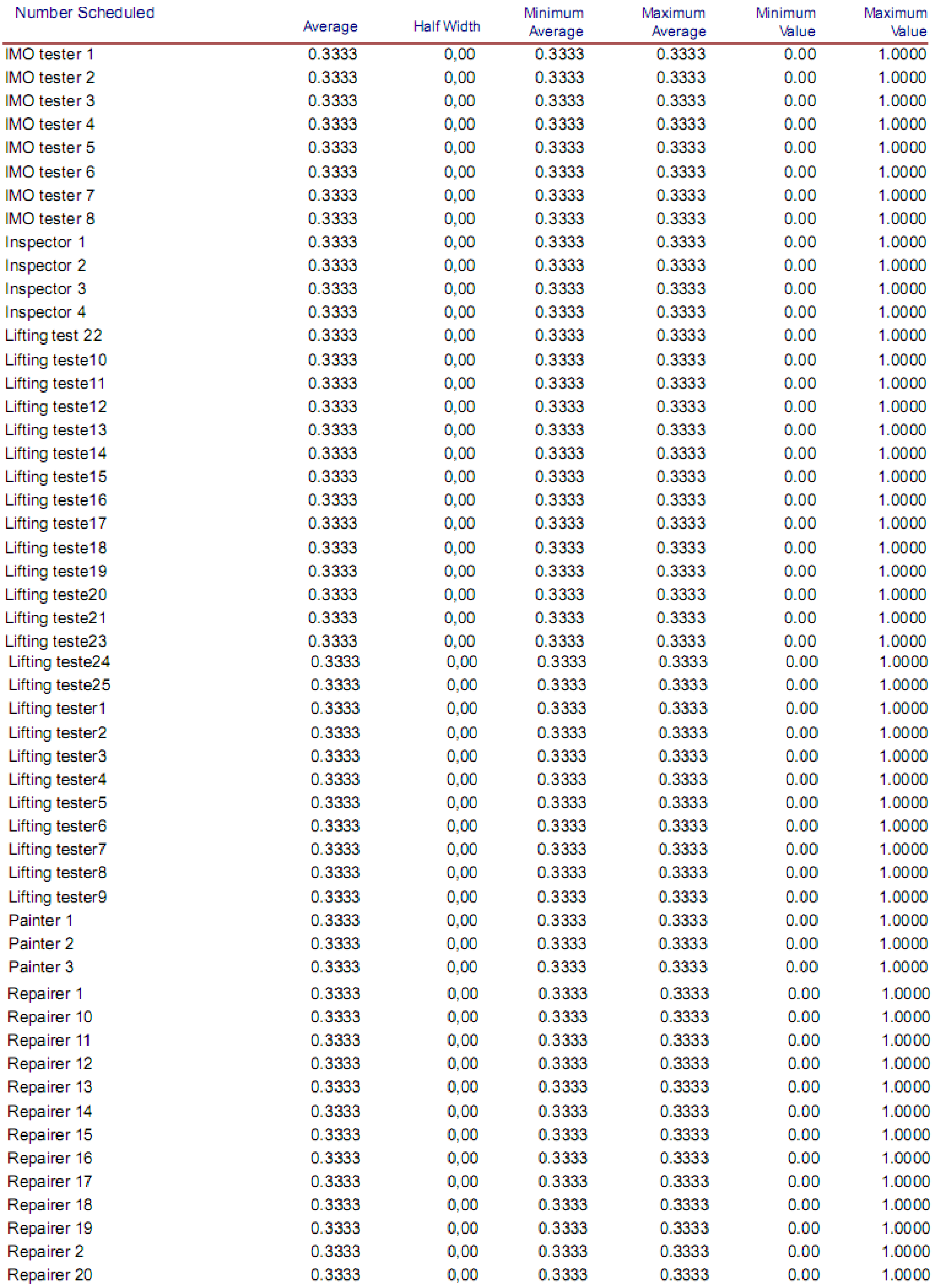
Appendix A: "Number busy" statistics of the first simulation model



Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IMO tester 1	0.02708333	0,00	0.02083333	0.03125000	0.00	1.0000
IMO tester 2	0.02604167	0,00	0.02083333	0.03125000	0.00	1.0000
IMO tester 3	0.02500000	0,00	0.02083333	0.03125000	0.00	1.0000
IMO tester 4	0.02313215	0,00	0.02083333	0.03125000	0.00	1.0000
IMO tester 5	0.02171186	0,00	0.01041667	0.03125000	0.00	1.0000
IMO tester 6	0.02003267	0,00	0.01041667	0.03125000	0.00	1.0000
IMO tester 7	0.01874829	0,00	0.01041667	0.03125000	0.00	1.0000
IMO tester 8	0.01666667	0,00	0.01041667	0.02083333	0.00	1.0000
Inspector 1	0.1226	0,00	0.1199	0.1253	0.00	1.0000
Inspector 2	0.1222	0,00	0.1207	0.1237	0.00	1.0000
Inspector 3	0.1197	0,00	0.1184	0.1211	0.00	1.0000
Inspector 4	0.1200	0,00	0.1192	0.1224	0.00	1.0000
Lifting test 22	0.01678196	0,00	0.01301915	0.01858125	0.00	1.0000
Lifting teste10	0.01715473	0,00	0.01532342	0.01935280	0.00	1.0000
Lifting teste11	0.01703702	0,00	0.01404669	0.01902682	0.00	1.0000
Lifting teste12	0.01667318	0,00	0.01525861	0.01810973	0.00	1.0000
Lifting teste13	0.01673071	0,00	0.01387277	0.01938300	0.00	1.0000
Lifting teste14	0.01685882	0,00	0.01586920	0.01870019	0.00	1.0000
Lifting teste15	0.01659222	0,00	0.01471750	0.01874345	0.00	1.0000
Lifting teste16	0.01648343	0,00	0.01488842	0.01774741	0.00	1.0000
Lifting teste17	0.01609158	0,00	0.01418417	0.01832353	0.00	1.0000
Lifting teste18	0.01600863	0,00	0.01304641	0.01873618	0.00	1.0000
Lifting teste19	0.01597505	0,00	0.01220763	0.02038060	0.00	1.0000
Lifting teste20	0.01641819	0,00	0.01357316	0.01857959	0.00	1.0000
Lifting teste21	0.01578185	0,00	0.01333162	0.01898864	0.00	1.0000
Lifting teste23	0.01679140	0,00	0.01311782	0.02036912	0.00	1.0000
Lifting teste24	0.01601170	0,00	0.01412747	0.01776240	0.00	1.0000
Lifting teste25	0.01587689	0,00	0.01335398	0.01746598	0.00	1.0000
Lifting tester1	0.01736434	0,00	0.01472846	0.01906656	0.00	1.0000
Lifting tester2	0.01722749	0,00	0.01455067	0.01900721	0.00	1.0000
Lifting tester3	0.01767141	0,00	0.01469917	0.01975049	0.00	1.0000
Lifting tester4	0.01709514	0,00	0.01518923	0.01848580	0.00	1.0000
Lifting tester5	0.01665249	0,00	0.01526221	0.01829287	0.00	1.0000
Lifting tester6	0.01672199	0,00	0.01533397	0.01906044	0.00	1.0000
Lifting tester7	0.01675420	0,00	0.01417400	0.01920806	0.00	1.0000
Lifting tester8	0.01685451	0,00	0.01503490	0.02102260	0.00	1.0000
Lifting tester9	0.01679998	0,00	0.01473581	0.01869726	0.00	1.0000
Painter 1	0.02484142	0,00	0.01710670	0.02940878	0.00	1.0000
