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FACULTY OF BUSINESS AND MANAGEMENT
INSTITUT OF MANAGEMENT

# VYUŽITÍ DISKRÉTNÍ SIMULACE PŘI ŘÍZENÍ VÝROBNÍHO PROCESU

MANUFACTURING PROCESSES MANAGEMENT WITH USAGE OF SIMULATION TOOLS

DIPLOMOVÁ PRÁCE
MASTER'S THESIS

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# MASTER'S THESIS ASSIGNMENT

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Pursuant to Act. No. 111/1998 Coll., on Higher Education Institutions, and in accordance with the Rules for Studies and Examinations of the Brno University of Technology an Dean's Directive on Realization of Bachelor and Master Degree Programs, the director of the Institute of is submitting you a master's thesis of the following title:

**Manufacturing Processes Management with Usage of Simulation Tools**

In the Czech language:

**Využití diskrétní simulace při řízení výrobního procesu**

Instruction:

Introduction
Statement the problem and goal of work
Theoretical background about the problem
Analysis of the problem and current status
Proposals and conditions of application
Improvement analysis and evaluation
Conclusion
Bibliography
Attachments

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Brno, 30.03.2011

## Abstract

By optimizing the logistics, production and other systems the simulation can reduce costs and rationalise business processes. By use of discrete simulation in software Witness Power with Ease is in this diploma thesis optimised logistical flow of material in the company Hella Autotechnik, s.r.o. The thesis introduces methods and particular phases of creating the model including its validation. The proposal in the diploma work suggests the improvement to lower the costs for the transportation services by 24,400 CZK per month.

## Abstrakt

Simulace výrobních procesů pomáhá optimalizovat výrobu, logistiku a další systémy, díky čemuž se snižují náklady a racionalizují se vnitropodnikové procesy. Využitím diskrétní simulace programu Witness Power with Ease se v diplomové práci optimalizuje logistický tok materiálu ve společnosti Hella Autotechnik, s.r.o. Práce přibližuje metody a jednotlivé fáze tvorby modelu včetně jeho validace a navrhuje vylepšení, díky kterému by mělo dojít ke snížení nákladů na dopravní služby o 24 400 Kč měsíčně.



## Key Words

Simulation, optimization of manufacturing process, logistics, kanban, kaizen, Witness, Visio, modelling, validation

## Klíčová slova

Simulace, optimalizace výrobního procesu, logistika, kanban, kaizen, Witness, Visio, modelování, validace

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## Čestné prohlášení

Prohlašuji, že předložená diplomová práce je původní a zpracoval jsem ji samostatně. Prohlašuji, že citace použitých pramenů je úplná, že jsem ve své práci neporušil autorská práva (ve smyslu Zákona č. 121/2000 Sb., o právu autorském a o právech souvisejících s právem autorským).

V Brně dne 26. května 2011

……………………………….

## Poděkování

Rád bych poděkoval vedoucímu mé diplomové práce Ing. Josefu Šunkovi, Ph.D. za zprostředkování prakticky zaměřeného tématu a cenné rady a připomínky, které zvýšily odbornou kvalitu výsledné práce.

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# INTRODUCTION

It can be very challenging to keep competitiveness in today dynamic environment. Companies try to shorten the period of reactions to the customer demands in many different ways. The pull system is logical result of consumer driven markets when the signal comes directly from users. Through the marketing activities and systems the demand comes to the production and it needs to be done as soon as possible.

At this place the modern approaches to the production comes to the scene. Methods as Just-in-time, Kaizen and Lean management are very efficient and broadly accepted in manufacturing corporations.

To proceed with effective changes in run-in processes and activities we need some tool to illustrate what consequences our decisions will have. For this reason are helpful computer simulations which compare the reality with modelled situations. Among those simulations belongs also software Witness Power with Ease 1.0 produced by company Lanner group from the United Kingdom. This program uses discrete simulation to study events and its effects during the run of simulation.

Company Hella Autotechnik, s.r.o. produces lights for cars and its complex production includes hi-tech assembly lines and other state-of-the-art machines. The most vulnerable bottleneck is seen in logistics which is managed by small carts operated by people. Because of high volume of transported parts there is always risk of material flow interruption. This breakdown can cause serious impacts on whole business so the company decided for the logical step, to manage these risks. By using simulation tools we will try to find crucial bottlenecks and optimise material flow to reduce costs.

Using simulation software is appropriate mostly for mid-size and large companies due to high purchase costs and necessity to hire professionals or to train own employees. The second mentioned option is long termed and is useful for ongoing and complex optimising process which is probably the right one for the analysed firm.

# 1 STATEMENT THE PROBLEM AND GOAL OF WORK

Company HELLA AUTOTECHNIK NOVA, s.r.o. located in Mohelnice is focused on producing lights for cars and vans. Its inner production system is based on pull principle and thus the delivery of material happens on the signals coming from assembly line.

The analysed segment in the company is the assembly line (2445) where the lights for Volkswagen Polo are made. Into this line is brought about 20 different pieces to assemble one final product. The transportations of these parts are outsourced by external company Fenix Solutions, s.r.o. The material is physically moved by several carriers which each of them follows specific rules and logic. In the diploma work is done the analysis of inner logistics, it is created model and performed the simulation on which basis are suggested proposals for more efficient production.

The simulation should be the springboard for more complex modelling and optimising of the material flow inside the factory in later stages.

The main goal of the work is **reducing the costs** of the inner logistic. This goal can be achieved by simulation tools which is the main topic of this thesis. Subsidiary goals which will help to fulfil this main goal are following:

**Subsidiary goals of the work:**

- *Analyze the situation and collect all necessary information (this also helps the company to realize what data are kept and which of them are useful and which are not recorded sufficiently)*
- *Creation of a model which can be used also later for other optimising activities*
- *To propose more efficient setup of logistic with use of Simulation software (costs reduction –human and equipment resources, time savings, detect risks etc.)*
- *Get the outside look at the logistics and bring fresh ideas how to manage it*
- *Show the advantages of using Witness Simulation Software*

# 2 THEORETICAL BACKGROUND ABOUT THE PROBLEM

## *2.1 Business processes*

Business process is set of activities which demands one or more inputs and produces an output with a value for the customer. The result of these periodically repeating actions is the delivery of product directly to customer. Process consists of single actions (elements). Process approach in company is visible through all business and is connected with non-producing departments, too. Information support can be found in these areas: SCM (Supply Chain Management), CRM (Customer relationship management) and e-business. (5)

Link between business processes and information systems is very tight. Outcome of implementing business information systems is better accessibility of data sets and to improve production processes. (3)

For each company and its sustainability on the market is necessary to improve individually single business processes. Customers demand better products and services so many firms begin to work with their inner processes. We need to map processes and document them and analyse, verify and measure frequency of change.

