KAUNAS UNIVERSITY OF TECHNOLOGY

MECHANICAL ENGINEERING AND DESIGN FACULTY

INDRĖ KUMETYTĖ

ANALYSIS AND IMPROVEMENT OF LAST WAREHOUSING PROCESSES

Master's degree final project

Supervisor

Assoc.prof.Dr. Kazimieras Juzėnas

KAUNAS, 2017

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KAUNAS, 2017

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(Title and code of study programme)

"Analysis and improvement of last warehousing processes"

DECLARATION OF ACADEMIC INTEGRITY

24 Gegužės 2017
Kaunas

I confirm that the final project of mine, **Indrė Kumetytė**, on the subject ".Analysis and improvement of warehousing processes." is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis has been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

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KAUNAS UN IVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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Production engineering	
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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree is research or applied type project, for completion and defence of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Analysis and improvement of last warehousing processes

Approved by the Dean Order No.V25-11-8, 21 April 2017

2. Aim of the project

To analyze and proof the main issue of lasts' warehousing processes and to suggest and reveal the effectiveness of the most effective method of controlling warehouse.

3. Structure of the project

The analysis of warehousing processes, inventory management and selection and adjustment of optimization model to certain warehousing processes.

4. Requirements and conditions

During research project time it should be maintained the company's and its customers' confidentiality in the cases which are made for the company and its customers' preferences.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 20__ ________ __st.

Student	______________________	______________________
	(*Name, Surname of the Student*)	(*Signature, date*)
Supervisor	______________________	______________________
	(*Position, Name, Surname*)	(*Signature, date*)

Kumetytė Indrė. Analysis and improvement of last warehousing processes. *Master's* Final Project / supervisor Doc. Dr. Kazimieras Juzėnas; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Research field and area: Technological Science, Production Engineering

Keywords: *warehouse, last, algorithm, optimization, pick path, logistic.*

Kaunas, 2017, 60 p.

SUMMARY

The efficiency and productivity are one of the most significant factors in every manufacturing company in order to maintain competitiveness and leadership in the market. To keep it, an enterprise has to pay a lot of attention and efforts to inside logistic and management of its inventory. The analyzed selected Lithuanian production company's activity and production principles addresses to major nowadays problem – inventory management and time reduction for warehousing processes. Thus, in this final master project it is analyzed the real issues of last warehousing processes, suggested alternatives for optimization, solving the problem of processes effectiveness. The results of investigation and analysis are used for the technological suggestion to the workshop thus increasing the productivity of warehousing processes.

Also, there is analyzed inventory management methods in other similar activity production companies worldwide. The technological path is suggested for inventory management – it is selected the optimize pick path algorithm due to create the whole new database of last warehouse with optimized searching methods of lasts.

Kumetytė Indrė. Kurpalių sandėliavimo procesų tyrimas ir tobulinimas. *Magistro* baigiamasis projektas / vadovas Doc. Dr. Kazimieras Juzėnas; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas

Mokslo kryptis ir sritis: Technologijų mokslas, Gamybos inžinerija

Reikšminiai žodžiai: *sandėlys, kurpalis, algoritmas, grietojo kelio paieška, optimizavimas, logistika*

Kaunas, 2017, 60 psl.

SANTRAUKA

Gamybos efektyvumas ir našumas yra vieni svarbiausių kriterijų kikevienoje gamybos įmonėje siekiant išlaikyti konkurencingumą ir lyderiauti rinkoje. Išlaikyti tai, įmonė taip pat turi daug dėmesio skirti vidaus logistikai ir inventoriaus valdymui. Išanalizavus pasirinktos Lietuvos gamybos įmonės veiklą ir gamybos principus, sprendžiama viena opiausių problemų – inventoriaus valdymas ir laiko mažinimas procesams sandėlyje. Tad šiame magistro baigiamaje darbe analizuojami konkrečios kurpalių sandėliavimo problemos, teikiamos alternatyvos optimizavimui, sprendžiamas efektyvumo klausimas. Analizės rezultatai panaudojami siūlant technologinį patobulinimą įmonės sandėlio valdymui, kuriame ir buvo atlikti tyrimas ir skaičiavimai.

Taip pat analizuojami inventoriaus valdymo klausimai ir jau įdiegti modeliai tarptautinėse kompanijose. Pateikiamas technologinis pasiūlymas inventoriaus valdymui-parenkamas optimizavimo algoritmas greitojo kelio paieškai taip siekiant sukurti naują kurpalių duomenų valdymo ir paieškos sistemą sandėlyje.

Content

Introduction

Lithuania continues to rise in industrial production and export volumes reviewing the logistics centres market in first half of 2016. The volume of industry in Lithuania tended to grow up to 10 billion euros threshold. Comparing with previous year, it increased up to 7.9% [1]. These results shows also the increment of logistics centre, its' development, more effective inventory management and high importance of effective models for controlling. Recently it has already started the most modern logistics centres construction in the Baltic States with modernized inventory management, its controlling systems and redistribution services. In this way, it is evident the real importance of effective and optimize logistics systems, inventory management models and efficiency.

Nowadays, with the fast-growing technology and economy worldwide and extremely competitive environment it would be particularly hard to discover an enterprise, which do not apply logistics principles as one of the main competitive tools, achieving its superiority. Thus, to acquire effective decisions, it is required a good coordination of production and warehousing processes, inventory management activities which are traditionally regarded as main logistics operations and not only. As Bill Gates, the chairman of Microsoft said: "The inventory, the VALUE of my company walks out the door every evening" [2]. This quote highlights the real importance and role of inventory in all kind of business fields and its crucial importance of maintaining, optimizing it. Many different inventory management models and systems are applied in production companies however it is not only enough to apply. The main goal is to discover the most effective system that will be the key element of company's success in the market. In this way, the real Lithuanian production company's inventory management issue is analysed which has direct influence to production and delay problems, to achieve the most effective path of solving it.

Aim of this project – to analyse and suggest the improvement model for controlling warehousing processes. Tasks of this project:

1. Analyse the methods of inventory management
2. Analyse warehousing processes in selected production company
3. Select and adjust the effective model of warehousing processes
4. Simulate implementation of a new warehousing system model with new data base and warehouse plan of storing lasts

1. Methods of logistics improvement and inventory management

Logistics itself is a very broad term and can be determined in different areas. Its management is a very significant and important factor in many companies. It takes supply chain management, which based on customer demands through planning, controlling, implementing, also storage and related information, goods and services flow with the main and global aim to reduce expenses and enhance customer's satisfaction.

Logistics management and organization is a key factor to provide smooth, operative and effective functionality of many processes in the company. Warehouse and inventory management systems will be the most important aspects and concerns for this research project with the main goal to find and adjust the most effective model and system to specific manufacturing company.

Logistic system

A brief overview of main logistic systems and its features based on inside logistic management in different enterprises.

1. Supply chain and its' management.

It consists of controlling, managing, improving flows of materials and information, which comes straight from supplier to final customers. "Planning and controlling all of the business processes – from end-customer to raw material suppliers – that link together partners in a supply chain in order to serve the needs of the end-customer" –as Vaaland and Heide summaries [3]. It is a connection, which is based on many functions linked together. Researchers and logistics managers sum up supply chain management into five basic principles such as organizational structure, product flow structure, and communication between main networks, activity control, information flow and controlling methods. The direct objective of supply chain management based on effective control of all networks and operations due to improve all the necessary performances in case to avoid and exterminate the waste and create more effective usage of capabilities and technologies [4].

2. The internal logistics system

It involves logistics main activities such as internal transports, material handling, storing, warehousing, and packaging. The design of internal logistics system is a key step to effectiveness and reduction of optimization in the company. In addition, internal system is controlled by conditions and main aims which are the directions of how the system's resources are managed [4] [5].

Logistics objectives:

Every enterprise has a goal to maintain the most useful and effective system in logistic. The main objectives are [5]:

- Cost reduction – reducing the costs related to storage and movement of goods
- Capital reduction – reducing the costs on investment to logistics systems with the aim to increase the return on logistics assets.
- Service improvement – pre-transaction elements, transaction elements, post-transaction elements.

Analysing and evaluating logistics system it can be created a complex model, which would help the company's manager to make strategic decisions about the management of new products, its distribution, and sales effectiveness and to ensure efficient customer service. It is vital to overview the methods of improvement seeking the optimization of certain warehouses inventory management, which is highly connected to logistic, and its management. To optimize the logistic system in the enterprise it is very important to evaluate the individual components of the system and to accomplish a comprehensive analysis thus including the capacity of logistics system, transportation costs, product profitability, industry standards and comparative analysis.

Improving the internal logistics system

The construction and new facilities planning are most common objectives of design of new internal logistics system. An important step is the improvement of supply chain parts and activities that also included logistics with its internal system. The main objective is the maintain cost reduction and service improvement and enhancement. Automation is extremely necessary tool for keeping logistics activity, maintaining its processes and improving competitiveness. Many automated applications and different kinds of equipment are used for improving logistics activity. Here are the examples of most popular and wide spread applications and types of automation [5]:

- Automated loading and unloading systems and guided vehicles (AGVs)
- Automated storage and retrieval systems (AS/RS)
- Bar code systems
- Industrial robots/robotics
- IT systems for planning, managing operations and systems, etc.
- Item picking devices
- Lifting aids for manual handling

- Mechanized palletizing
- Radio-frequency identification systems
- Sorting or screening systems
- Various forms of information automation for communication, data handling, monitoring.
- Vision systems

Inventory management models and its control is the vital issues in organizational management and main concern in business area. This is the main object of this research as the real production company's example will be analysed and proper solutions will be presented. Overall, inventory management encompasses all aspects of managing an enterprise's inventory such as purchasing, receiving, tracking, warehousing and storage, turnover. These functions must be performed in sequence in case to have a well-run inventory management and control system. Computerization plays a crucial role nowadays in business environment, which makes it possible to integrate various functional subsystems that are a part of inventory management with the goal to maintain a single cohesive system.

Nowadays, even small or mid-sized enterprises rely on computerized inventory management systems. Like there are lots of retail outlets, manufactures which continue to rely on manual means of inventory tracking due to some financial issues. But for the firms which operates in industries with higher volume turnover of raw materials and finished products, computerized tracking systems have become as a key component of business strategies aimed at increasing productivity and maintaining competitiveness.

Automation has a huge impact for all phases of inventory management like monitoring and counting of items, recording and retrieval of item storage location, noting any changes in inventory and even including handling requirements. As D. Eskow noted in *PC Week* [10], business executives are: "increasingly integrating financial data, such as accounts receivable, with sales information that includes customer histories. The goal: to control inventory quarter to quarter, so it does not come back to bite the bottom line. Key components of an integrated system are general ledger, electronic data interchange, database connectivity, and connections to a range of vertical business applications". It was made a huge improvement for tools, which are used in managing inventories. It is a vendor-managed inventory (VMI) systems newly trend of inventory control. In this system, the distributors and manufacturers decide on that customers take control over the inventory management. In this way, daily reports are being sent automatically from the customer to the distributor and the distributor adds the customer stocks according its needs. The manufacturer observes what is being sold and makes all arrangements to send new products to customers automatically.

In this certain model, no specific paperwork or phone calls are needed to maintain the process and remain the supply chain uninterrupted. Indeed, it is savings on labour costs and time. As warehousing expert, S. Bergin has noted: “The key to getting productivity gains from inventory management is placing real-time intelligent information processing in the warehouse. This empowers employees to take actions that achieve immediate results. Real-time processing in the warehouse uses combinations of hardware including material handling and data collection technologies. But according to these executives, the intelligent part of the system is sophisticated software which automates and controls all aspects of warehouse operations." The significant component of good inventory management is implementation and maintaining of sensible, effective warehousing design, which is well-organized storage layout with the system. This could include stock locator database, grid coordinate numbering system, communication systems.

Here have been analyzed basic models of inventory control management applied in many enterprises worldwide. There dominate many diverse techniques of inventory control to ensure the maximum efficiency and profitability. As one example is maintaining a perpetual inventory system – also known as automatic inventory system. This method is designed with the aim to keep a constant track of quantity and value of each stored item. Many wholesale distributors leverage a combination of an Enterprise Resource Planning (ERP) or Warehouse Management System (WMS) in conjunction with an Inventory Optimization solution, such as EazyStock, to optimize inventory balances. Most ERP and WMS technologies struggle to keep costs low and service rates high, which is why optimization software can be so valuable to operations processes. Another widely used model is ABC analysis model, which is highly used in enterprises maintaining several types of inventories where is no need to exercise the same degree of control on all the items. The main idea is to allocate the items closets to the shipping and receiving area according its’ demand frequency. As the demand for each product decreases over time, products should be allocated backwards to free up space for items with higher inventory turnover or for new product introductions that have high demand. The goal is to design optimized warehouse layout to reduce time spent looking for product in the back. This core of technique is going to be applied in further analysis of last warehouse optimization model where the lasts will be allocated according them frequency of orders.