Painter 2	0.02402721	0,00	0.01699273	0.02929920	0.00	1.0000
Painter 3	0.02293519	0,00	0.01430337	0.02945680	0.00	1.0000
Repairer 1	0.2645	0,01	0.2342	0.2836	0.00	1.0000
Repairer 10	0.2584	0,01	0.2414	0.2736	0.00	1.0000
Repairer 11	0.2574	0,01	0.2376	0.2674	0.00	1.0000
Repairer 12	0.2607	0,01	0.2419	0.2865	0.00	1.0000
Repairer 13	0.2580	0,01	0.2401	0.2764	0.00	1.0000
Repairer 14	0.2598	0,01	0.2463	0.2775	0.00	1.0000
Repairer 15	0.2537	0,01	0.2368	0.2636	0.00	1.0000
Repairer 16	0.2546	0,01	0.2361	0.2751	0.00	1.0000
Repairer 17	0.2532	0,01	0.2434	0.2688	0.00	1.0000
Repairer 18	0.2533	0,01	0.2337	0.2704	0.00	1.0000
Repairer 19	0.2558	0,00	0.2435	0.2652	0.00	1.0000
Repairer 2	0.2640	0,01	0.2406	0.2788	0.00	1.0000
Repairer 20	0.2530	0,01	0.2295	0.2792	0.00	1.0000

Repairer 20	0.2530	0,01	0.2295	0.2792	0.00	1.0000
Repairer 21	0.2555	0,01	0.2350	0.2686	0.00	1.0000
Repairer 22	0.2519	0,01	0.2143	0.2760	0.00	1.0000
Repairer 3	0.2597	0,01	0.2379	0.2791	0.00	1.0000
Repairer 4	0.2644	0,01	0.2502	0.2855	0.00	1.0000
Repairer 5	0.2604	0,01	0.2365	0.2819	0.00	1.0000
Repairer 6	0.2537	0,01	0.2331	0.2698	0.00	1.0000
Repairer 7	0.2589	0,01	0.2312	0.2785	0.00	1.0000
Repairer 8	0.2598	0,01	0.2387	0.2874	0.00	1.0000
Repairer 9	0.2575	0,01	0.2405	0.2757	0.00	1.0000
Sandblaster 1	0.06533696	0,01	0.04990445	0.07875193	0.00	1.0000
Sandblaster 2	0.06160784	0,01	0.04700560	0.07658516	0.00	1.0000
Washer 1	0.03480460	0,00	0.02969262	0.03769681	0.00	1.0000
Washer 10	0.03404420	0,00	0.03135583	0.03836766	0.00	1.0000
Washer 11	0.03259244	0,00	0.03055439	0.03717328	0.00	1.0000
Washer 12	0.03341117	0,00	0.03143308	0.03884478	0.00	1.0000
Washer 13	0.03167631	0,00	0.02876914	0.03573960	0.00	1.0000
Washer 14	0.03346523	0,00	0.02788464	0.03525328	0.00	1.0000
Washer 15	0.03270632	0,00	0.02930450	0.03764148	0.00	1.0000
Washer 16	0.03210761	0,00	0.02692925	0.03556367	0.00	1.0000
Washer 2	0.03385714	0,00	0.03036054	0.03810822	0.00	1.0000
Washer 3	0.03509908	0,00	0.03150263	0.03798539	0.00	1.0000
Washer 4	0.03352681	0,00	0.02625187	0.03958305	0.00	1.0000
Washer 5	0.03366484	0,00	0.03037220	0.04068141	0.00	1.0000
Washer 6	0.03371224	0,00	0.03008177	0.03797993	0.00	1.0000
Washer 7	0.03283714	0,00	0.02851204	0.03832357	0.00	1.0000
Washer 8	0.03300471	0,00	0.02964388	0.03759539	0.00	1.0000
Washer 9	0.03254799	0,00	0.02786550	0.03683041	0.00	1.0000

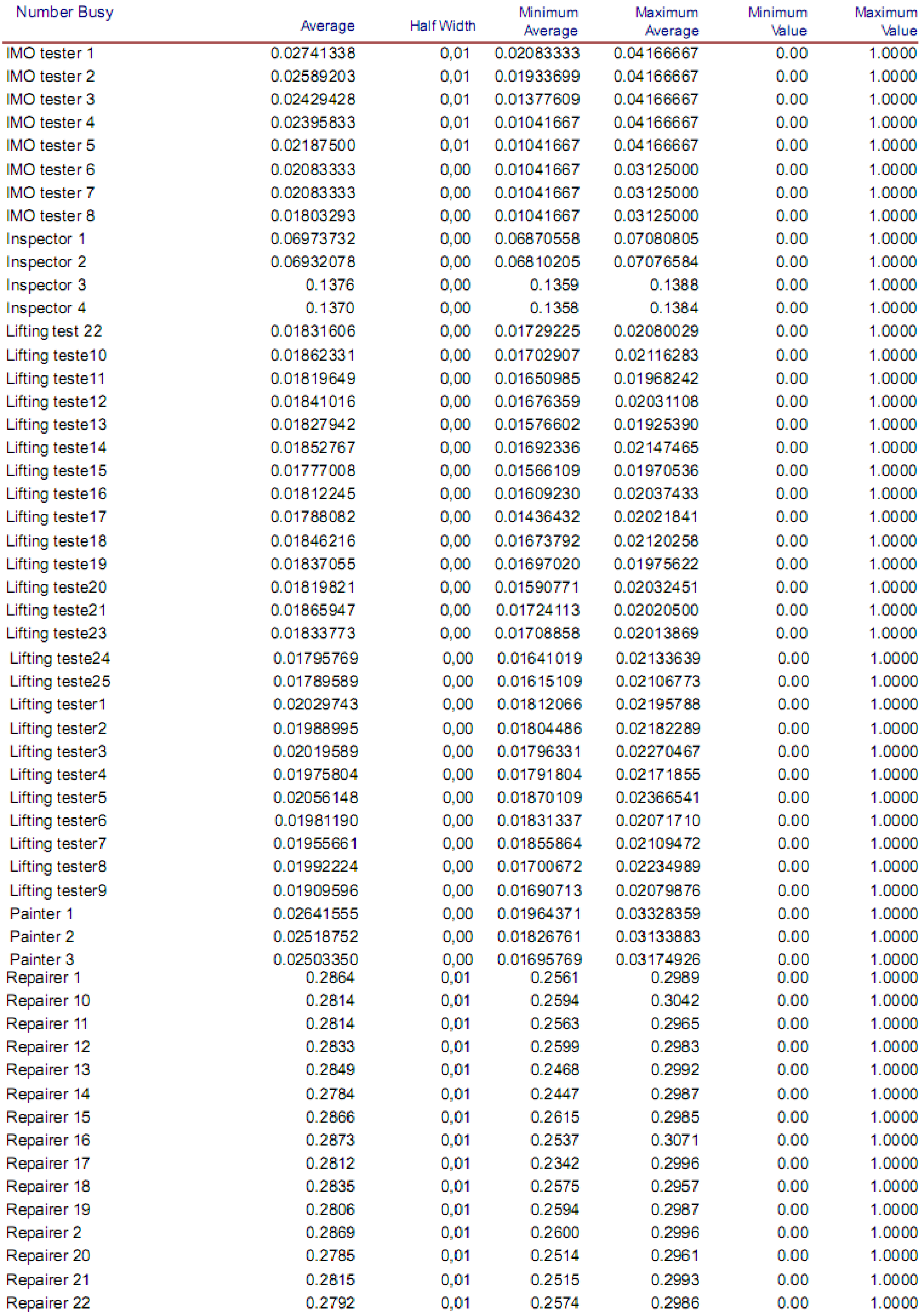
Appendix B: "Number scheduled" statistics of the first simulation model



Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IMO tester 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 5	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 6	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 7	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 8	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Inspector 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Inspector 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Inspector 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Inspector 4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting test 22	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste10	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste11	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste12	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste13	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste14	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste15	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste16	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste17	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste18	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste19	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste20	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste21	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste23	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste24	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste25	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester5	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester6	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester7	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester8	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester9	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Painter 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Painter 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Painter 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 10	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 11	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 12	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 13	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 14	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 15	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 16	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 17	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 18	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 19	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 20	0.3333	0,00	0.3333	0.3333	0.00	1.0000

Repairer 21	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 22	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 5	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 6	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 7	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 8	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 9	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Sandblaster 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Sandblaster 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 10	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 11	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 12	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 13	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 14	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 15	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 16	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 5	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 6	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 7	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 8	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 9	0.3333	0,00	0.3333	0.3333	0.00	1.0000

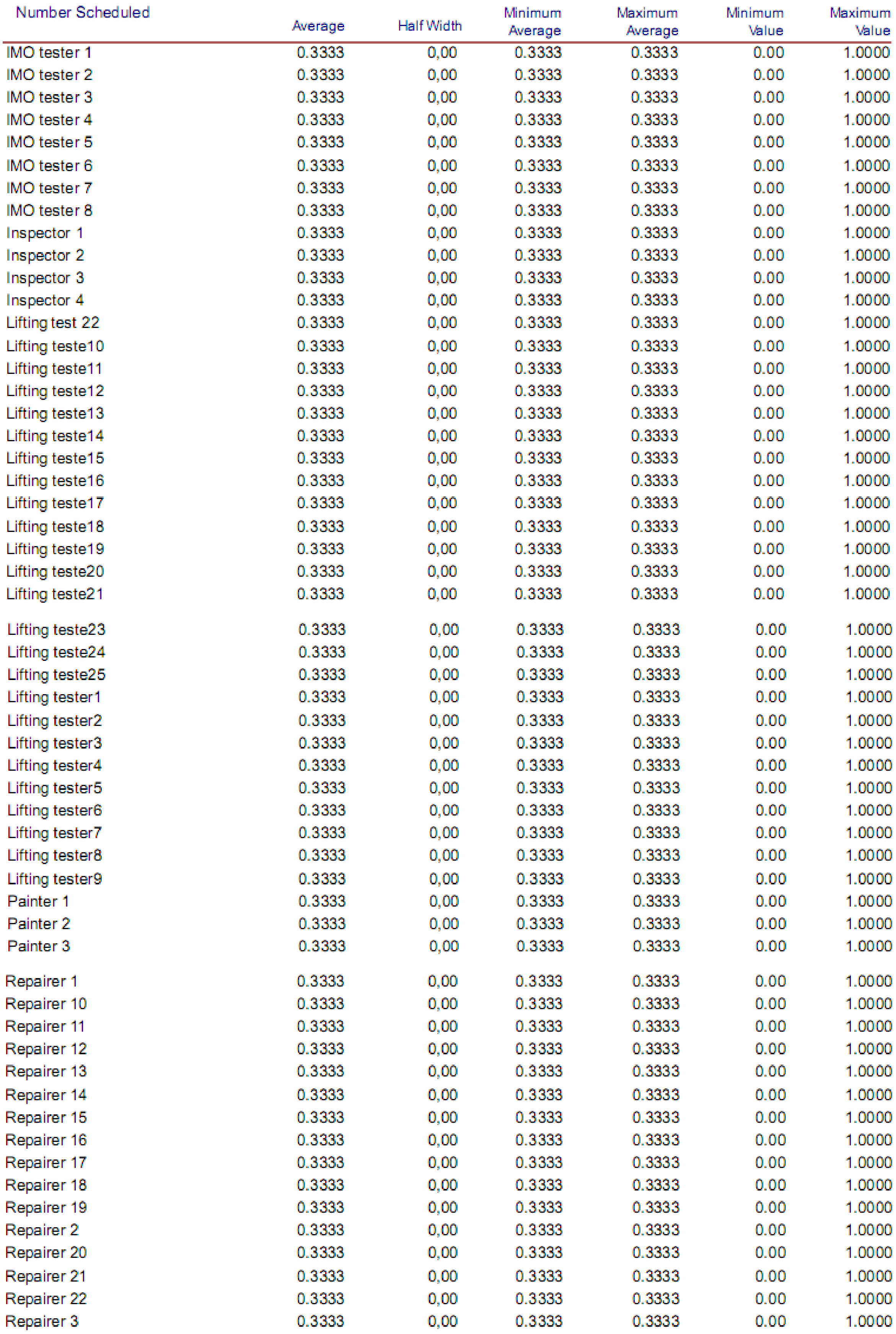
Appendix C: "Number busy" statistics of the second simulation model



Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IMO tester 1	0.02741338	0,01	0.02083333	0.04166667	0.00	1.0000
IMO tester 2	0.02589203	0,01	0.01933699	0.04166667	0.00	1.0000
IMO tester 3	0.02429428	0,01	0.01377609	0.04166667	0.00	1.0000
IMO tester 4	0.02395833	0,01	0.01041667	0.04166667	0.00	1.0000
IMO tester 5	0.02187500	0,01	0.01041667	0.04166667	0.00	1.0000
IMO tester 6	0.02083333	0,00	0.01041667	0.03125000	0.00	1.0000
IMO tester 7	0.02083333	0,00	0.01041667	0.03125000	0.00	1.0000
IMO tester 8	0.01803293	0,00	0.01041667	0.03125000	0.00	1.0000
Inspector 1	0.06973732	0,00	0.06870558	0.07080805	0.00	1.0000
Inspector 2	0.06932078	0,00	0.06810205	0.07076584	0.00	1.0000
Inspector 3	0.1376	0,00	0.1359	0.1388	0.00	1.0000
Inspector 4	0.1370	0,00	0.1358	0.1384	0.00	1.0000
Lifting test 22	0.01831606	0,00	0.01729225	0.02080029	0.00	1.0000
Lifting teste10	0.01862331	0,00	0.01702907	0.02116283	0.00	1.0000
Lifting teste11	0.01819649	0,00	0.01650985	0.01968242	0.00	1.0000
Lifting teste12	0.01841016	0,00	0.01676359	0.02031108	0.00	1.0000
Lifting teste13	0.01827942	0,00	0.01576602	0.01925390	0.00	1.0000
Lifting teste14	0.01852767	0,00	0.01692336	0.02147465	0.00	1.0000
Lifting teste15	0.01777008	0,00	0.01566109	0.01970536	0.00	1.0000
Lifting teste16	0.01812245	0,00	0.01609230	0.02037433	0.00	1.0000