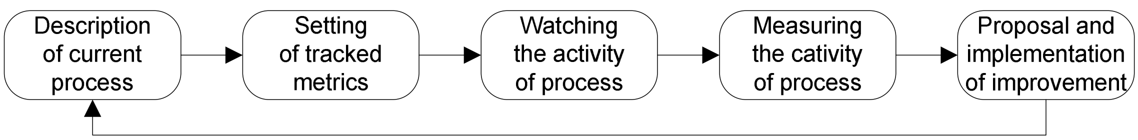


*Chart 1: Improving of processes.*

There are different kinds of processes:

- ***Key process** – main process which fulfil the mission of company. It is a place where main added value for the customer is created. It is represented by sequence of activities coming from customer requirement to his satisfaction.*

- ***Supporting process*** *– ensures the product to inner customer or key process. Thought this product can be obtained externally without endangering the mission of company, it is made internally for the economic purposes or to reduce a risk.*
- ***Secondary process*** *– is executed within the company for the economic purposes.* (10)

Controlling processes are another group of processes. In practise it is used a method CMM (Capability Maturity Model) which separates processes according to their maturity:

- ***Non-existing*** *– company have not recognized the problem yet*
- ***Random*** *– company finds out the problems and wants to solve them*
- ***Repeated*** *(only intuitive) – effort to create standard processes but they are used solely intuitively*
- ***Formalized*** *- employees are trained for the standardized processes*
- ***Measurable*** *– controlling process is added for continuous improvements*
- ***Optimised*** *– processes were developed to the best possible state* (1)

## *2.2 Production management systems*

We recognize two main approaches in production management. Term push and pull is widely used in logistics and SCM but it can be also found in marketing. Push-pull system describes flow of product and information between two objects in company. In customer markets the goods or information are "pulled" by customers, while manufacturers and suppliers "push" the goods to the market. (9)

### 2.2.1 Push system

In push system the production is realized according to production plan and availability of material which force an order through the production process. Another meaning of push strategy in marketing can be found in communication between seller and buyer. According to used information the communication can be interactive or non-interactive. For example, if the seller uses TV or radio for promotion, the interaction is not possible. On the other side, the customer can interact with seller when the message is broadened by internet or phone call. In the first case, the information is pushed to buyer, while in second example it is possible to buyer to demand necessary information according to his requirements.

Signs of push system:

- *is used for the part of supply chain in which the demand is insecure and relatively small*
- *production and distribution is based on long term prognoses*
- *inability to satisfy changing structure of demand*
- *unacceptable levels of services*
- *excessive inventory according to the need of safety reserves*
- *smaller expenses to promotion*

This principle is used in methods MRP and MRS where determines terms and dates to order material according to structure of production plan.

### 2.2.2 Pull system

In this system the customer demands a product and pulls it via offered channel. Example can be found in company Ford Australia. Ford Australia produces only cars which were order by customers in advance – tailor made. The ones who decide what will be produced and when, are customers. Ideal model is when the number of goods is the same as demanded amount by consumers. It is market aimed approach to production. KANBAN and JIT (Just-in-time) principles belong to this system. It is a key tool used in pull manufacturing system. In tight connection with pull manufacturing system is also lean manufacturing, which helps to remove wasting during a production process.