In this way, order picking systems and its brief overview is necessary to find the most effective one for selected warehouse model. Order picking is divided in high-level approaches names as order picking systems (OPS). Their main design depends on such warehousing elements as products number, size, value, also customer order to layout of the warehouse. Here below is the description of four main OPR:

- Picker-to-parts is a system based on human work. Employers pick up the products between aisles on foot using specific vehicles suitable for carry out items from warehouse. This system allows picking up from only one item or even a batch of multiple orders. Also it is divided into low-level picker to parts system where the items are taken out from warehouse and high-level system, where a lifting truck or even a crane is necessary to select the products especially those which are from high storage places [11].
- Pick-to-box is a system based on the division of multiple area and pickers are divided and assigned to certain zones for picking. Orders can be picked up zone after zone or simultaneously in all zones. All those zones could be connected by a conveyor belt, which carry out the items. The advantageous of this system is that there is save time on travelling for pickers and also research time because picker know their area thus picking process is faster [11].
- Pick-and-sort is a system based on automatization in warehouse. Items are picked up and put on the conveyor, which takes them to sorting areas. This is beneficial due to the reduction on travelling time and searching out. On the other hand, it is more suitable for huge warehouses fully automated [11].
- Parts-to-picker is a system based on full automatization as well. There are certain pallets, which are retrieved from warehouse to picking, are. The picker selects the necessary products and the rest of pallet travels back to the warehouse. This is advantageous because employer does not need to go to warehouse and spend time on searching out [11].

After brief analysis of common order picking systems, it is evident that to maintain the order retrieval process in the warehouse is necessary a good management system and models. For huge quantities warehouses with huge areas it is essential to have automatization systems to keep the efficiency and the effectiveness of whole processes. The main aim of this research is to find the best tool for optimal inventory management production company. Considering many models and techniques given previously, it is important to highlight main objectives that must be implemented for inventory control. Many small companies are trying to manage their inventory through EXCEL spreadsheet and specific formulas. As an example, this technique is also applied in certain footwear production company in Lithuania – brief explanation will be explained in further chapter. However, to control a huge quantity is extremely difficult and especially when business starts to grow fast – rely on Excel spreadsheets for inventory management becomes very limited. Thus, appears a need to track inventory management constantly instead of periodically.

Automatization is the biggest advantage of inventory management processes control. To consider basic steps that should be implemented in future last warehouse, here are several inventory optimizations best practices that leads to more optimized supply chain:

Categorize the inventory.

A bit similar with the ABC model. The main object of it is to categorize the inventory due to its value and speed of turnover, which are sales numbers and profitability margins. The software like "EasyStock" helps to track the item's demand and lifecycle.

Automate demand forecasting

It could be used for prediction of how much inventory should be carried for certain period of times. This calculates inventory items based on their demand (sales data) in this case to guarantee minimum and maximum order quantities.

Continuous investments into inventory optimization technology

These are the main factors, which must be considered before starting inventory optimization. Also, these 3 specific features are going to be implemented in planning last warehouse optimization model to create an efficient and well-organized system. But before that, it is essential to analyse the real already operating methods in companies worldwide to realize the effectiveness and see the difference and the results how it can lead to a great success.

2. Case analysis of inventory optimization models application in real companies worldwide

For every enterprise and business, a common goal is to reduce man-hours and increase the overall profit margin of the business. In warehouse, related businesses, optimization of efficiency of order picking can lead to great reductions in the times which takes orders to ship as well as improving the whole effectiveness of its workers. Of all costs associated with warehouse operations, 55-65% of the operational funds are allocated towards order picking [12]. Thus, the numbers reveal the necessity and importance of optimizing this phase of the warehouse process.

Several examples of the influential companies worldwide has been analysed according their warehouse management systems and implemented optimization models. A great example is a worldwide e-shop Amazon based in United Kingdom. Founded in 1994, Amazon is now worth $ 247bn. As they say, "As for any business with tight margins, efficiency is key". The question raise- where is the real success of such a great efficiency? In the warehouses of Amazon, the employees are guided and monitored by certain software. When a customer orders some items online, this system quickly works out where that item is allocated in the inventory and in this way, dispatches an employee to pick up items. As general manager Henry Low explained: "It's not about learning where things are, in your head, or having to memories" [12]. The key thing of this system is that items allocated randomly, there is no logical sequence of the products on shelves. Moreover, the managers confirm that this model help workers to find items easily without thinking too long – whole process is modelled to be as streamlined as humanly possible. The handheld devices (like scanners) which each worker has in all warehouses count down the seconds that they instruct the picker where to go counting down how much it will take to reach certain items. In this way, an employee can pick up to 1,000 items per day because it has a control system. For example, if come up an order with 15 different items at once- the system based on certain algorithm calculates the specific path according which all these 15 items will be picked up according the sequence, without any wandering or spending a lot of time on thinking or trying to remember where these all items could be allocated.

On the other hand, as the world is full of innovations and robotics, the human element is still a weak link to ensure the most effective and efficient warehouses. In this way, many companies create computer-based systems which promises to automate the production chains and not only. The Amazon is one of them – the recent news reveals the Amazon's goal is warehouse based on robotics, automatization of operations to ferry the products. Kiva System is Amazon subsidiary that develops hi-tech warehouse robotics. It’s still not that widely used but the goal is to expand the usage of this robots in warehouses that they would be replace instead of humans picking items from shelves in large spaces. “The shelves are mobile and travel on wheels to stationary pickers who simply lift off the required item. Dutifully, the robot shelves then return to their place” - as Amazon manager H. Low reveals. Even though, more companies such as Sick also has invented sensing equipment that is used in highly automated warehouses and replacing human work. According the recourses, Sick Inspector S30 company replace human workers to visual sensor robotics – automated crane system that can pick and place more quickly, saving up to 10 seconds per pick which is potentially 15% extra picking cycle per hour.

Another great and successful example is the world’s largest home furnishing retailer IKEA, ranked as number 41 on Forbes’ esteemed World’s Most Valuable Brands list [13]. IKEA is an important competitor for many enterprises worldwide with its unique supply chain and inventory management techniques. As the main objective is the inventory management system, it is important to highlight the strategy called High-Flow & Low-Flow. Store operations are supported by high-flow facilities (focused on the 20% of SKUs that account for 80% of the volume) and low-flow warehouses which are manual. In high-flow warehouses, there is automatic storage and retrieval systems for the inventory which has the highest demand (so called costs-per-touch - IKEA’s famous method). And in the low-flow facility there are located products which are not in high demand and those operations rely more on manual process in this case to save employees from shifting and moving inventory around loads of time. This key strategy in warehouse made IKEA world’s most successful enterprise with low operating costs and high product demand.

The recent examples reveal that warehouse optimization in all companies plays an important role and each of it figures out the best and most effective models and alternatives to improve the warehouse processes. For analysed Lithuanian individual orthopaedic footwear company’s warehouse needs an effective optimization model to improve human work. After analysed Amazon’s model it was came up with the decision to find the most effective algorithm model for pick path optimization in last warehouse and implement it with certain requirements.

Company "X" main activity, logistic structure, problems

Company „X" is one of the biggest producers of individual orthopaedic devices in Europe. Its manufacturing centre is in Kaunas, Lithuania. Main clients are B2B companies, more than 90% of production go for export – mostly European countries such as Germany, Switzerland, Benelux, Scandinavia, Finland, and more others. In addition, there are customers in Middle East, Australasia and other places. The enterprise is offering the complete solutions for serving their own patients that includes know-how method, online ordering system, all stages of design and production quick service and possibility to use 3D scanning system.

It is a manufacturing company, which offers the complete production of orthoses, special insoles for shoes, CAD-CAM lasts production, custom-made orthopaedic footwear. Lithuanian enterprise combines the expertise of footwear technicians, footwear engineers-technologists, physicians, orthopaedists and IT engineers. They apply modern technologies such as human body scan, computer designing of production forms, CAM carving and unique business management software are employed.

The production also contains well-known brand EASY WALK – pre-preg carbon fibre production worldwide. The whole production range from ordinary FO's (Foot Orthosis) in figure 2.1 below to complicated KAFO's (Knee Ankle Foot Orthosis) in figure 2.2 below.

Figure 2.1 AFO orthosis [14]

Figure 2.2 KAFO foot orthoses [14]

The other production sector is individual CAD - CAM lasts. The lasts are made according to individual patient's blueprints and girths measurements (each customer sends the data) by adjusting a pair from companies' lasts storage place that most resembles to contours of patient's feet. Mainly beech, oak, wood are used. There is also a production of handmade synthetic lasts for feet with complicated orthopaedic problems. The shape of foot is obtained by filling the plaster and the so-called quick sock is obtained. If digital data of patient's feet or lasts are received from customer, 3D CAD/CAM technology is applied. 3D foot is transformed into a digital last which is much faster than accomplishing it by hand. Then digital model is sent to 5-axis milling machine. The lasts are made from wood and manually inspected in their final stage of production. Consequently, CAD CAM technology let the company to produce lasts more accurately and faster which means lower costs and lower price for customers. In addition, customer can save money and time on transportation expenses.

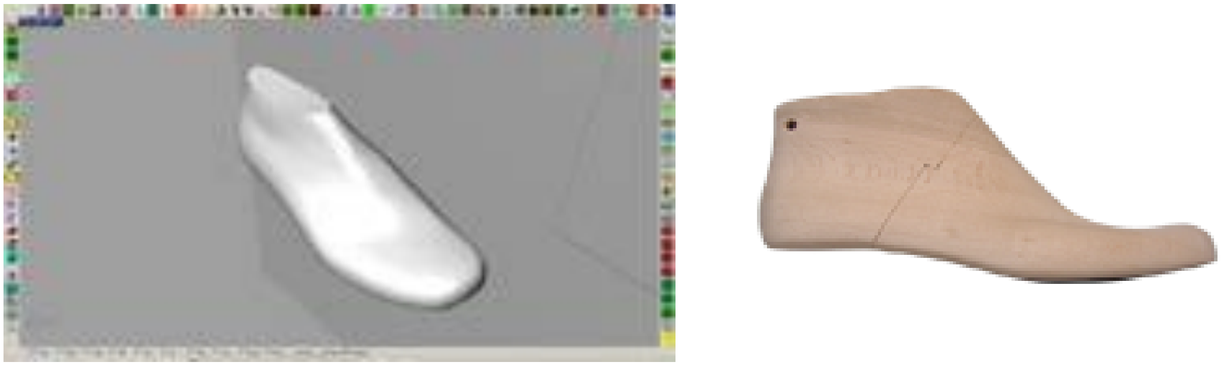

Figure 2.3 CAD data and wooden last [14]

Figure 2.4 The individual footwear with specific stiffeners [14]

Each of the order has its own requirements for production according each customer. The production capacity of individual orthopaedic footwear is around 10,000 pairs per year. The capacities are fluctuating all over the year thus means there is no strict boundary of how many pairs the company has to produce in certain week, month, or during 3 months. In this way, many problems come up: production management, time controlling, just-in-time production, flow of orders, production quality.

The quality is a priority in the company's business activity. A product must meet the specifications provided by the customers, production must be produced according to the requirements stipulated in the Technological Manual of the company, a number of nonconforming products must not exceed the level specified by the quality management system of the company and products must be produced in time observing the production terms agreed with the customer. The following conditions are significantly important for prosperous business and manufacturing activity with the goal to keep customers and maintain their satisfaction, but the reality is showing different results.

The recent problems company is facing with is in the inside logistic. The production results reveal that the most common problem is production terms and distribution of orders in time flow.

Production terms and distribution – main problem of inside logistic of the company

Inside logistic of the company is very important factor for further production and business development. The production results and effectiveness reveals the disadvantages of the logistic structure thus requiring the optimization of inside logistic from the very first steps. It is significantly important to analyse precisely all processes and identify which chain is the weakest one and needs to be re-organized and optimized.

Production time and planning consists of several steps. Usually orders are approved 2-3 weeks ahead and during the peak time – up to 1 month ahead. According 2016-year statistic of individual orthopaedic shoe production's capacities in the table 2.1 below it is seen the quantity of orders during peak time and on average.

Table 2.1 The statistics of received orders for individual orthopaedic shoes production

AVERAGE	PER MONTH	1400
	PER DAY	64
PEAK TIME	PER MONTH	1700
	PER DAY	77

Until now, the "peak time" is not strictly determined. This means that capacities are always fluctuating and production always has to be ready and prepared for higher capacities. In this way, there is an issue with confirmation dates for customers when their orders are going to be produced and send to their companies. In this way, to ensure smooth collaboration and to give approximate time for customers, there is manual confirmation letter sending system (Figure 2.5) which is done by logistics manager and the letters must be sent every day (after each order is released to production).

We would like to inform you that the below listed orders have been confirmed on 2015.08.20

Order number	Product	Shipping scheduled on	Patient
67754 Fred	FW5IMPUB	2015.09.03	[redacted]
67760 Fred	FW5IUB	2015.09.03	[redacted]
67744 Oslo	FW5IMPUB	2015.09.03	[redacted]

This e-mail was generated by the order processing software.