Lifting teste17	0.01788082	0,00	0.01436432	0.02021841	0.00	1.0000
Lifting teste18	0.01846216	0,00	0.01673792	0.02120258	0.00	1.0000
Lifting teste19	0.01837055	0,00	0.01697020	0.01975622	0.00	1.0000
Lifting teste20	0.01819821	0,00	0.01590771	0.02032451	0.00	1.0000
Lifting teste21	0.01865947	0,00	0.01724113	0.02020500	0.00	1.0000
Lifting teste23	0.01833773	0,00	0.01708858	0.02013869	0.00	1.0000
Lifting teste24	0.01795769	0,00	0.01641019	0.02133639	0.00	1.0000
Lifting teste25	0.01789589	0,00	0.01615109	0.02106773	0.00	1.0000
Lifting tester1	0.02029743	0,00	0.01812066	0.02195788	0.00	1.0000
Lifting tester2	0.01988995	0,00	0.01804486	0.02182289	0.00	1.0000
Lifting tester3	0.02019589	0,00	0.01796331	0.02270467	0.00	1.0000
Lifting tester4	0.01975804	0,00	0.01791804	0.02171855	0.00	1.0000
Lifting tester5	0.02056148	0,00	0.01870109	0.02366541	0.00	1.0000
Lifting tester6	0.01981190	0,00	0.01831337	0.02071710	0.00	1.0000
Lifting tester7	0.01955661	0,00	0.01855864	0.02109472	0.00	1.0000
Lifting tester8	0.01992224	0,00	0.01700672	0.02234989	0.00	1.0000
Lifting tester9	0.01909596	0,00	0.01690713	0.02079876	0.00	1.0000
Painter 1	0.02641555	0,00	0.01964371	0.03328359	0.00	1.0000
Painter 2	0.02518752	0,00	0.01826761	0.03133883	0.00	1.0000
Painter 3	0.02503350	0,00	0.01695769	0.03174926	0.00	1.0000
Repairer 1	0.2864	0,01	0.2561	0.2989	0.00	1.0000
Repairer 10	0.2814	0,01	0.2594	0.3042	0.00	1.0000
Repairer 11	0.2814	0,01	0.2563	0.2965	0.00	1.0000
Repairer 12	0.2833	0,01	0.2599	0.2983	0.00	1.0000
Repairer 13	0.2849	0,01	0.2468	0.2992	0.00	1.0000
Repairer 14	0.2784	0,01	0.2447	0.2987	0.00	1.0000
Repairer 15	0.2866	0,01	0.2615	0.2985	0.00	1.0000
Repairer 16	0.2873	0,01	0.2537	0.3071	0.00	1.0000
Repairer 17	0.2812	0,01	0.2342	0.2996	0.00	1.0000
Repairer 18	0.2835	0,01	0.2575	0.2957	0.00	1.0000
Repairer 19	0.2806	0,01	0.2594	0.2987	0.00	1.0000
Repairer 2	0.2869	0,01	0.2600	0.2996	0.00	1.0000
Repairer 20	0.2785	0,01	0.2514	0.2961	0.00	1.0000
Repairer 21	0.2815	0,01	0.2515	0.2993	0.00	1.0000
Repairer 22	0.2792	0,01	0.2574	0.2986	0.00	1.0000

Repairer 3	0.2831	0,01	0.2490	0.3004	0.00	1.0000
Repairer 4	0.2857	0,01	0.2545	0.3007	0.00	1.0000
Repairer 5	0.2847	0,01	0.2686	0.2987	0.00	1.0000
Repairer 6	0.2836	0,01	0.2518	0.2928	0.00	1.0000
Repairer 7	0.2873	0,01	0.2739	0.3016	0.00	1.0000
Repairer 8	0.2820	0,01	0.2493	0.2941	0.00	1.0000
Repairer 9	0.2847	0,01	0.2501	0.3025	0.00	1.0000
Sandblaster 1	0.08006686	0,01	0.06752328	0.0939	0.00	1.0000
Sandblaster 2	0.07657183	0,01	0.06462968	0.0936	0.00	1.0000
Washer 1	0.03762765	0,00	0.03160636	0.04241296	0.00	1.0000