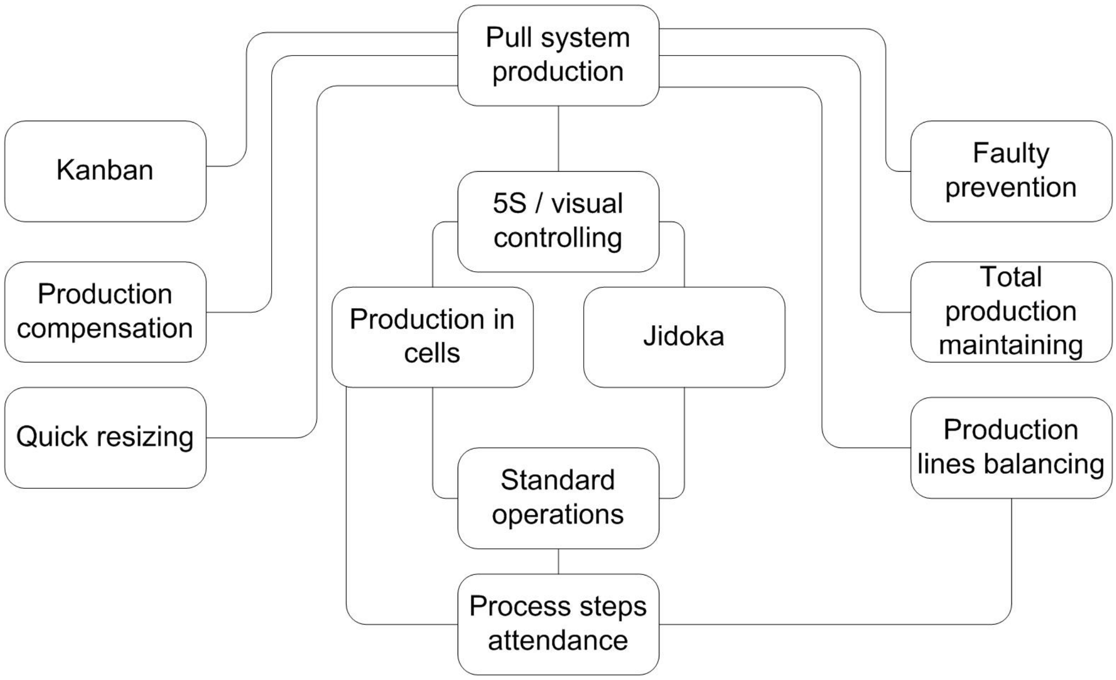


*Chart 2: Related methods in lean manufacturing.*

- ***5S*** *– focuses on wasting caused by mess on workplace, e. g. chucked or missing tools which does not have their keeping place, badly marked material and parts, overfull storage areas and corridors.*
- ***TPM*** *– deals with lost time and costs during unplanned shutdowns*
- ***Kanban*** *– helps to reduce overproduction and production-in-progress*
- ***Quick resizing*** *– focuses on reducing the time necessary to change the setting of production machinery time*
- ***Faulty prevention*** *– removes lost time and costs linked with wrong procedures*
- ***Standardization*** *– determines standard procedures for each manufacturing operation and supervise its complying with standards and improving of single processes*
- ***Jidoka*** *– or so-called "human automation" is a process which provides an option for the workmen to stop the manufacturing line whenever they find faulty performance, so they can remove this shortcomings*
- ***Production lines balancing*** *– shifting the workmen to a production line where the largest production is*[1]

[1] PRODUCTIVITY PRESS DEVELOPMENT TEAM: *Kanban for the Shopfloor.* Productivity Press. 2002. 120 p .ISBN 978-1563272691

The only way to shorten the production time is the method of lean manufacturing. Switch-over to pull system influences the information flow and finally it will have the impact also to a production plan.

**Pull vs. Push system**

The pull system removes wasting of material which comes from push system production where accessible material is pushed from beginning to the end of production programme. In push system accessibility of raw material is the starting point for beginning of the production and buying of material is based on forecasts from last periods. This system results in overproducing and delay of delivery. Material cumulates in stocks and on every critical point. Bottlenecks appear on the places where the production has different cycle than preceding production.

Push and pull systems determine quantity of production, sales and define on which basis the decisions will be made. The main difference is the subject which analyse the market and which decides what amount of goods will be delivered to the customers. Important aspect in this decision process is information.

JIT is typical representative of pull system and MRP II of push system. TOC (Theory of Constraints) as the newest method, combine both principles where the generic points are bottlenecks.

## *2.3 Modern approaches to production management*

To eliminate inefficiency in earlier used systems there were developed new concepts of production which comes out from certain principles and approaches to production management. Aim of these new concepts is to remove absence of strategic thinking in production management, use of old-fashioned procedures and remove insufficient support of production by information technologies.

### 2.3.1 MRP and MRP II (Material Requirement Planning)

MRP is concept developed in early sixties in USA. Originally it was more focused on material stock control than on production planning. This model replaced generally used control based on norms and introduced direct material ordering according to real stock level. The dispensable inventory is also included in the planning. Calculation of MRP is quite simple and today they are implemented in software for production planning. In almost every cases when this system is used the costs to keep the stock level decrease. The disadvantage is that the planning is based on information from rough production distribution. (4)

The main features of MRP are:

- ***Focus on product*** *– comes from calculation based on structure of the product determined by material items necessary for the product.*
- ***Focus on future*** *– instead of statistical data it uses basic information in files and expected demand.*
- ***Complying with demand in time*** *– into the account are included also running times of orders apart material items' requirements.*
- ***Complying with priorities*** *– with regard to customer needs and production plan.* (1)

**Calculation of material needs in MRP**

By use of piece list, warehouse stock level and production plan defines material needs. It sets the proposals for purchase of material and production orders of pieces. Calculation basis is the value of customer requirements or market prognoses determined for the highest item in piece list within the production plan. Afterwards it is lowered by stock level and expected material arrivals.

Production plan needs
+ allocations
- expected stock level
- expected material arrivals (realized orders)

---

= net material requirements, purchase or production orders

The main issue with MRP systems is data integrity. If there are some faults in data as for example in piece list or in production plan (MPS – master production schedule) then output data will be wrong, too (GIGO – Garbage in, garbage out). Most of the sellers of these systems recommends at least 99% data integrity to get useful results. Another problem of MRP systems is to determine how long it will take to manufacture a product from the pieces (when all of them are accessible). Last not least there have to be trainings for great amount of employees to use this system.

Method MRP plans orders regarding to minimal stock level and necessary time which leads to cutting the financial resources. It can be applied to items which are bought from suppliers as well as to configurations which are parts of more complex subjects.

Requirement to correlate earlier mentioned methods (MRP, CRP, MPS and feedback) leads to new system called MRP II which is connected to trade and purchase plan as well as to financial analyses.

In the seventies new system called MRP II arose by improving MRP. The new method had detailed production schedule which had tighter connection with material orders and capacity calculations. The main advantage was the expressive cut-down of floating capital fixture, cost savings to acquire and keep inventory.

### 2.3.2 TOC (Theory of Constraint)

Theory of Constraint is overall management philosophy introduced by Dr. Eliyahu M. Goldratt in his book called The Goal in 1984, where he focuses on helping organisations to reach their goals. The name comes from the fact that whatever system is limited to reaching its goal by small amount of constraints and there is always at least one of them. The main assumption of the theory is each organisation can be measured and managed by three scales: transmittance, operating costs and inventory level. Transmittance is the money (or unit aims) which comes from sales. Inventory level is money invested to system to sell its goods and services. Operating costs are all the money which the system spends to transmit the inventory. Process TOC tries to identify the constraint and restructure the rest of organisation by using following five steps:

1. *Identify the constraint (the resource or policy that prevents the organization from obtaining more of the goal)*
2. *Decide how to exploit the constraint (get the most capacity out of the constrained process)*
3. *Subordinate all other processes to above decision (align the whole system or organization to support the decision made above)*
4. *Elevate the constraint (make other major changes needed to break the constraint)*
5. *If, as a result of these steps, the constraint has moved, return to Step 1. Don't let inertia become the constraint*. (2)

These five steps should ensure continual improving of the constraints in organisation. In literature is TOC mentioned as "process of continuous improving" (POOGI). These steps are crucial to develop specific applications mentioned below.