Figure 2.5 Confirmation letter for customer generated by order processing software

Capacity planning is an essential process in the inside logistics of "X" company. They directly influence production capacity. The enterprise concluded the following industrial resource capacity plans:

- Annual capacity planning – this plan evaluates the quantity of production capacities need for certain period of time. For example, there could be an extra employment in production sector if the sales plan identifies future capacity shortages or plan employee's holidays or trainings if the capacity is unused.
- The quarterly capacity plan - quarter term capacity planning. When preparing the quarterly capacity plan it is important to take into account the vacation schedules, future recruitment and termination of employment. Process Manager prepares the quarterly capacity plan.
- Weekly capacity plan - revised 1 or 2 upcoming week capacity plan. Logistics managers prepare weekly capacity plan manually.

There are main factors and restrictions, which must be taken into account in case to choose the right time for order production and delivery time:

- The order has to be made and send according to agreements personally with customer
- Production time has to be planned according to capacity planning
- Optimal batch grouping of orders in case to avoid high shipping costs
- Follow the shipping methods and shipping schedule for reach client

In this sequence, the determination and planning of production time is complicated and cause loads of negative factors overall in production, complaint from customers and so many others. In this way, there follow many other problems:

- There is not accurate estimation of company's production capacity and an ability to produce the order on time because of the lack of convenient and accurate information calculation system, which would calculate and show the planned production capacity at specific real time throughout the production chain.
- There is no informative system to follow how the customer carries out agreed obligations (complies with agreed quotas, ordering production in certain quantity at certain time, which was agreed before). This would allow optimizing the usage of available production that firstly the order from the prior contracts would be produce.
- For planning production capacity, there is no real connection with manufacturing bars capacity for certain time thus if in some cases the manufacturing bar's capacity is changing (might be due to staff illness, equipment failures) there is no automatically recalculation of production plans. Customer service managers follow the weekly report of production capacity that can be not that accurate.
- Orders are entering to "X" system (company's software system) without the sequence but picking up the orders which are in the certain production departments the lack of it. For example, there are received order of IT (Production of insoles and testing shoes), MPUB (modelling the shoes). In insoles department, there are 20 orders waiting for the production, in modelling – 5 orders. In this way, the priority to take MPUB orders. Selecting orders causes delays and it takes time.

Apkrovimai (vnt.)

Data	010LC	020L	030L	040IC	050I	060T	110BB	140M	150D	160C	170U	180BU	190BP
Vėluoja	10	7	6	1	14	3	6	18	11	37	50	34	91
2016.02.23	2	3	16	1	8		8	25	17	36	55	28	45
2016.02.24		2			6		1	38	51	58	49	49	44
2016.02.25			2	2	1			19	47	50	61	44	48
2016.02.26	1	1		2	7		4	7	23	29	46	53	49
2016.02.29			1	2	4		2	13	10	12	27	43	52
2016.03.01				3	3			7	15	17	11	26	43
2016.03.02				2	4			3	7	7	17	11	25
2016.03.03				1	2			4	3	3	7	17	14
2016.03.04					2			2	4	4	3	7	17
2016.03.07								2	2	1	4	3	7
2016.03.08									2	3	2	4	3
2016.03.09											2	2	4
2016.03.10												2	1
2016.03.14													2

Apkrovimai (min.)

Data	010LC	020L	030L	040IC	050I	060T	110BB	140M	150D	160C	170U	180BU	190BP
Vėluoja	269	330	222	40	765	162	495	873	428	1941	7255	1233	10919
2016.02.23	65	150	1397	40	357		560	1125	693	1815	7237	908	5433
2016.02.24		100			345		35	1678	1700	2744	6693	1719	5640
2016.02.25			64	60	67			1041	1406	2310	8304	1457	5579
2016.02.26	4	30		80	375		305	293	943	1634	5962	1729	5545
2016.02.29			47	80	230		140	680	307	566	4265	1421	5063
2016.03.01				85	135			291	542	874	1435	861	4964
2016.03.02				45	230			128	221	363	2488	386	2762
2016.03.03				5	197			193	107	160	1102	622	1898
2016.03.04					100			88	166	245	463	217	2135
2016.03.07								105	73	70	615	93	901
2016.03.08									82	163	244	124	291
2016.03.09											327	62	306
2016.03.10												62	112
2016.03.14													231

010LC - Kurpaliai CAD-CAM
020L - Kurpaliai (1a.)
030L - Kurpaliai (2a.)
040IC - Įdėklai CAD-CAM
050I - Įdėklai
060T - Testinis apavas
110BB - Bepam. kojinė
140M - Modeliavimas
150D - Detalizavimas
160C - Supjovimas
170U - Siuvimas
180BU - Montažas užtraukimas
190BP - Montažas padiniai

Figure 2.6 Production capacity plans [13]

When there is a huge flow of orders which exceeds the maximum of production capacity there are situations when the order cannot be produced according its estimated time because all production departments are already full. If the order has its own strict estimated production (or requested delivery) time thus that order is in the priority list with bigger number of minutes for production, which means the exceeding of production capacity. This situation always causes the failures on time for other orders and even the failure of that certain order. In that case, the order is being delivered not by land (which is much cheaper option) but by air increasing the product price but not for customer, for the production company. The goal is to avoid as much as possible these failures, ensure the accurate production time and deliver the products on time with the minimum shipping costs.

Analysed issues in company reveal the necessity of a new system which controls production capacities and ensures more effective production time. To control the orders and ensure just in time production it is created new "X -2" system. The system is able to control the flow or orders, ensure the limit of orders for a day, week, and month. The orders will have filtering system upon the importance of customers and agreed production terms with each customer. The new software system will be strict with production terms – the orders will not be allowed to be proceeding to certain days if that day is already full of orders. In this way, the production delays will be maximally reduced to ensure just in time production.

3. Analysis and suggestions for improvements of storing lasts in warehouse

Inside logistic of the company is very important factor for further production and business development. The production results and effectiveness reveals the disadvantages of the logistic structure thus requiring the optimization of inside logistic. Pointing view form the first beginning of production there is a goal to find the weakest point of the whole organization structure– where is the highest waste of time, thus meaning which operation or production steps requires the most time consumption. After the analysis of many processes and production, steps it was came up with the main issue. The very first step of starting the production after the order is received from customer – is searching out the certain pair of lasts from the last warehouse for the customer and starting the production (production of orthopaedic shoes). Wooden lasts are the background of modelling and producing shoes according the specific orders. The whole production chain will be described further but the key point of the problem is that there is spent a lot of time of searching manually for a pair of wooden lasts in warehouse to start the production. Furthermore, it is not only important for orthopaedic shoes production, but also for CAD-CAM lasts production. Company also provides only lasts production to other companies, and if for example customer wants to make same changes or corrections of his lasts, it takes too much time only for first step- to search out the lasts. The whole last production with designing (CAD) and manufacturing (CAM) takes 137 min, and from further analysis accomplished it is evident that up to 22 % of whole production time is spent on lasts picking up from warehouse – it is a huge number, which takes even ¼ of the whole production time.

To prove this issue, the research was accomplished during the certain period – 4 months. During every working day, the time waste was calculated and recorded for searching for one certain pair of lasts in warehouse for specific orders. 20 days were taken into account for each month to observe the results and time waste in warehouse. Due to collected data and final values it is seen the **average time** waste for one pair of lasts in warehouse – **15.53 minutes**, the **min value is 3.5** minutes and **maximum time** waste is even **31.5** (Table 3.1)

Table 3.1 Time consumption of manually searching lasts in warehouse

Month/Time Consumption(in minutes)																									Average values	Sum	Min value	Max value
2016.02	16	8	9	23	27	3	16	35	13	9	22	14	16	22	15	11	14	15	26	9	10	13	23	14	15,96	383	3	35
2016.03	7	12	5	12	18	29	14	6	26	13	11	26	7	7	14	35	15	26	11	7	3	14	7	13	14,08	338	3	35
2016.04	21	9	4	13	6	18	13	7	22	9	4	27	14	18	20	14	18	20	19	20	18	18	9	21	15,08	362	4	27
2016.05	9	14	9	18	7	18	15	27	22	18	15	27	20	18	21	20	19	17	9	21	29	11	4	20	17,00	408	4	29
																									15,53	**1491**	**3,5**	**31,5**

According the presented values in Table 3.1 it is evident that one pair of lasts takes approximately 15.53 minutes to find it. Even the max value which is 31.5 minutes shows significant issue - spent way too much time only for searching out and picking lasts to production. This data and analysis reveal the real cause why there are so many delay products, why the production chain is always not in time, which also has influences to quality and final check.

The suggestions for improvement in lasts warehousing

After the analysis of the problem and justifications with the real-time waste results it was came up with the idea to optimize and modernize the lasts' warehouse. Several industrial ideas and concepts are overviewed due to select the best and most effective one.

The first one is to analyse if the wooden lasts could be changed into 3D lasts.

As the manufacturing enterprise has the production sector of CAD – CAM, the lasts are being modelled by specific software and then 3D CAD/CAM technology is applied. 3D printers are very common and highly used, thus the question raises – could the 3D lasts be used instead of wooden lasts. This concept is suggested due to save production time and space for warehousing it. It would also be very convenient just to storage 3D files in database and whenever the customer send the order to produce shoes, the lasts according the given measurements are printed or could be modelled with minimum changes of circumferences and then printed as well. Then the 3D model would be sent directly to customer with ordered shoes because there is no necessity to keep them in the company because the lasts would weight a little and they could be shipped together with order.

However, before that, it is essential to overview the completely technological process of wooden lasts been made at this moment in the company and it could be compared with the alternative model to identify if the new concept is valuable and perspective.

When the customer sends the order and he wants the whole package which includes lasts and insoles production, uppers and bottoming, he must send the CAD files (usually. stl files figure 3.1) the company could start the lasts production.

- The first step of production is to model the lasts with specific software systems – CAD programs according all specifications, circumferences, toe form and length, all specific requirements if the customer has some issues with his feet's. The modelling is essential step because the files what customer sends are the scans of foot or blueprints or foam imprints. In this way, the real forms and completions of lasts must be made in case to CAM the final version of lasts. (Figure 3.1)

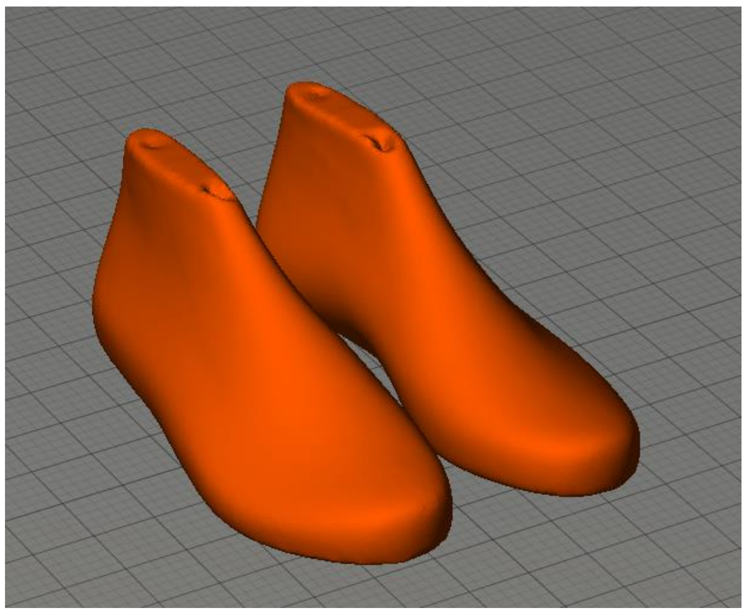

Figure 3.1 The completed .stl file of modelled lasts [14]

- Secondly, after the primary quality control, the file is sent to lasts' production centre for CAM. CNC machines start the production of last from selected wooden material. The process takes 35 min.
- After the lasts are taken out from the machine, they are manually completed that takes 40min. by splitting the lasts at heal part according special requirements that the lasts could be taken out from the shoes after the production of whole shoes, and drilling a hole in the heel to put a screw.
- The final operation is to grind the surface and make the lasts ready for shoes production which takes 7min. (Figure 3.2)

Figure 3.2 Wooden lasts after CAD-CAM [14]

The alternative of applying 3D technology of lasts production to manufacturing company is a perspective concept but there are as well many factors, which should be analysed.

The advantage of 3D lasts:

1. Files of scans and 3D models would be storage in company's database (computers) - do not need a certain warehouse for it: savings on warehouse maintenance, salary for employers.
2. 3D lasts can be shipped to customers - they are light and convenient to ship: reducing price on shipping cost, more convenient.
3. Easier to modify if customer sends new circumferences.