Washer 10	0.03549238	0,00	0.03174409	0.03895733	0.00	1.0000
Washer 11	0.03495960	0,00	0.02984158	0.03776416	0.00	1.0000
Washer 12	0.03629351	0,00	0.03210448	0.03781333	0.00	1.0000
Washer 13	0.03529586	0,00	0.02824397	0.04127484	0.00	1.0000
Washer 14	0.03546524	0,00	0.03315285	0.03928512	0.00	1.0000
Washer 15	0.03560806	0,00	0.03128545	0.03822398	0.00	1.0000
Washer 16	0.03595946	0,00	0.03245910	0.04100498	0.00	1.0000
Washer 2	0.03674778	0,00	0.03120611	0.04006560	0.00	1.0000
Washer 3	0.03788658	0,00	0.03538913	0.04069141	0.00	1.0000
Washer 4	0.03679155	0,00	0.03373633	0.03998688	0.00	1.0000
Washer 5	0.03543026	0,00	0.03234829	0.03924241	0.00	1.0000
Washer 6	0.03508676	0,00	0.03261326	0.03810630	0.00	1.0000
Washer 7	0.03598502	0,00	0.03078453	0.03994313	0.00	1.0000
Washer 8	0.03562004	0,00	0.03202206	0.03918453	0.00	1.0000
Washer 9	0.03624201	0,00	0.03354185	0.04016219	0.00	1.0000

Appendix D: “Number scheduled” statistics of the second simulation model



Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
IMO tester 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 5	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 6	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 7	0.3333	0,00	0.3333	0.3333	0.00	1.0000
IMO tester 8	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Inspector 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Inspector 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Inspector 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Inspector 4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting test 22	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste10	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste11	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste12	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste13	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste14	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste15	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste16	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste17	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste18	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste19	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste20	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste21	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste23	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste24	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting teste25	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester5	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester6	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester7	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester8	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Lifting tester9	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Painter 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Painter 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Painter 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 10	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 11	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 12	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 13	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 14	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 15	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 16	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 17	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 18	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 19	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 20	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 21	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 22	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000

Repairer 4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 5	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 6	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 7	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 8	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Repairer 9	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Sandblaster 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Sandblaster 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 1	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 10	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 11	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 12	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 13	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 14	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 15	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 16	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 2	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 3	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 4	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 5	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 6	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 7	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 8	0.3333	0,00	0.3333	0.3333	0.00	1.0000
Washer 9	0.3333	0,00	0.3333	0.3333	0.00	1.0000