A constraint is anything that prevents the system from achieving more of its goal. There are many ways that constraints can show up, but a core principle within TOC is that there are not tens or hundreds of constraints. There is at least one and at most a few in any given system. Constraints can be internal or external to the system. An internal constraint is in evidence when the market demands more from the system than it can deliver. If this is the case, then the focus of the organization should be on discovering that constraint and following the five focusing steps to open it up (and potentially remove it). An external constraint exists when the system can produce more than the market will bear. If this is the case, then the organization should focus on mechanisms to create more demand for its products or services. (12)

Part of TOC is OPT (Optimised Production Technology) which is method of scheduling dictates that material should only be launched on to the shop floor at the rate at which it is consumed by the bottleneck. The aim of OPT is to schedule bottleneck capacity in an efficient way. This schedule is the master for the demand placed on other capacities.

The main features of OPT are:

- *Balance flow not capacity.*
- *The level of utilization of any part of the system, which is not a bottleneck, is dependent on other constraints in the system, not the potential of the worker.*
- *The utilization and activation of a resource are not synonymous.*
- *An hour lost at the bottleneck is an hour lost for the total system.*
- *An hour saved at a non-bottleneck is just a mirage.*
- *Bottlenecks govern both throughput and inventories.*
- *The transfer batch may not, and many times should not be equal to the process batch.*
- *The process batch should be variable, not fixed.* (14)

Executives of OPT are planning modules. OPT is based on two phases. In the first phase the preliminary planning is going retroactively. The goal of this phase is to find bottlenecks and identify critical and uncritical manufacturing resources. In the next phase – final planning – is planned via forward schedule.

### 2.3.3 JIT (Just-in-time) and Kanban

Just-in-time is a strategy which pursues the improving of investment return by reducing the semi finished material and related operating costs. JUT is focused on material flow fluency. They are reduced running times of produce by minimising the idle times and by type casting of the machine. The variable size of manufacturing batches is used. To fulfil the aim of JIT the process uses a Kanban system. According to this system it is possible to divide the production to “seller” and “buyer” who sends the label (Kanban) with order. The seller reacts by supplying demanded product to the buyer. The method requires single-direction material flow and synchronization of operations. (1) Kanban system, if used properly, can improve investment return, quality and efficiency of the manufacturing company.

Philosophy of JIT is simple and is oriented to eliminate 5 basic kinds of losses: coming from overproduction, idling, transport, keeping the stock level and poor quality products. Briefly speaking, just-in-time system is focused to have material on proper place, in proper time and in proper quantity without need of keeping the safety stock. System JIT is typical for cost strategies:

- *Keeps stock holding costs to a bare minimum*
- *Works on a demand-pull basis*
- *Reduces lead times and uses frequent deliveries with minimized lot sizes*
- *Reduces set up times*
- *Minimises motion waste by shortening the distance among workplaces*
- *Makes production simple and transparent*
- *Supports motivation of staff at all levels of the organization*
- *Avoids to manufacture a thing  which can be bought for cheaper* (4)

As a result the JIT can bring reduced stock level and semi-finished production, smaller and more efficient storage areas, shorter through and set-up times, higher efficiency a usage of workplaces and machines, lowering of overhead costs and increased quality. On the other side implementation of JIT is highly sophisticatedy expensive and time-consuming.

**Lean management**

Lean management (sometimes just “Lean”) is manufacturing process which identifies all non-value adding actions for final customer as wasting and which distracts the company from achieving its goal. Lean manufacturing is similar to concept of efficiency based on flow optimisation. People are solving the problem of inefficiency and wasting during the history by empiric methods and they try to decide what the crucial point is. Lean manufacturing is usually seen as softer version of older attempts which can take up to work of leaders as Taylor or Ford and to avoid their mistakes. (4)

### 2.3.4 KAIZEN

Kaizen method comes from Japan and means improvement apart that it is one of the most used words there. Kaizen refers to philosophy or processes of continual improvement in production, engineering and business processes and control support. Kaizen focus to improve activities in every aspect of business. It contains all functions and processes as purchasing department, logistics and SCM and has impact on all levels of staff from CEO to workers on production lines. This method is used widely across the world. Kaizen contains several crucial practices:

- Focus to customers
- Total quality management and quality improvement
- Robotics of automation
- Quality circles
- System of improvement suggestions
- Discipline on the working place and absolute maintenance of production facilities
- Just-in-time and Kanban
- No flaw goods
- Good relationships with customer on all lines
- New products development
- Teamwork (7)

**5 steps of Kaizen**

1. *Sorting* ***(Seiri)*** *- Eliminate all unnecessary tools, parts, and instructions. Everything else is stored or discarded. Essential items keep in easily-accessible places.*

2. *Straightening or setting in order / stabilize* ***(Seiton)*** *- There should be a place for everything and everything should be in its place. The place for each item should be clearly labelled or demarcated. Items should be arranged in a manner that promotes efficient work flow.*

3. *Sweeping or shining or cleanliness / systematic cleaning* ***(Seiso)*** *- Keep the workplace tidy and organized. A key point is that maintaining cleanliness should be part of the daily work – not an occasional activity initiated when things get too messy.*

4. *Standardizing* ***(Seiketsu)*** *- Work practices should be consistent and standardized. All work stations for a particular job should be identical. Everyone should know exactly what his or her responsibilities are for adhering to the first 3 S's.*

5. *Sustaining the discipline or self-discipline* ***(Shitsuke)*** *- Maintain and review standards and do not allow a gradual decline back to the old ways. While thinking about the new way, also be thinking about yet better ways.*

Kaizen represents humane approach because it assumes that all workers will join to cooperate. It is based on idea that every labourer can contribute to improvement of system. Strategy is paying attention to process as well as to result.

## *2.4 Process modelling*

Nowadays it is not quite possible to describe real systems because of their extensiveness and complex inside and outside connections and also because of external effects which are difficult to predict. One of the tools to study these systems is modelling which simplify the reality to essential factors with greatest impacts. The aim is determined in the first steps during the real system modelling, in other words it is set the problem which has to be solved. By modelling we mean creating of model. (8)

## Types of models

In fact of wide range and complexity of real objects we need to decide which kind of model we will use. There are several options and points of view how to divide them.