For 3D last printing the nylon (Polyamide) material is selected for 3D printing due to its technical requirements (table 3.3 below). Nylon (Polyamide) is widely used by many manufacturers worldwide and is well known for its impressive durability, high strength-to-weight ratio, flexibility, low friction and corrosion resistance. With its ability to withstand significant mechanical stress, nylon is a great choice of 3D printing tools where is necessity for very strong and durable material especially for production of certain shapes. A rugged, durable material is great for fixtures, handles and high force prototypes. This material is perfectly suitable for large and strong parts, requiring weight bearing and longevity, which would be perfectly suitable for, lasts production.

Table 3.2 Parameters of Nylon material [15]

Material	Maximum service temperature in air	Printing temperature	Heated bed(HB)	HB temperature	Enclosure
Nylon	60 - 100 °C	235 - 260 °C	must have	120 °C	required

However, there are many aspects why the 3D lasts are not suitable for certain manufacturing company. First, according the technological process of orthopaedic shoes and the analysis of all main production steps it is evident that for making solid and durable shoes with all specific requirements, the lasts on which the shoes are made must be strong, solid and tough. Thus, means the material has to be very strong. Nowadays in production, company uses different kind of wooden (oak, beech, hornbeam). The most durable is oak and it is widely popular among customers as well. Not so popular is to produce synthetic lasts and the production process is more complicated and more expensive.

But the question raises-why the 3D lasts will not be suitable for shoes production? To prove this concept, it is necessary to overview and analyse precisely the whole production process that it would be clear why it is very important to have strong material lasts.

First, when the lasts are produced (in this case wooden lasts), the production so called "box" travels to insoles bar where the specific insoles for that pair of lasts are produced according all specifications. The insoles are made mainly from Dyatec, soft EVA, Podofoam, foam, porolon materials. Hard cork is quite popular as well. Every insole is stamped to the last that it will be fixed strongly. Further production step is uppers where the upper and lining materials are fixed to lasts after designing and styling the model of shoe. This step does not strongly influence the material of lasts because upper can be created and modelled also on the 3D figure as well. For bottoming process- there are many significant processes steps that directly influence the lasts material. For example, the production of stiffeners is the most important process. As this individual orthopaedic shoes' production has certain rules and requirements and 99% of customers have issues with their foots, the stiffeners: material (leather: soft, medium, hard, synthetic: rhenoflex 1mm-3mm, soft material: ercoflex 1.1mm – 3mm, form: peroneus, arthrodesis, high lateral/medial boards, length, height, stiffed lining) plays the most important role to keep the foot, ankle places in a right way according the axis. In this way, for fastening hard materials, producing padding stiffeners, quarters, padding lateral/medial ankle places it is essential that the last would be very strong material and could keep its forms with any deformations while hammering. Also, after putting up final materials such as rocker sole, heel and soles for most of the shoes the lasts are taken out. To take out a last from shoe, there is a screw into last, when it is twisted out, the last is divided into two pieces for the convenience to take it out. Even for this process- it is obvious that the softer material could be broken down while taking it out from shoes because inside everything is tight.

According this brief introduction to the basic technological process chain, it is obvious that lasts should be from very strong and durable material in case to avoid mistakes, deformities of shoes, shape. In this way, an experiment and analysis have been accomplished to highlight the main differences and proof the hypothesis.

Table 3.3 Comparison between wooden lasts and 3D technology lasts

	Wooden lasts	**3D lasts**
Storage	Necessary to have a huge warehouse (for storing over 9000 lasts)	Files are storage in computers in database
Time of production	2,3 hour	Over 13 hours
The complexity of production	• CAD file is received from customer prepared for CAM ▪ CNC machine CAM the lasts ▪ Cut the last ▪ Put screw ▪ Grinding and polishing operations for edges ▪ Lasts are ready for production of shoes.	▪ CAD file is received from customer ▪ 3D printer is installed to certain operations – requires certain time ▪ 3D printing ▪ For any modifications – new installations
Price	100 €	Over 300 €
Material	Wooden, synthetic	Nylon (it was chosen as an alternative for experiment)

The table 3.2 above is the comparison of two alternatives of lasts production. After the analysis and experiment which was accomplished with the desire to compare these two alternatives, it was came up with the conclusion to keep the production of wooden lasts due to its simplicity, the requirement to use very durable and strong material for orthopaedic shoes production, materials' simplicity – not so expensive, easier to make some modifications, and for sure price difference which is relatively high.

The price for wooden last is around 100 € including materials, employees wage and other inputs. For experiment and as alternative

For experimental purposes the 3D last' expenses were calculated and reached an amount which is over 300 € without including employees' wages which would increase a price even more. According these indicators, the conclusion is evident that wooden lasts production and storage of it is more worth for the company than 3D printed lasts. Thus, the real question raises – how the problem with storage and maintenance of lasts should be solved and what methods should be applied to modernized and optimize the whole warehouse of lasts.

After the analysis of inventory management systems and methods and real and effective examples of systems in worldwide companies it was determined to select a certain pick path optimization model and adjust it to last warehouse management. It is important to highlight the current situation and model of inventory management in selected company and give precise description of optimize model of last warehouse with solved algorithm, certain devices and mapping and distribution of lasts.

4. Pick path optimization model for last warehouse

To find an order or an item in a warehouse is a direct expense in every business area. It is the largest component of labour in real distribution centre. It can also be called a waste because it costs labour hours but does not make any value but it matters because it affects customer service. The faster the item will be finding, the quicker it will be finished and ready for sale to final customer. Pick path optimization is a key factor to most warehouses – not the exception is Lithuanian individual footwear company. According previous research made and given conclusions it is evident that certain production company has an issue with warehousing management. In this way, to solve this important problem the pick path optimization model will be implemented and warehouse model with items alignment will be implemented to improve the present of warehouse model.

To find an optimal solution quickly by computer can be presented by order retrieval in a warehouse presented in special case of TSP in which travelling is constrained by aisles. Many companies and especially in Lithuania do not support pick path optimum finding algorithms because they do have to know the geometric layout of warehouses, distances between all pairs of storage locations and most of WMS do not maintain such information. For this analysed lasts warehouse management model-this information will be gathered. Also, even to have such information there is another problem of communication between the path and the picker. There should be a system created that picker could see the sequence of locations and actual path to follow. Because now typically WMS tells the picker only the sequence. Also, important to consider the path outlines. It helps the picker to get visualization where the next locations of items are and how to travel there most directly. An effective path outline is necessary for physical layout to see where most popular items are stored and what a typical search of more than several items looks like. Also, it is significant for a management to implement basic rules based on path outline related to customer order. These factors of last warehouse optimization model will be described in further chapter describing the implementation of the new system.

To summarize the implementation of pick path method in last warehouse it is necessary to:

- Define the most effective algorithm that will generate shortest pick path
- Establish rules for managing database that would also help picker with new system
- Place items (lasts) to work with path outline
- Implement WMS model of the warehouse layout to compute the shortest paths
- Assure that it will generate significant savings.

There are plenty of various types of algorithms of shortest path and TSP. For this certain problem solving analysis there are focused on a handful of popular ones and the way in which it works including its' complexity, closeness to the optimum solution giving brief analysis.

For generating pick path, it involves solving two main problems: the shortest path problem and traveling sales person problem (TSP). For further lasts warehouse analysis, these 2 problems will be solved and analysed the feasibility of generating pick paths using the algorithms.

<u>Shortest path algorithms:</u>

1. Dijkstra's algorithm is used to find the shortest distance between some starting vertex and all other vertices in the graph [6]. Dijkstra's algorithm is quite popular for its performance, with a worst-case performance of $O(|E|+|V|\log|V|)$ where E = number of edges and V = number of vertices [6]. The algorithm is also easy to alter so that Dijkstra's will not only return the distance of the shortest path to each vertex, but also the path to traverse. In pick path optimization, Dijkstra's is very useful as it can be used at each location to find the shortest distance between this location and all remaining locations on the order. Dijkstra algorithm is basically used in finding a shortest communication path between two nodes connected in a network. Even Google Maps are based on this algorithm. Dijkstra relies on a key idea from dynamic programming.
2. Another also popular is Floyd's algorithm which is used to find the all-pairs of shortest paths, meaning that in one run Floyd's can find the shortest path between all vertices on a graph [6]. The algorithm can be run once before solving the TSP end of the problem. By running the algorithm once and storing the result to be referenced throughout the solving of the TSP, there is an ability to reduce the time spent determining the distance between the current location and all other locations on the order.
3. The twice-around-the-tree algorithm is a minimum spanning tree-based algorithm. "These types of algorithms leverage the connection between Hamiltonian circuits and spanning trees, where a Hamiltonian circuit minus one edge produces a spanning tree" [6]. This algorithm can be performed in polynomial time, although its exact timing depends on the implementation of the first step, where a minimum spanning tree is constructed. Another benefit of this approach is that, it is guaranteed that accuracy of the shortest tour generated by this algorithm is at most twice as long as the optimum tour [6]. This algorithm is recommended due to its guaranteed upper bound and the fact that the algorithm is performed in polynomial time.

4. Christofides' algorithm is similar to the twice around-the-tree algorithm which is also works with minimum spanning trees. "Christofides' utilizes more advanced implementations of graph theory to form a guaranteed lower cost tour than the other algorithms" [6]. This algorithm can be performed in polynomial time and produces a minimal tour that is guaranteed to be within 1.5 times the optimum tour. This algorithm is highly used for implementation in finding an optimal pick path.

After the analysis performed about most common algorithms used in warehouse related companies for pick path optimization, it was decided to adjust Dijkstra's algorithm for selected task to optimize last warehouse in the footwear production company. This algorithm is used in modern routing findings systems. Dijkstra algorithm is selected due to its clearness and its features which is highly related to solve certain issue in lasts warehouse.

4.1. Current model and system of last warehouse

To reveal the real difference and importance of improvement for last warehouse it is also important to present the current situation and model of last warehouse and the management system of it. The main issue is the alignment of lasts in warehouse. Here are the main drawbacks:

- No warehouse model – aisles are not numbered and not coded.
- Lasts are hanged on aisles without any coding or zoning system.
- Lasts are grouped only by customers' companies.
- Lasts are named by customer names.
- Database of lasts is in Excel form simply coding the lasts by the customer companies and names.
- The tracking function of lasts is only by marking in Excel -/+. If the last is in warehouse hanging in aisles it is marked as plus +, if not - as minus -.
- After the analysis made, employer can search for up to 31.5 min. to find the necessary last.

To demonstrate the real and present situation of last warehouse several photos of warehouse were taken (Figures 4.1. – 4.2.) below.

Figure 4.1 The last warehouse in production company

Figure 4.2 Last identification model in company

4.2. Dijkstra’s Algorithm Adjustment

After following studies and analysis of different shortest paths algorithms, it was selected to adjust Dijkstra algorithm for shortest path analysis. To implement this algorithm and adjust to real situation it is selected to use Excel Solver Parameters program to calculate pick paths. This is very effective and suitable model for searching the shortest path from one item to the other. The real examples and adjustment to the inventory-searching model is given further with the explanation and brief analysis of every step.

There are submitted 9000 storage locations – each black dot is a last location in a warehouse and named in Excel program from 1 to 9600. A start point is allocated at the top – marked as red dot (Fig.4.3). The certain layout with the number of rows and columns are already chosen according Excel program. The visualization of last warehouse in the company is the same – lasts are divided to rows and columns. The lasts distribution is in aisles with customer’s company names on it and specific coding system. To reveal how Dijkstra’s algorithm works and calculates pick path, it is selected coding system-numbers to identify the real values and distances. Each last (1-9600) has its own location – determined by row and column according Excel function. As example is last number 1 – which location is determined “Row: 10 Column: 14” as shown in Fig.4.4. Main functions of the system are indicated on right side of the Fig.4.4. and briefly explained:

Clear W - clears the path
Clear Grid - clears everything, start, end points, walls and paths
Find Shortest Path - shows the path by sequence
Show Optimal Path – shows the optimal pick path

The aim of this project is to find the shortest pick path in warehouse using Dijkstra’s algorithm. In this case, it is randomly selected 15 lasts distributed in different locations in warehouse. Based on macro command, the program calculates the pick path and distance with these 14 random items (Table 4.1).