Following image shows the division according to J. Daněk: (16)

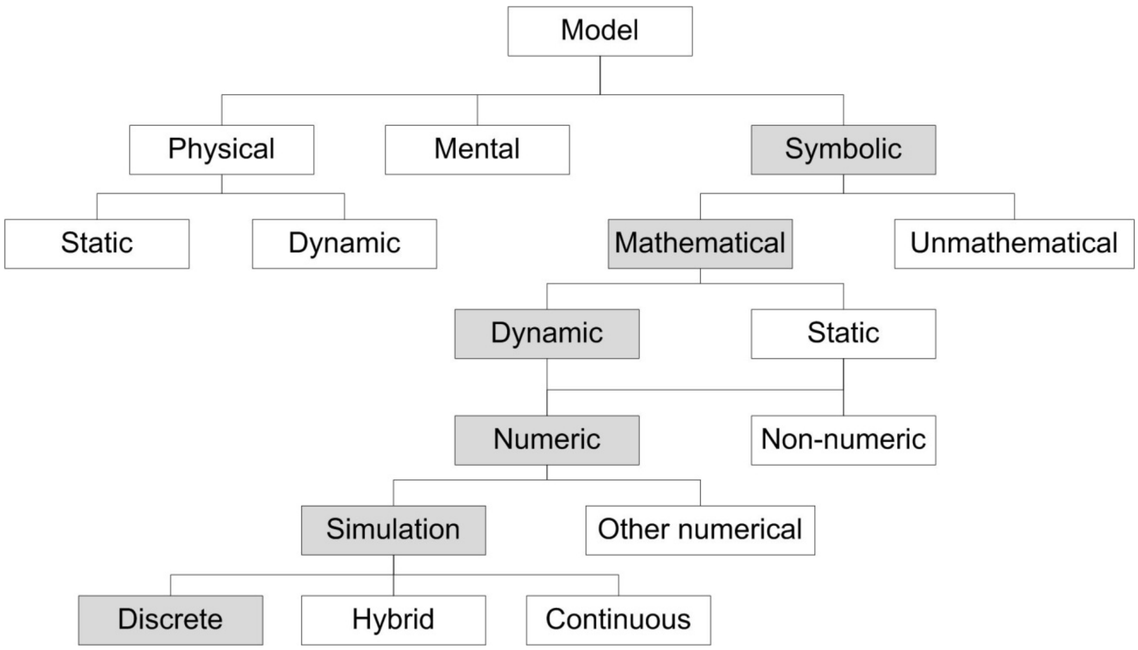


*Chart 3: Types of models by J. Daněk.*

Models are useful in many economic areas and suitable to solve wide range of problems. Discrete event models are usually used for real operations. Via them it is possible to coordinate demands of different workplaces, reduce operational costs, improve material flow through assembly line etc. These models or by simulation modified version of them provide detailed statistical processes. They are useful on lower management levels, for example at production process control. On strategic level they are not used so much because of their in-depth, detailed and focus on one process character. It is not possible to provide efficient overlook of business as a whole.

Continuous or real-time simulations are contrary used on aggregate level what means they represents their states and changes in time. As example of aggregated state can be business performance. In practice this models are used as tools to support strategic decisions, marketing plans and to elaborate business plan. (23)

## *2.5 Simulation*

Simulation software is widely used in many areas of human existence and it became the part of scientific and common practices. Together with increasing technology and programme resources the simulation allows to process through complex calculations and experiments which is currently one of the most important methods how to acquire new findings.

Simulation models provide information about probable consequences of alternative decisions. Its use is appropriate mostly in case we follow more goals. (15) The most usage of simulation is nowadays in technical areas such as mechanical and electrical engineering and in chemistry.

### 2.5.1 Discrete event simulation

Discrete event simulations are characterized by step discontinuous variables which change only if some event occurred. They is used next-event technique (model changes only when event is realized) to control the behaviour of model.

Model (simplification of reality) which is base of simulation contains chronological continuous actions. Due to results obtained from simulation we can find out behaving of complex dynamic system which is changing in time under various conditions.

Discrete event simulation uses some typical discrete items which represents every discrete system.

- ***Clock*** *– according to set units (hours, minutes, seconds) the time changes instantaneously.*
- ***Events list*** *– changes in the simulation system. They can be expressed by change of entity state and time when the change occurred.*
- ***Random-Number Generators*** *– to generate numbers they are pseudorandom number generators in use. Their aim is to imitate reality, for example when customers come during different times and in different amount.*
- ***Statistics*** *– The result of simulation are statistical data gained during the simulation which we need to process and analyze to get the proper information.*
- ***Ending Conditions*** *– the simulation would be never-ending without ending conditions. They can be for example 20 repetitions or 5 shifts in shop floor.*

### 2.5.2 Phases of computer simulation production

The aim of simulation projects is business processes improving (higher efficiency, lower costs, etc.). The production passes through certain phases which are not always obligatory and strict.

Skip or underestimation can save time and money but more often it ends with higher price of project. There are many ways hot to classify phases and steps of the project but in general we can speak about following scheme:

**PHASE 1 Problem recognition and aim determination**

Proper definition of problem is essential for success. It is common that even good managers are not able to determine the cause of problem from the beginning. It is crucial in this moment to arrange meeting between client and research team.

**PHASE 2 Conceptual model creation**

Before the computer model is made it is necessary to make a basic conception about modelling system. Entry data are:

- *What business we simulate and who are the customers*
- *Efficiency criteria determination*

- *Level of profundity determination*
- *What objects are present in system*
- *What requests and demands entry the system*
- *How are the sources allocated*

To be capable to create a production systems model and included processes it is essential to comprehend the structure of manufacture and to get know its sections:

- *Type of manufacture*
- *Topology and lay-out*
- *Material flow*
- *Information flow*
- *Machinery and equipment*
- *Staff and HR*

**PHASE 3 Data gathering**

Simulation is very demanding for data. The problem occurs when they are not disposable. It is possible to create the model without data if there are sufficient alternative prerequisites (expert's testimony, analogy, etc.). Another option is to listen to the people from shop floor that have the most experience.

**PHASE 4 Simulation model creating**

Simulation model comes out from conceptual model (Phase 2). Creating of computer model is the first checkpoint of conceptual model because computer's logic discloses the issues which were omitted.

**PHASE 5 Verification and validation**

By verification we mean verifying if the model is accordance with conceptual model. It is a check-up of transform from real world to the simulation programme. Validation stands for revising if the model is in compliance with reality. The best way how to prove it is to compare data output from the model with real data. There will never be complete conformity between both systems and it is appropriate to avoid over detailed models which are difficult to run. There can be three types of validity:

- ***replicate validity*** *- reproduce data from real world*
- ***predictive validity*** *– model outputs data before the real world*
- ***structural validity*** *– model is able to reproduce observed data and it also reflects the way of actions in reality*

**PHASE 6 Experimenting and results analyses**

In this stage the model brings first results what is very rewarding for the research team. It is recommended to begin a discussion about the functionality of model and how to hand the results to the client. It is convenient to prepare several alternatives to discuss.

**PHASE 7 Documentation**

Often is this phase underestimated which makes it very difficult to return for the created model later and use it again. It is necessary to describe the structure, development of the model and gained results to keep it understandable for other users.

**PHASE 8 Implementation**

The last phase is very important because if we do not implement the simulated model, all the effort will have no effect and it will be just a waste of resources. Sometimes there is a problem with staff who does not want to accept proposed changes. (11)

# 3 ANALYSIS OF THE PROBLEM AND CURRENT STATUS

## *3.1 Company review*

HELLA AUTOTECHNIK is a Germany based company producing lights for passenger and goods vehicles.

### 3.1.1 Company structure

*Hella Corporate Center Central & Eastern Europe, s.r.o.* is hundred-per-cent owner of *HELLA AUTOTECHNIK, s.r.o.*, *HELLA AUTOTECHNIK NOVA, s.r.o.* and *HELLA CZ, s.r.o.* At the same time *Hella Corporate Center Central & Eastern Europe, s.r.o.* (found in 2008) is subsidiary of *Reinhold Poersch GmbH* from Lippstadt, Germany.

HELLA AUTOTECHNIK NOVA, s.r.o. focuses mainly on production, while HELLA AUTOTECHNIK, s.r.o. is focused on research, development, measuring and testing. These two firms are based in Mohelnice as Hella group Mohelnice. HELLA CZ, s.r.o. takes care about spare parts sales and support for customers. And Hella Corporate Center Central & Eastern Europe, s.r.o., based in Zruč nad Sázavou, supports subsidiaries with IT services, buying services, finance, HR etc. (19)

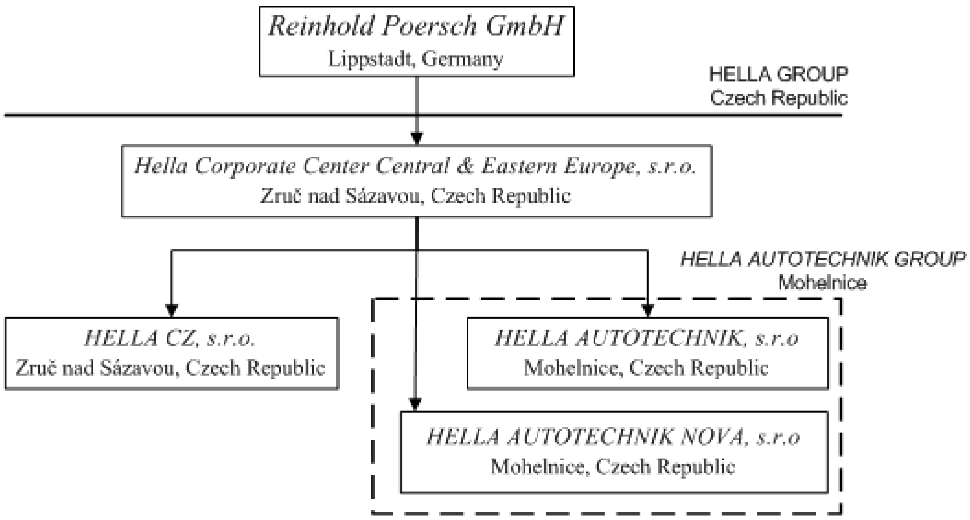


*Chart 4: Company structure of Group in the Czech Republic. (Own structure. Source: ARES - Ekonomické subjekty. [online]. 2011 [cit. 2011-05-21]. Available at: <http://wwwinfo.mfcr.cz/ares/ares_es.html.cz>.)*

**HELLA AUTOTECHNIK, s.r.o. - (HAT)**

| | |
|---|---|
| Name: | HELLA AUTOTECHNIK, s.r.o. |
| ID: | 47154888 |
| Date registry to the Company Register: | 25th September 1992 |
| Residence: | Družstevní 338/16<br>Mohelnice, 789 85 |
| Legal form: | Limited liability Company |

Subject of Enterprise:

- Production, installation and repairs of electronic machines and devices
- Leasing and lending movable assets
- Waste treatment (except dangerous)
- Reality activities
- Production of machines and devices which use mechanical energy
- Projection of electrical devices
- Testing, measuring and analysing and controlling
- Technical advisory in car industry
- Machine operators instructing
- Wholesale
- Motor vehicles and equipment retail
- Trade and services procurement

| | |
|---|---|
| Statutory body: | Ing. Karel Bill<br>Ing. Marek Ryšavý, MBA |
| Fixed capital: | CZK 300,211,000 |

**HELLA AUTOTECHNIK NOVA, s.r.o. – (HAN)**

| | |
|---|---|
| Name: | HELLA AUTOTECHNIK NOVA, s.r.o. |
| ID: | 25834151 |
| Date registry to the Company Register: | 22nd March 1999 |
| Residence: | Družstevní 338/16<br>Mohelnice, 789 85 |
| Legal form: | Limited liability Company |

Subject of Enterprise:

- Production, installation and repairs of electronic machines and devices
- Leasing and lending movable assets
- Reality activities
- Production of machines and devices which use mechanical energy
- Projection of electrical devices
- Testing, measuring, analysing and controlling
- Technical advisory in car industry
- Motor vehicles and equipment retail
- Trade and services procurement
- Technical lay-out design and preparation

| | |
|---|---|
| Statutory body: | Ing. Marek Ryšavý, MBA |
| Fixed capital: | CZK 469,600,000 |

At first HELLA AUTOTECHNIK NOVA produced only limited types of lights but as cooperation continued in good way, the mother company decided to broaden the production. Nowadays HELLA AUTOTECHNIK NOVA produces more than 30 different types of lights, each with many variants (for EU/US market, left driving countries etc.).