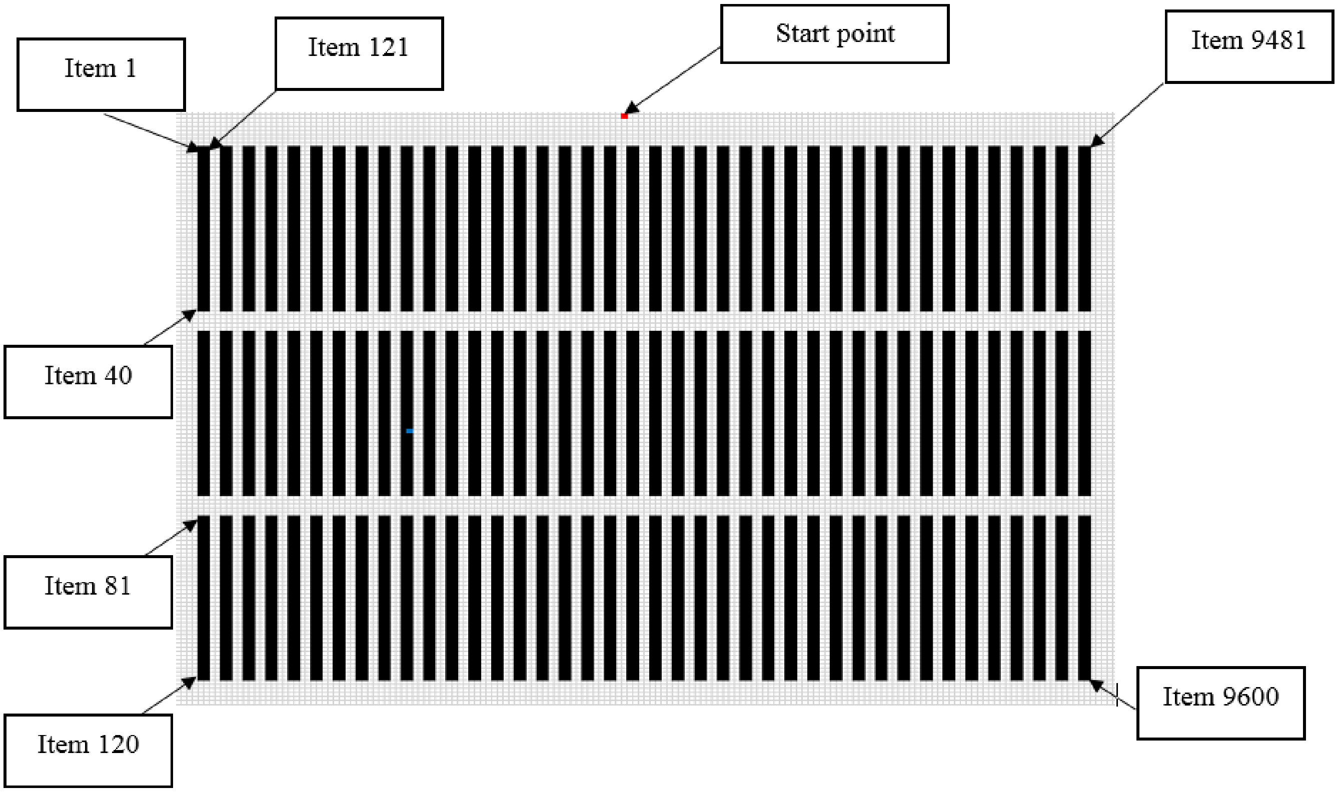

Figure 4.3 The warehouse layout plan in Excel

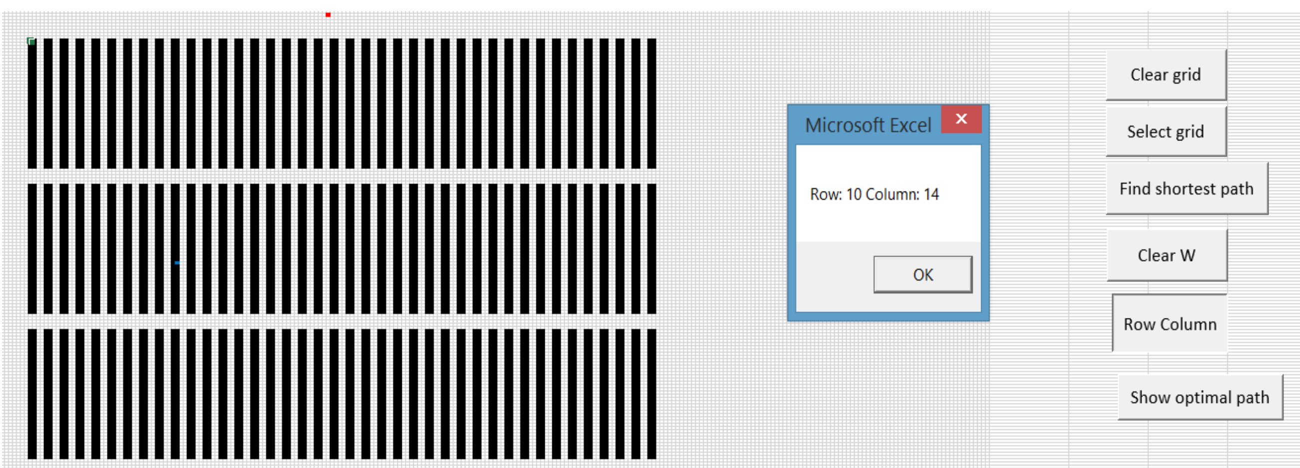

Figure 4.4 The warehouse layout showing the location of last number 1.

Table 4.1 The list of 14 random items

#	15 random items	Row	Column
0	Start	2	89
1	5	14	14
2	419	73	19
3	567	106	22
4	689	108	23
5	789	83	26
6	1090	19	31
7	2345	79	51
8	3900	74	78
9	4079	138	79
10	4300	119	83
11	5000	94	95
12	5190	39	99
13	5555	44	106
14	7424	123	135

Table 4.2 Dijkstra's algorithm path

Items	Items														
	Start	5	419	567	689	789	1090	2345	3900	4079	4300	5000	5190	5555	7424
Start		79	123	149	147	129	64	97	72	136	116	93	39	48	145
5	79		59	91	94	70	31	94	113	174	159	151	119	128	215
419	123	59		32	34	34	58	66	91	117	102	94	106	105	158
567	149	92	32		16	22	87	51	80	92	87	79	132	131	143
689	147	94	34	16		24	89	49	78	86	85	77	130	129	141
789	129	70	34	22	24		64	52	81	103	88	80	112	111	144
1090	64	31	58	87	88	64		72	91	152	137	129	104	105	193
2345	97	94	66	51	49	52	72		57	79	64	56	80	79	120
3900	71	113	91	80	78	81	91	57		63	45	37	51	50	101
4079	135	174	117	92	86	103	152	79	63		24	51	104	103	72
4300	116	159	102	87	85	88	137	64	45	24		28	81	80	86
5000	91	151	94	79	77	80	129	56	37	51	28		54	50	63
5190	39	119	106	132	130	112	104	80	51	104	81	54		17	105
5555	48	127	105	131	129	111	105	79	50	103	80	50	17		96
7424	146	215	158	143	141	144	193	120	101	72	86	63	105	96	

To find the shortest pick path between 14 random locations Excel Solver is used. But before that it is essential to make a sequence table with distances by Excel as well. The table below 4.1 shows the Excel model before solving and tables 4.3 and 4.4 after solving with Excel Solver's Evolutionary method.

Table 4.3 Total pick path

#	Sequence	Distance
0	Start	0
1	5	79
2	419	59
3	567	99
4	689	16
5	789	91
6	1090	131
7	2345	72
8	3900	57
9	4079	63
10	4300	24
11	5000	159
12	5190	54
13	5555	17
14	7424	145
0	Start	146
	Total distance:	1212

Table 4.4 Optimize total pick path

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	4300	116	119	83
11	5000	28	94	95
14	7424	63	123	135
13	5555	96	44	106
12	5190	17	39	99
8	3900	51	74	78
9	4079	63	138	79
6	1090	152	19	31
3	567	87	106	22
2	419	32	73	19
1	5	59	14	14
4	689	94	108	23
5	789	24	83	26
7	2345	95	79	51
0	Start	97	2	89
	Total distance:	1074		

With Excel Solver command the optimal path distance is given- this is based on Dijkstra's algorithm. (Table 4.3) Here in the table 4.4 below is the pick path – with calculated distance 1074. In last warehouse, it determines steps to find all 14 random last. For comparison, if the warehouse worker searches the lasts by the numbering (Table 4.3) it is seen that he would make up to 1212 steps. In optimize pick path the number is 1074. Concluding this optimization model, it is striking difference, which optimize the warehouse efficiency 11.4%.

To visualize the optimize pick path here are the figures of how the system works and the map route identifies the distances which are also determined in tables in Excel sheets. For example, here is the first step – from start point to item, numbered **4300** that calculates 116 steps (distance) from start point. It is the minimum value from calculated table (Table 4.4) and this is why the pick path is started from this location. (Fig.4.5) The last distance identifies the last location in warehouse from where to last items is picked up before coming back to star position. (Fig.4.6) The last item to be picked up from storage is **2345** and the distance from this item to start point is 91.