### 3.1.2 Products

Thanks to very high quality and obtained certifications, HELLA AUTOTECHNIK NOVA makes lights for high pitch car brands as **Audi**, Jaguar, **Mercedes Benz**, Volvo, Volkswagen, **Škoda Auto**, Ford etc.

*Image 1: Volkswagen Polo light – manufactured in production line 2445. (Source: Hella Autotechnik spol. s r.o.: Volkswagen. [online]. 2011 [cit. 2011-05-21]. Available at: <http://www.hella.com/produktion/HellaPortal/WebSite/Internet_cz/Internet_HAT_cz/OFirme/Current_Production/Volkswagen/Volkswagen.jsp>. Last update 2009-05-04.)*

### 3.1.3 Economic data

Hella group Mohelnice made in 2010 revenues of **5,523,062,000 CZK** (increase by 20.79% compared to year 2009) and profit of about **861,000,000 CZK** (from 376,000,000 CZK in 2009, **229%** decrease**).**

| Thousands of CZK | 2008 | 2009 | 2010 |
|---|---|---|---|
| **Revenues** | 5,018,302 | 4,572,619 | **5,523,062** |
| **Profit** | 651,000 | 376,000 | **861,000** |

*Table 1: Revenues and profit decrease during financial crisis and its return. (Own structure. Source: EMIS: HELLA AUTOTECHNIK NOVA, s.r.o. | Česká republika. [online]. 2011 [cit. 2011-05-21]. Available at: <http://www.securities.com/Public/company-profile/CZ/HELLA_AUTOTECHNIK_NOVA_sro_cs_1422026.html>. Last update 2011-03-02.)*

In August 2010 the company employed **1271 employees** (21) which is about 100 more than during the financial crises when the company had to dismiss about 300 people. (22) According to financial data and employee statistics it seems the crises was already surpassed. Hella group Mohelnice obtained many awards during its business activity, for example it was one of 100 most admired companies in Czech Republic. (18)

## *3.2 Production in HELLA AUTOTECHNIK NOVA, s.r.o.*

In HELLA AUTOTECHNIK NOVA, s.r.o. in Mohelnice there are 9 different **production lines**[2] [Appendix 1]. On each line there is defined a project. **Project** means what kind of light is produced (for what car). At a time there is produced only one type of light. Every time we need to produce different type, we must change the project and the assembly line has to be adjusted. This can take about 2 days.

Each type of light can be made in several variations. **Variations** can be Right-handed lights, Left-handed lights, variations according to different export markets (American market has other specifications than EU's).

Our analysed line has identification number **2445**. The current project on the line is **Volkswagen Polo** lights. Currently there are produced four variations (for right-handed and left-handed traffic and lights for left and right side of a car).

There is a **multi-shift** operation in HELLA AUTOTECHNIK NOVA:

- Morning shift – $6^{00}$ – $14^{00}$
- Day shift – $14^{00}$ - $22^{00}$
- Night shift – $22^{00}$ - $6^{00}$

### 3.2.1 Technology

In HELLA AUTOTECHNIK NOVA, s.r.o. there are used state-of-the-art transportation technologies, information systems, reading devices etc.

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[2] Each line is specified by 4-digit identification number

**Milk-run carts**

The parts are delivered from the central stock to the assembly line by carts operated by cart-men. Each cart has its defined route and always serves more than one assembly line. These carts are figuratively called **milk-runs** as from a real word, where they serve every day the same route.


*Image 2 Milk-run cart Still during handle of assembly line. (Own picture)*

The capacity of cart is extendable by joining another trailer in stock.

**Storage vehicles**

High-lift trucks and additional trolleys are used to operate the material right in the stock. The transportation from the stock to the production line is entirely in charge of Milk-run carts.

**Storage racks**

The parts and material are stored at different kinds of racks. For bigger parts are used multi-storeys pallet racks, for smaller parts which can be hardly to find in large areas are used specialized automated selective racks called **Kardex**.

**Reading devices**

Every box with parts has its unique identify number labelled by barcode. This barcode is named **e-Kanban** and is represented by label in the shel. These codes are readable by electronic devices and wirelessly transferred to the central database. HELLA AUTOTECHNIK uses information software to collect all necessary information. In a section below we will present the structure of gained data.

### 3.2.2 Provided data

**Piece List**

Each final product – light - is composed of many small parts. Some of the parts are prefabricated in HELLA AUTOTECHNIK NOVA, s.r.o. in Mohelnice and some other are **outsourced** from company BÖHM PLAST-TECHNIK a.s. in Česká Třebová.

In analysed line 2445 there are 4 different variations[3] of lights produced:

- **247.051-017** – left light for right-hand traffic
- **247.051-027** – right light for right-hand traffic
- 247.051-037 – left light for left-hand traffic
- 247.051-047 – right light for left-hand traffic

Each variation is made of slightly different parts. We will deal with first two variations only. In the first file [Appendix 3] there is piece list which defines what parts are used, in what amount and in which succession.

[3] Different variations of model are characterized by last three digits in ID number.

| Success. | Part | Title  MB TA | Amount | Type | Amount / Unit | Unit |
|---|---|---|---|---|---|---|
| .1 | 171.930-02 | SKLO+RAM  P SKUP.     POLO | 1 | Product. | - | - |
| ..2 | 167.869-02 | SKLO KR. P            POLO | 1 | Product. | 120 | ROL |
| ...3 | 065.120-12M | PC WIE LEXAN LS1 111H | 47,071 | Raw mat. | 19400 | EUR |
| ...3 | 600.013-63M | LACK  UVHC 3000 | 0,77 | Cooper. | 180 | |
| ..2 | 167.877-02 | RAM VNEJSI  P         POLO | 1 | Product. | 80 | ROL |

*Table 2: Sample of Piece list for part 247.051-047.*

Every variation is made of 65 pieces. However some of the parts are already prefabricated in other places in factory or are outsourced. So in fact in assembly line 2445 there are used only 22 prefabricated parts[4]. In this amount also additional material is included (labels, plastic foil, wrapping etc.). This material is delivered ad-hoc when it is necessary because of its very low turnover rate.