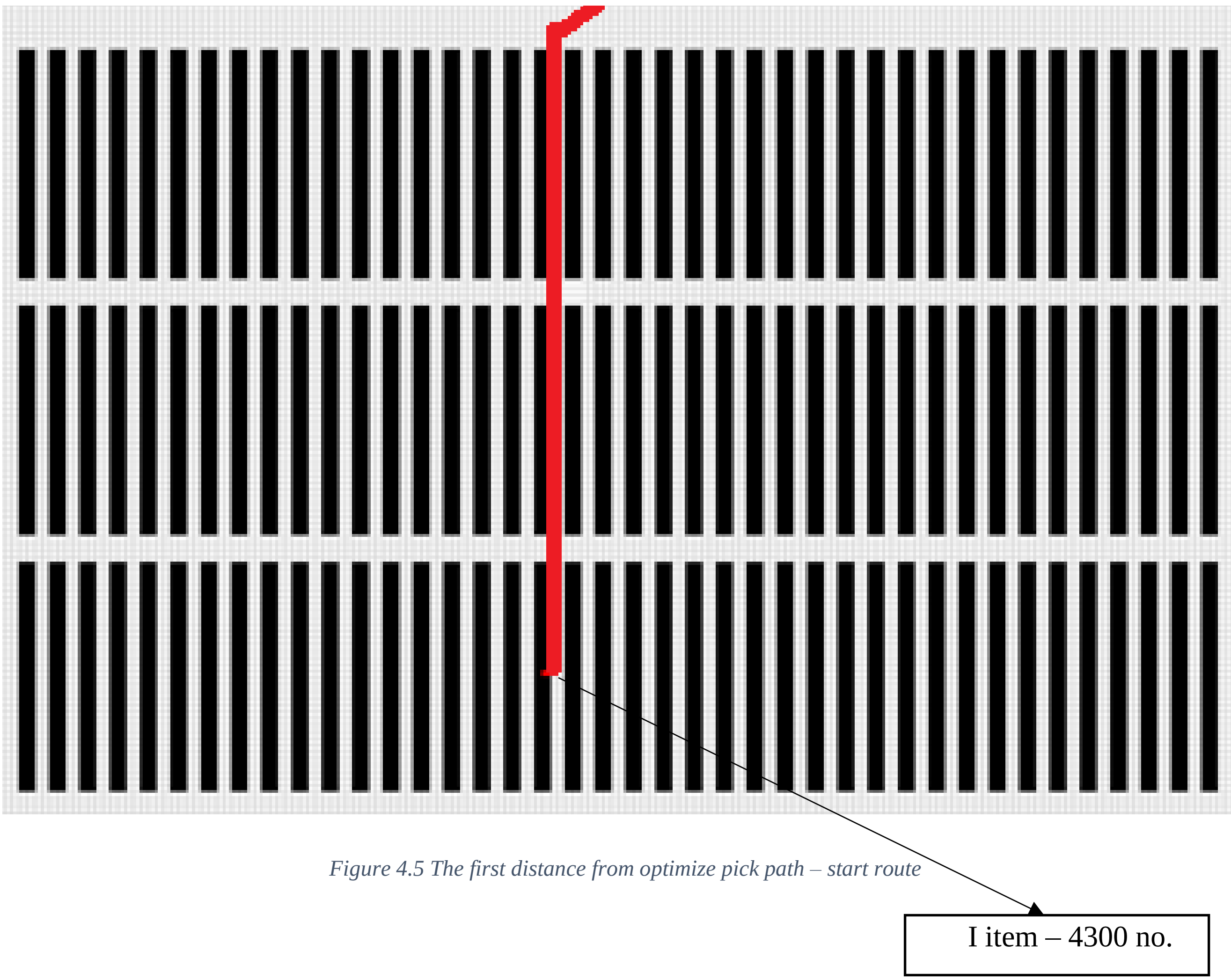

Figure 4.5 The first distance from optimize pick path – start route

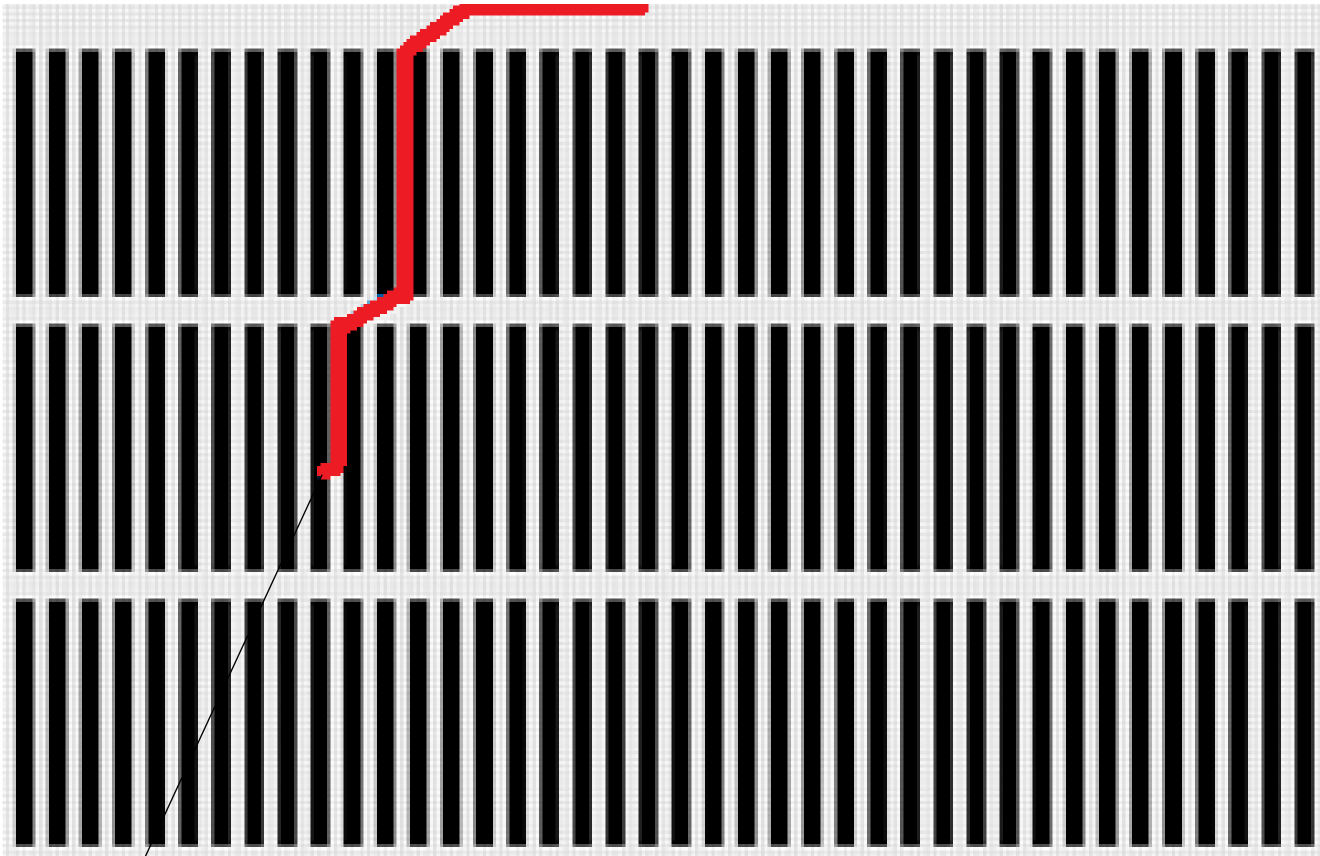

Figure 4.6 The last distance from optimize pick path- end of route

14 item - 2345

To show the running of the optimize pick path model to certain warehouse it is essential to present more different paths and cases with different searching locations. As an example, 14 randomly taken lasts-each of it has 10 steps different from each other. In the table 4.5 below, it is sequence of the items 10 -140. From the results, it is seen that application of Dijkstra's algorithm is not necessary in this certain case. If the searcher use so called "basic model" – searching in a sequence, he makes 746 steps and if implementing algorithm- he makes 830 steps. This case presents, that not for 100% all cases this algorithm is suitable and effective to use, if the items are allocated by sequence it is not even effective according the results presented in tables 4.5 and 4.6.

Table 4.5 Total pick path

#	Sequence	Distance
0	Start	0
1	10	84
2	20	9
3	30	9
4	40	9
5	50	91
6	60	131
7	70	9
8	80	9
9	90	14
10	100	9
11	110	9
12	120	9
13	130	119
14	140	145
0	Start	90
	Total distance:	746

Table 4.6 Total pick path

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	100	170	119	14
11	110	9	129	14
14	140	99	29	15
13	130	9	19	15
12	120	119	139	14
8	80	44	94	14
9	90	14	109	14
6	60	34	74	14
3	30	34	39	14
2	20	9	29	14
1	10	9	19	14
4	40	29	49	14
5	50	14	64	14
7	70	95	84	14
0	Start	142	2	89
	Total distance:	830		

One more example is presented. 14 randomly selected items are taken to find the shortest pick path. From tables 4.7 and 4.8 it is seen the calculated path distance. Selecting last by sequence – sum up is **1388** steps, and by optimize pick path – **1280** steps. To sum up this case, the results and difference is not that high as it was from the first example (around 30%). These results are due to the selection of first items and the higher the difference is, the more steps are reduced. Another example is taken as well. And to conclude the results, the efficiency is up to 13% - applying the algorithm the result is **950** steps comparing with picking by sequence – **1087** steps. (Table 4.9, 4.10)

This aim of adjusting pick path Dijkstra algorithm is to find the shortest path but mainly for the larger quantity of searching items. For real, this search model would not be suitable for smaller quantities like searching for 3-6 items in the warehouse. But as the warehouse is based on large quantities of lasts, this model is perfectly combined for optimizing the warehouse processes - less distance per order = more orders per hours.

Table 4.7 Total pick path

#	Sequence	Distance
0	Start	0
1	90	159
2	314	20
3	590	40
4	8900	225
5	1000	149
6	2339	39
7	4589	63
8	5009	69
9	5900	80
10	7800	123
11	8000	44
12	8003	7
13	8900	74
14	9000	109
0	Start	187
	Total distance:	1388

Table 4.8 Optimize total pick path

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	7800	165	139	142
11	8000	44	94	146
14	9000	52	139	162
13	8900	109	29	162
12	8003	74	102	146
8	5009	56	108	95
9	5900	80	29	111
6	2339	96	73	51
3	590	80	129	22
2	314	40	88	18
1	90	20	109	14
4	8900	212	29	162
5	1000	149	49	30
7	4589	68	38	90
0	Start	35	2	89
	Total distance:	1280		

Table 4.9 Total pick path

#	Sequence	Distance
0	Start	0
1	6	80
2	422	61
3	570	32
4	700	30
5	1089	101
6	2500	106
7	4009	76
8	4307	62
9	5009	44
10	5300	78
11	5559	24
12	6000	92
13	7590	114
14	8000	54
0	Start	133
	Total distance:	1087

Table 4.10 Total pick path

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	5300	29	29	102
11	5559	24	48	106
14	8000	78	94	146
13	7590	54	39	139
12	6000	113	139	111
8	4307	38	126	83
9	5009	44	108	95
6	2500	69	119	54
3	570	58	109	22
2	422	32	76	19
1	6	61	15	14
4	700	104	119	23
5	1089	101	18	31
7	4009	85	63	79
0	Start	60	2	89
	Total distance:	950		

The whole process of optimize pick path model usage is presented in flow chart algorithm using Microsoft Visio software program.

It is important describe in broader every step starting from the receive order from customer process till end of searching lasts and delivering it to production. First of all, when order is received from customers, the data goes directly to last warehouse database, where is the whole information about all lasts, to which company it depends, if the lasts are already in warehouse or need to be modelled again. Once the information travels to warehouse database, the employer comes to warehouse to pick up the necessary lasts. When he enters the inventory area, in the certain computer there is already configured map based on pick path algorithm with the specific map – how to find certain lasts in warehouse. Map shoes the pick path, each item's location identified by aisles (in Excel by rows and columns). The map is printed and searcher starts the lasts' picking process. The pick path model is used if he searches more than 2 items. Sometimes, according the given examples in previous section, it could be that pick path algorithm is not that effective, thus the searcher uses the total pick path – when items are being collected by sequence which examples were given above in tables. Other process step which has a huge impact to following process is the classification of lasts. In this case, the most important factor is the mass of each lasts. If it is high lasts, it is considered not to carry out more than seven lasts because they might weight more than 20 kg. which is forbidden for employers according the Labour Code. This factor concludes for usage of vehicle – specific carriage in warehouse area to carry out lasts. If the searcher needs to pick up more than 7 lasts, he takes a carriage specifically specialized to put the lasts instead of carry them. It should be considered the exact quantity of how many need to be carry with carriage. Indeed, it depend if the lasts are high or low. Usually, if all lasts are low it could be carry on without using any carriage, but if the lasts are high – around 250-300 mm height which could weight up to 3kg each pair , it is hard to carry even more than 7 of them. In this way, it is suggested to use specific carriage adjusted to easily carry out lasts in warehouse between aisles. When searcher picks up all lasts from the warehouse, he comes to terminal – computer and scan all lasts (lasts have their own codes – coding system is described further) which were taken from warehouse. In this way to ensure control system of the lasts and avoid any loss or misleading information. Once they are scanned, he bring them to logistics where they are divided into production boxes and the order processing starts.

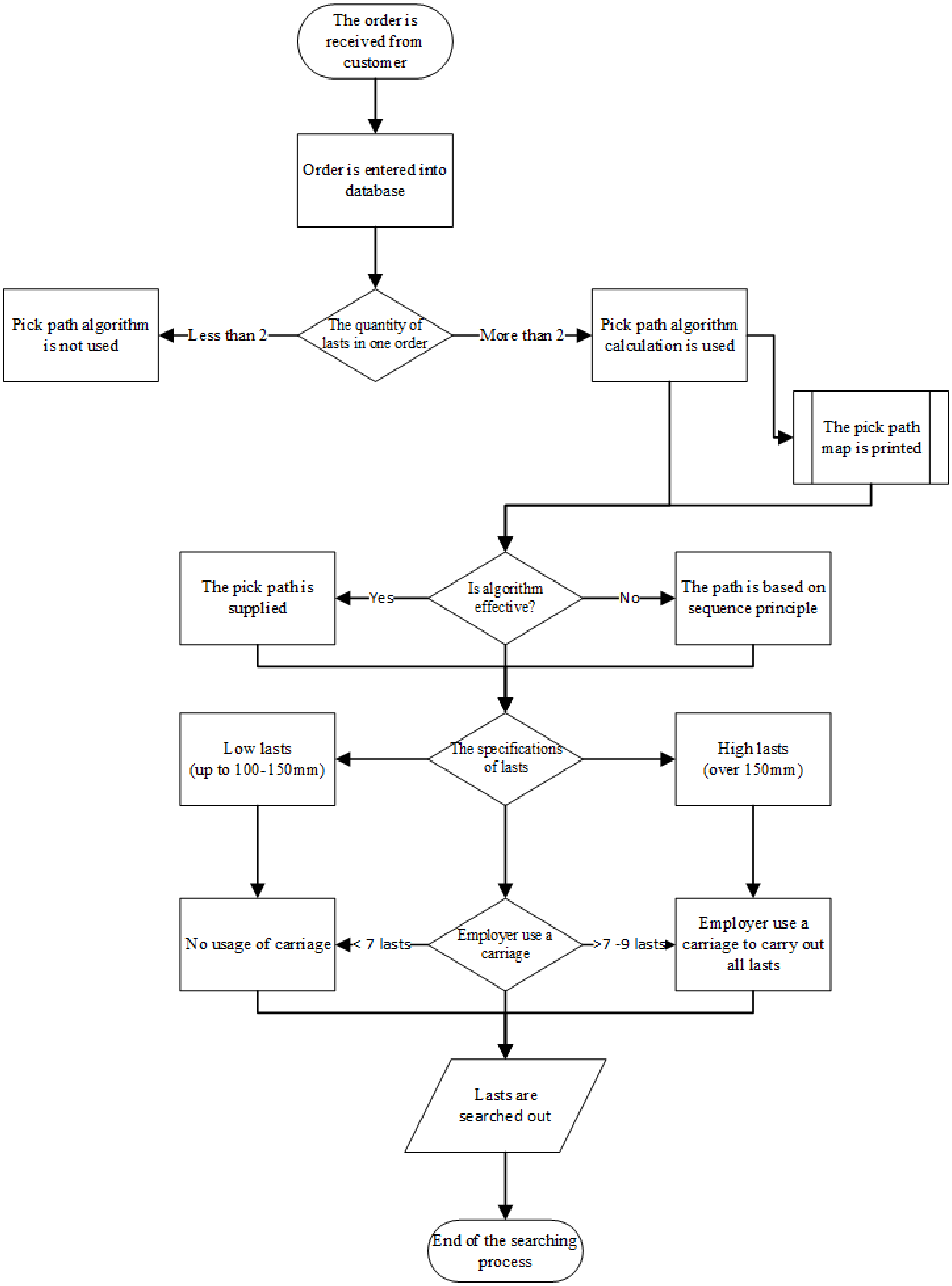

Figure 4.7 The process algorithm of pick path searching model in last warehouse

4.3. Improved system of last warehouse

It is significantly important to create a technological design of last storage in the company. The Dijkstra's Algorithm main function is to calculate the shortest path in the warehouse between shelves that worker would be able to find not only one pair of lasts easily without spending a lot of time searching and wandering the location of certain lasts. In this way, the main goal is to ensure effectiveness of the order picking thus saving time on a research. And this will work, if the last warehouse will be designed in logically and correctly.

Firstly, the layout design of the warehouse is a key component of further optimization and plays crucial role on order picking and travelling distances in the storage area. According F.Carron it was found that the layout design has more than 60% effect on the total travel distance and three basic types of warehouses were presented [17]. According K. J. Roodbergen there are some factors considered in layout design like: the number of blocks, the length, width and number of picking aisles, number and shape of cross aisles, position of input/output gates in warehouse [18]. For example a new Flying-V and Fishbone design of cross aisles (Fig. 4.9.) where presented by R.D.Meller, which offers 10%-20% reduction of traveling distance [18]. The layouts are mostly narrow-aisle-like, which increase the space utilization with lower costs. Based on this model it will be design last warehouse taking "Traditional Layout 2" model (Fig. 8.4.) according the type and space of warehouse is in the selected company.

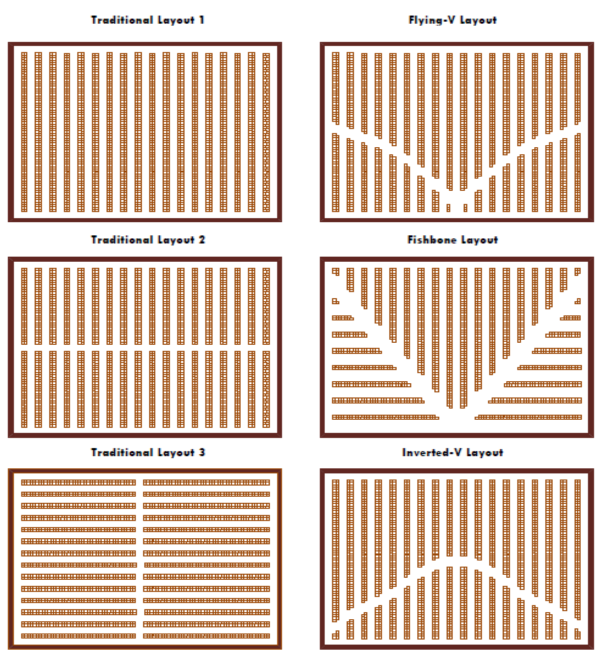

Figure 4.9 The warehouse layout examples [17]

Optimization of operation structure is another step to last warehouse improvement. In warehouse based companies there dominate two basic slotting strategies (storing assignment policies): random and dedicated [19]. In this certain case it is concentrated on dedicated strategy model which is based on storing items in specified locations. In this way, the storage locations can be organized as:

- *Class-based storage* – items are clustered according their ordering frequency. This model assigns the most frequently requested goods to the closest locations from input/output gates [20].
- *Family grouping* – items are clustered according the similarities or relations between products or orders [20].

In optimising last warehouse, the class-based storage model will be implemented due to save time for travelling distances and grouping lasts according the customers priority. As in every business field, there are customers which are at the priority. In this certain case, this kind of customers are those who order the most of the individual footwear. They can order to produce even over 200 pairs per week. In this case, they should be at the front/top of the warehouse due to the high frequency of searching lasts for this customer and saving time for searching. As last warehouse optimization model implementing Dijkstra' algorithm is based on more orders picking during single order-picking tour, the items *batching* model will be used.

Secondly, the lasts in storage must have their own identification numbers to keep the order of the items. All the lasts will have their own classification numbers and all data will be fixed in the system. Every time new lasts arrived in warehouse, they will be coded and scanned and system will have all data about each last. In this way, it will be easy to track the lasts, to see how many and which lasts for certain customer are in company's database. Coding system is the essential step in creating a new optimized warehouse model. As an example – N125, first letter is the identification of customer company, and number identify last number. As almost all customers specify their lasts according numbers, thus it is not confusing to keep the same rule for last identification. In today's warehouse, some of the customers have their lasts with name and surname of their patient; other companies have their last by specific code system. In this way, the task is to identify all lasts with same coding system that it would be easier for workers to search and they could recognize quickly to which company these lasts depends with all necessary information.

Thirdly, code colouring system applied to lasts. Colour helps people to memorize certain information by increasing attention level. According the researchers [21], colour has the potential to attract attention and remember better things, items, information. They also further explained that warm types of colour such as yellow, red and orange have a greater effect on attention compared to cool type colours like brown and grey. To improve more accurate search path and many other factors for further production steps, it was coming up with the conclusion to mark all lasts with colour on the top of lasts. The colour will appear on the top of the last in the frame where the first letter identifies the customer's company and the numbers – the last all data. Warm colours: **Red**, **Yellow**, **Green**, **Pink**, **Purple**, **Orange** will be selected for the highest important and frequency of order customers where the flow of lasts is higher than other. It is also important to mention another factor and advantage of colouring method. It is focused on the fact that employees will recognize the lasts by the customer's company in the cases when the lasts will be left without any ordering sheets or specific production boxes which were explained in previous chapter. It will help to save time and avoid loss of orders.

5. The benefits of algorithm implementation to last warehouse

Every optimization model adjustment to some certain processes in production or other fields have to bring a success which is usually counted by savings, cost of value and payback period. To calculate the pay back for this last warehouse optimization model is quite complicated due to lack of real analyses after implementation of pick path system with the real time savings. In this way it could be calculated approximate savings, how this optimization model would be beneficial to company, production processes and the real time and expenditures savings.

The simulation was accomplished by using pick path algorithm in last warehouse the whole month – 20 working days. It is taken into account that every day employer is going to the last warehouse to pick up 14 items. 14 is the average number of each delivery to logistic department every day. In table 5.1 it is all results of simulation with calculated efficiency rate in percentage thus showing each optimize pick path efficiency comparing to basic pick path. The average value of warehousing processes efficiency is **15%**. And the figure 5.1 below shows the maximum, minimum and average factors of efficiency (%) in warehousing processes after optimization model implementation.

Table 5.1 Efficiency factor

Total Pick Path	Optimize Total Pick Path	Steps Difference	Efficiency (%)
1212	1074	138	11.4
1388	1280	108	7.8
1087	950	137	12.6
1046	1035	11	1.1
1217	1064	153	12.6
937	754	183	19.5
938	922	16	1.7
1065	1043	22	2.1
1155	1004	151	13.1
1083	639	444	41
1163	980	183	15.7
840	740	100	11.9
1059	1025	34	3.2
1143	1053	90	7.9
999	974	25	2.5
1175	1086	89	7.6
1238	905	333	26.9
1512	987	525	34.7
1267	863	404	31.9
1174	769	405	34.5

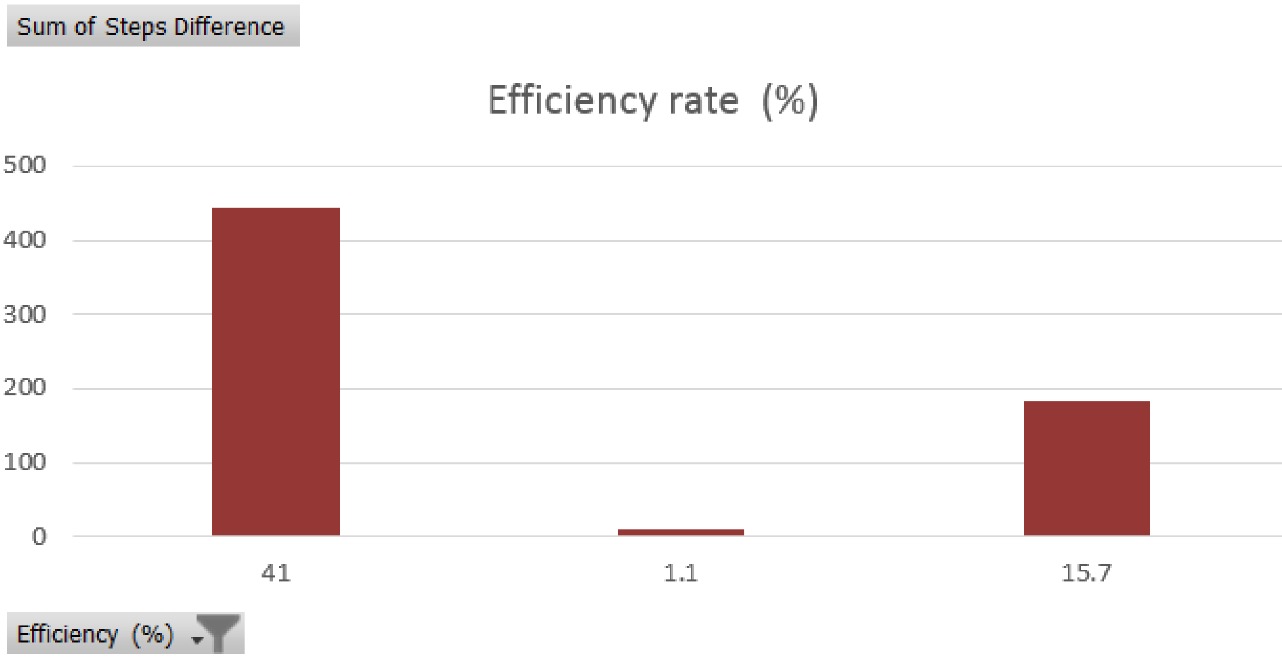

Figure 5.1 Efficiency rate – max, min, average values.

After implementation of pick path algorithm model, it is also necessary to calculate the real value and savings to company. Before in the last warehouse, the logistic manager or in certain cases employer from warehouse was responsible for picking up lasts from warehouse. According the previous analysis accomplished and gathered results, it is evident that it was spent too much time on searching on lasts and thus causing time ineffectiveness in the company. In this case, it is suggested to assign this task to one extra employer (already existing) for searching out lasts in warehouse in this case for saving up time for logistic managers. According the previous analysis made counting the time spent on searching lasts in warehouse, it could be concluded that for searching 14 lasts, the employer could spent up to 3.5h => 14 lasts x 15min/last

Taking into account company's average salary per hour (for a warehouse operator) as 2.5€ - it will cost 8.75€ for a company to search out 14 lasts. With this algorithm implementation which, due to simulation results would save up to 15%, it would save up to 1.3125€ per each search out in warehouse. 2x times per day would be 2.625€ and 20 x times per month - 2.625€ x 20 days = 52.5€/month. Summing up the analysis and results, the savings for company could be up to **52.5€/month**, because the payroll system in the company is temporary which is based on formula:

$w = A * t$

where: A - hourly tariff wage, Euro/hour.;
t – amount of hours being worked.

Another very significant factor for implementation of a new system based on pick path algorithm warehouse model is the reduction of errors. This is very important due to savings on time and most importantly avoiding errors in production and fault order for final products. With this optimize algorithm the errors will be avoided due to all control of the whole warehouse and identification for each lasts. To implement it, there is a need to build a specific terminal with the integrated computer and scanning barcoding system. Each last will be scanned after it is taken out from the warehouse. If, accidentally, the searcher takes out fault item, the scanning system shows that item is fault and thus it will not come to further production area, it will be directly replaced.

To implement pick path algorithm to last warehouse it is essential also to integrate:

- Create new data base
- Built terminal with scanner
- Assign one employer to be responsible for last warehouse
- Built a new last warehouse with new coding system, new aisles numeration, lasts classification

On the other hand, this pick path optimization model will be also important for reverse method. When the orders will be finished and packed for shipment, lasts have to be taken back to warehouse to their set locations. In this way, same system will be used to bring the lasts back to their position to maintain the warehouse completely accurate and orderly. Firstly, employer will have to scan the lasts to the terminal, that all these lasts will come up to database that they are bringing back to warehouse and then according the same sequence the pick path model is applied to show the route of putting lasts back to their locations. This is very important due to reduction of errors or misleading information and most importantly for logistic department to follow the database of lasts and their current location – are they in warehouse, or in production.

After implementing optimization pick path model in last warehouse, it is seen that efficiency and productivity of warehousing processes increases up to 15%. The aim is to achieve less distance per order that would make more orders per hours. Thus means, that the sooner the lasts are brought to logistic to proceed the order, the quicker the order travels to production and it causes the more effectiveness to final product being manufactured on time.

Conclusion

The inventory management models and systems are various and highly used in many production companies worldwide. However, the main factor and hardest task is to find the most accurate and effective one that will bring the effectiveness and successful management system that creates the higher impact to productivity and final results to the company. In this research project, the main and accurate analysis of inventory improvement has been accomplished and following tasks were performed in order to suggest the most effective optimized model to control lasts in warehouse in certain Lithuanian production company.

1. The main issue of last warehousing is time waste on picking up lasts
2. Dijkstra's algorithm is selected for pick path optimization
3. The simulation was accomplished with selected optimization model and effectiveness of warehousing processes with applied optimization model increases up to 15% and it could even rise up to 41% as maximum, thus reducing time of searching of lasts and saving up company's expenses on payments for employer.
4. The new system with built scanning system and terminal, warehouse plan is suggested to maintain the orderly system of warehouse items and reduce errors.

All the performed tasks and analyses accomplished in workshop area are valuable knowledge about inventory management and control issues, which highly affects the total productivity of manufacturing company. Application of analysed algorithm is vital important for solving pick path problems in warehouse area which may be very significant and important for future warehouse with higher storage items and more difficult controlling systems and models.

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APPENDIXES

The pick path optimization results after simulation

#	Sequence	Distance
0	Start	0
1	100	170
2	490	99
3	900	55
4	1050	34
5	2390	60
6	2900	100
7	4678	121
8	5870	30
9	5999	13
10	6300	63
11	6890	38
12	7000	14
13	7430	79
14	8000	37
0	Start	133
	Total distance:	1046

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	6300	83	74	118
11	6890	38	64	127
14	8000	46	94	146
13	7430	37	129	135
12	7000	79	49	130
8	5870	87	129	110
9	5999	13	138	111
6	2900	146	29	62
3	900	69	74	27
2	490	55	19	22
1	100	100	119	14
4	1050	42	109	30
5	2390	60	129	51
7	4678	46	137	90
0	Start	134	2	89
	Total distance:	1035		

#	Sequence	Distance
0	Start	0
1	15	89
2	65	54
3	615	59
4	955	109
5	999	85
6	1000	207
7	1015	19
8	2015	52
9	3015	95
10	4015	53
11	5015	53
12	6015	91
13	7015	53
14	8015	53
0	Start	145
	Total distance:	1217

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	4015	67	69	79
11	5015	53	114	95
14	8015	74	114	146
13	7015	53	69	130
12	6015	53	24	114
8	2015	143	114	46
9	3015	95	24	63
6	1000	58	49	30
3	615	29	24	23
2	65	59	79	14
1	15	54	24	14
4	955	111	134	27
5	999	85	48	30
7	1015	20	69	30
0	Start	110	2	89
	Total distance:	1064		

#	Sequence	Distance
0	Start	0
1	559	143
2	809	14
3	2039	51
4	2099	64
5	3055	46
6	3090	39
7	4242	65
8	4300	62
9	4639	25
10	5899	81
11	6356	106
12	6654	67
13	7514	42
14	7605	39
0	Start	93
	Total distance:	937

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	5899	40	28	111
11	6356	106	135	118
14	7605	92	59	139
13	7514	39	88	138
12	6654	42	68	123
8	4300	83	119	83
9	4639	25	93	90
6	3090	33	109	63
3	2039	49	138	46
2	809	51	108	26
1	559	14	93	22
4	2099	48	73	47
5	3055	46	69	63
7	4242	33	56	83
0	Start	53	2	89
	Total distance:	754		

#	Sequence	Distance
0	Start	0
1	599	181
2	899	65
3	1059	44
4	2099	57
5	3400	38
6	3908	32
7	4001	28
8	4444	44
9	4700	24
10	5900	56
11	6454	84
12	6654	44
13	7779	58
14	8900	94
0	Start	89
	Total distance:	938

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	5900	41	29	111
11	6454	84	113	119
14	8900	109	29	162
13	7779	94	118	142
12	6654	58	68	123
8	4444	83	13	87
9	4700	24	29	91
6	3908	61	82	78
3	1059	76	118	30
2	899	44	73	27
1	599	65	138	22
4	2099	85	73	47
5	3400	38	49	70
7	4001	8	55	79
0	Start	52	2	89
	Total distance:	922		

#	Sequence	Distance
0	Start	0
1	104	174
2	409	60
3	908	41
4	1050	26
5	2400	71
6	3009	131
7	4600	55
8	5879	93
9	6290	74
10	6899	37
11	7001	17
12	7000	5
13	7070	79
14	8050	135
0	Start	67
	Total distance:	1065

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	6899	94	73	127
11	7001	17	55	130
14	8050	47	19	147
13	7070	115	129	130
12	7000	79	49	130
8	5879	96	138	110
9	6290	74	64	118
6	3009	90	18	63
3	908	92	82	27
2	409	41	63	19
1	104	60	123	14
4	1050	46	109	30
5	2400	51	139	51
7	4600	95	49	90
0	Start	46	2	89
	Total distance:	1043		

#	Sequence	Distance
0	Start	0
1	14	88
2	69	59
3	625	53
4	985	32
5	998	71
6	1001	131
7	1030	28
8	2030	53
9	3030	95
10	4030	53
11	5030	53
12	6030	91
13	7030	53
14	8030	135
0	Start	160
	Total distance:	1155

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	4030	82	84	79
11	5030	53	129	95
14	8030	66	129	146
13	7030	53	84	130
12	6030	53	39	114
8	2030	143	129	46
9	3030	95	39	63
6	1001	43	55	30
3	625	20	34	23
2	69	53	83	14
1	14	59	23	14
4	985	51	34	30
5	998	12	47	30
7	1030	95	84	30
0	Start	126	2	89
	Total distance:	1004		

#	Sequence	Distance
0	Start	0
1	1	74
2	401	44
3	801	44
4	1201	89
5	1601	71
6	2001	131
7	2401	89
8	2801	44
9	3201	44
10	3601	89
11	4001	44
12	4401	44
13	4801	89
14	5201	135
0	Start	52
	Total distance:	1083

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	3601	14	10	74
11	4001	44	55	79
14	5201	19	55	99
13	4801	46	10	94
12	4401	89	100	86
8	2801	63	55	59
9	3201	44	100	66
6	2001	19	100	46
3	801	19	100	26
2	401	44	55	19
1	1	46	10	14
4	1201	19	10	34
5	1601	44	55	39
7	2401	95	10	54
0	Start	34	2	89
	Total distance:	639		

#	Sequence	Distance
0	Start	0
1	5	79
2	310	69
3	695	30
4	910	29
5	1305	71
6	2015	131
7	3055	57
8	4095	53
9	5095	53
10	6015	53
11	7055	91
12	8055	95
13	8555	36
14	8995	135
0	Start	181
	Total distance:	1163

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	6015	36	24	114
11	7055	91	114	130
14	8995	60	134	162
13	8555	89	44	155
12	8055	36	24	147
8	4095	94	24	82
9	5095	53	69	98
6	2015	89	114	46
3	695	46	114	23
2	310	30	84	18
1	5	69	14	14
4	910	78	84	27
5	1305	39	124	34
7	3055	95	69	63
0	Start	75	2	89
	Total distance:	980		

#	Sequence	Distance
0	Start	0
1	111	181
2	222	29
3	333	8
4	444	17
5	555	71
6	666	131
7	777	8
8	888	25
9	999	13
10	1110	13
11	1221	8
12	1332	33
13	1443	8
14	1554	135
0	Start	160
	Total distance:	840

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	1110	84	39	31
11	1221	8	30	34
14	1554	102	133	38
13	1443	120	12	38
12	1332	8	21	35
8	888	41	62	27
9	999	13	48	30
6	666	31	80	23
3	333	32	112	18
2	222	8	121	15
1	111	29	130	14
4	444	39	103	19
5	555	13	89	22
7	777	95	71	26
0	Start	117	2	89
	Total distance:	740		

#	Sequence	Distance
0	Start	0
1	1000	96
2	1900	70
3	2000	24
4	2300	65
5	2510	91
6	2912	131
7	3314	47
8	3716	46
9	4118	87
10	4520	48
11	4922	83
12	5324	46
13	5726	47
14	6128	145
0	Start	33
	Total distance:	1059

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	4520	91	94	87
11	4922	83	11	95
14	6128	27	17	115
13	5726	87	105	107
12	5324	47	58	102
8	3716	97	135	74
9	4118	87	47	82
6	2912	28	41	62
3	2000	59	94	46
2	1900	24	119	43
1	1000	70	49	30
4	2300	41	29	51
5	2510	99	129	54
7	3314	95	88	67
0	Start	90	2	89
	Total distance:	1025		

#	Sequence	Distance
0	Start	0
1	11	85
2	311	64
3	511	44
4	711	89
5	931	91
6	1191	131
7	1351	89
8	1571	40
9	1771	89
10	1991	24
11	2211	40
12	2531	45
13	2911	40
14	3711	145
0	Start	127
	Total distance:	1143

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	1991	111	85	46
11	2211	40	65	50
14	3711	81	130	74
13	2911	90	40	62
12	2531	40	20	55
8	1571	34	20	39
9	1771	89	110	42
6	1191	44	130	31
3	511	90	40	22
2	311	44	85	18
1	11	64	20	14
4	711	110	130	23
5	931	40	110	27
7	1351	95	40	35
0	Start	81	2	89
	Total distance:	1053		

#	Sequence	Distance
0	Start	0
1	9	83
2	509	42
3	709	89
4	909	44
5	1009	91
6	2009	131
7	3339	48
8	4409	40
9	4999	19
10	5009	14
11	5559	61
12	6009	38
13	6669	69
14	7009	145
0	Start	85
	Total distance:	999

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	5009	106	108	95
11	5559	61	48	106
14	7009	31	63	130
13	6669	38	83	123
12	6009	69	18	114
8	4409	103	108	86
9	4999	19	93	95
6	2009	59	108	46
3	709	54	128	23
2	509	89	38	22
1	9	42	18	14
4	909	73	83	27
5	1009	19	63	30
7	3339	95	118	67
0	Start	116	2	89
	Total distance:	974		

#	Sequence	Distance
0	Start	0
1	4	78
2	24	19
3	84	99
4	224	28
5	444	91
6	666	131
7	704	42
8	888	60
9	904	15
10	1444	65
11	2994	159
12	3334	38
13	4444	105
14	5004	145
0	Start	100
	Total distance:	1175

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	1444	54	13	38
11	2994	129	133	62
14	5004	70	103	95
13	4444	89	13	87
12	3334	105	113	67
8	888	83	62	27
9	904	15	78	27
6	666	32	80	23
3	84	27	103	14
2	24	69	33	14
1	4	19	13	14
4	224	109	123	15
5	444	28	103	19
7	704	95	123	23
0	Start	162	2	89
	Total distance:	1086		

#	Sequence	Distance
0	Start	0
1	2	76
2	809	97
3	900	99
4	987	37
5	1010	91
6	1400	131
7	1590	54
8	1780	79
9	1909	33
10	2003	25
11	2456	159
12	3456	53
13	4567	104
14	5678	145
0	Start	55
	Total distance:	1238

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	2003	121	102	46
11	2456	32	70	54
14	5678	71	47	107
13	4567	53	16	90
12	3456	104	115	70
8	1780	60	119	42
9	1909	33	128	43
6	1400	36	94	35
3	900	25	74	27
2	809	33	108	26
1	2	98	11	14
4	987	41	36	30
5	1010	27	64	30
7	1590	95	39	39
0	Start	76	2	89
	Total distance:	905		

#	Sequence	Distance
0	Start	0
1	114	184
2	409	70
3	509	99
4	709	89
5	900	91
6	1400	131
7	1590	54
8	2017	76
9	3456	53
10	3999	67
11	5000	159
12	6099	34
13	7000	73
14	9000	145
0	Start	187
	Total distance:	1512

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	3999	45	48	79
11	5000	53	94	95
14	9000	103	139	162
13	7000	107	49	130
12	6099	72	118	114
8	2017	100	116	46
9	3456	53	115	70
6	1400	47	94	35
3	509	62	38	22
2	409	24	63	19
1	114	70	133	14
4	709	27	128	23
5	900	53	74	27
7	1590	95	39	39
0	Start	76	2	89
	Total distance:	987		

#	Sequence	Distance
0	Start	0
1	2009	127
2	2590	28
3	2800	99
4	2998	87
5	3001	91
6	3290	131
7	3339	53
8	3789	35
9	4170	25
10	4460	79
11	4900	159
12	5205	60
13	5670	20
14	5990	145
0	Start	128
	Total distance:	1267

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	4460	26	29	87
11	4900	89	119	94
14	5990	48	129	111
13	5670	89	39	107
12	5205	20	59	99
8	3789	54	83	75
9	4170	25	109	82
6	3290	49	64	67
3	2800	17	49	59
2	2590	34	84	55
1	2009	28	108	46
4	2998	47	137	62
5	3001	126	10	63
7	3339	95	118	67
0	Start	116	2	89
	Total distance:	863		

#	Sequence	Distance
0	Start	0
1	5	79
2	25	19
3	50	99
4	75	24
5	95	91
6	110	131
7	135	104
8	155	19
9	180	29
10	205	29
11	225	159
12	250	104
13	270	19
14	295	145
0	Start	123
	Total distance:	1174

#	Sequence	Distance	Row	Column
0	Start	0	2	89
10	205	151	104	15
11	225	19	124	15
14	295	54	69	18
13	270	29	39	18
12	250	19	19	18
8	155	24	44	15
9	180	29	74	15
6	110	54	129	14
3	50	64	64	14
2	25	29	34	14
1	5	19	14	14
4	75	74	89	14
5	95	24	114	14
7	135	95	24	15
0	Start	85	2	89
	Total distance:	769		