As mentioned earlier, there are two material flows, one of bigger parts and other of small parts.

Our final product is made of 6 big parts which are packed in Rollboxes [Appendix 3]. These pieces are unique for each Variation. In the parenthesis there is stated the number of pieces in one box:

[4] Is valid for variations 247.051-017 and 247.051-027. For variations 247.051-037 and 247.051-047 there are 27 prefabricated parts.

- 168.327-01 (48)
- 167.877-01 (80)
- 167.869-01 (120)
- 167.881-01 (360)
- 171.222-01 (64)
- 171.223-01 (168)

The Rollboxes are brought by operator who supplies only **one assembly** line.

On the other side the small parts are the same for variations 247.051-017 and 247.051-027 (plus some of them are used more times in one light). There are 11 small pieces for each type of light. The amount of parts in one box is mentioned in parenthesis again.

- 168.326-01 (36)
- 168.326-02 (36)
- 159.924-37 (10.000) - used 4x -
- 155.665-00 (400)
- 153.873-00 (360)
- 144.952-00 (1.800) - used 2x -
- 006.841-14 (600)
- 007.157-12 (180)
- 003.594-16 (5.000)
- 153.092-37 (3.000) - used 4x -
- 007.157-14 (180)

These parts are brought by different operator who supplies also **other lines** (see below). Note the parts 168.326-01 and 02 which are unique for each variation but are delivered by Kardex-ers. It is because this part is a light bulb which is stored in locked shelves near Kardex racks and the operators need to have proper authorisation to access them.

**Timing data**

Every time the operator comes to the Supermarket where the empty place is for the part, he uses his reading device to read the barcode. The code is transferred to central information system and stored there. These are the basic information which we will use to create our model.

We have available data set for the period of four weeks (04/12/10 – 05/02/10). First file contains data about parts brought to the line [Appendix 4] and second about how many final lights were carried away from the line to the central stock [Appendix 5].

Both data sets have the same structure:

| **Part** | Stock | **Date** | **Time** | Mov. key | **Amount** | Stock Balance | Receipt | To Stock | **Operator** | **Line** |
|---|---|---|---|---|---|---|---|---|---|---|

*Table 3: Structure of data provided for the analyses.*

All the titles seem to be obvious. Crucial columns are Part, Date, Time, Amount, Operator and Line. Other titles are useless for our model.

### 3.2.3 Material flow

In Hella Autotechnik the in-house logistic is outsourced by external company **Fenix Solutions s.r.o.** which is in charge of managing delivering the material and uses other related services (ordering IS, controlling the machinery etc.)

Each production line is supplied with material (parts) from **central** and **external stock** (Meriva). [Appendix 1] Each line possesses its own area (called **Supermarket**, **Kanban** or **Pull area**) where parts are laid for prompt usage. Every line has its own master (line handler), who coordinates material flow right in the production line and pulls it manually from Supermarket to the destination workplace.

The material is packed in boxes with different capacity and it is essential to distinguish two different material flows, because each group follows different schedule and route:

- ***Small parts*** *– high capacity boxes (360-10,000 pieces per box) – operators are nicknamed* ***KARDEXers*** *(actually the name of storage racks for small pieces) and every operator supplies between 3 – 4 lines.*

- ***Big parts*** *– lower capacity boxes (36-360) – these boxes are called Rollboxes and operators simply* ***delivery men****. Every delivery man attends to one assembly line only.*

(In the next chapter this topic will be explained in more detail.)

The logistical supply system used in factory is **PULL production** (stated in the part Theoretical basis). That is why we begin to describe the material flow with final operation - assembly of light and its transportation to the stock. In the next step we will see how the pull system demands other pieces and how this situation is covered.

Still it is essential to distinguish two separate material flows. When the amount of packs in Supermarket sinks under certain level:

- *the Milk-run operator brings other packs from the **central stock** in amount based on empty places – (case of small parts),*

- *the line handler orders parts from **external stock** or **remote pull area** and delivery man brings them to the assembly line - (case of big parts).*

Empty places are clearly visible due to Kanban system.

## *3.3 Final products and empty boxes flow*

The assembly line produces final parts which are packed to rolls by **24 pieces**. During one machine cycle - **45 seconds** – the machine produces one light of each variation – 247.051-017 and 247.051-027. That makes two different rolls every 18 min or so.

### 3.3.1 Logic of flow

Because of limited space, the area for final parts consists only of **one roll place** for each variation of light. This means every approximately **18 min** the rolls with final products **have to be changed** for the empty one and transported to the stock.

The final parts delivery man is in charge of only these rolls and he takes them to the stock for **later expedition**. From the stock on the way back he takes **empty rolls** prepared for the storage of final products.

### 3.3.2 Time analyses

Following time data were found out from observing and measuring of the delivery man activities:

- ***The way to the assembly line*** *– 2.5 min*
- ***Loading of final rollers*** *– 2 min – in this time is included changing of rolls with final parts to empty rollers.*
- ***The way to Stock*** *– 2.5 min*
- ***Unloading*** *– 9 min – this time consists of unplugging rolls with final parts, storing them and preparing empty rollers ready for final products filling.*

## *3.4 Small parts flow*

As mentioned earlier smaller parts are operated by so-called Kardex operators. According to analysis [Appendix 2] the Kardex-ers supply following lines together (distributed by shifts):

| 6-14 | 14-22 | 22-6 |
|---|---|---|
| 2445 | 2445 | 2445 |
| 2443 | 2443 | 2443 |
| 2437 | 2325 | 2325 |
| 2435 | 2420 | |

*Table 4: Production lines supplied by one KARDEX operator during the shifts. [Own construction]*

We can see that our analysed line **2445** is handled with two or three other lines by one person.

The operators supplying lines are identified by these names:

- HELLPA1N
- KREJTO1N

- NEDVJA1N
- ROSUMI1N
- SISMVL1N

### 3.4.1 Logic of flow

Logic scheme is key element when analysing logistics. The small parts are brought together by one Milk-run:

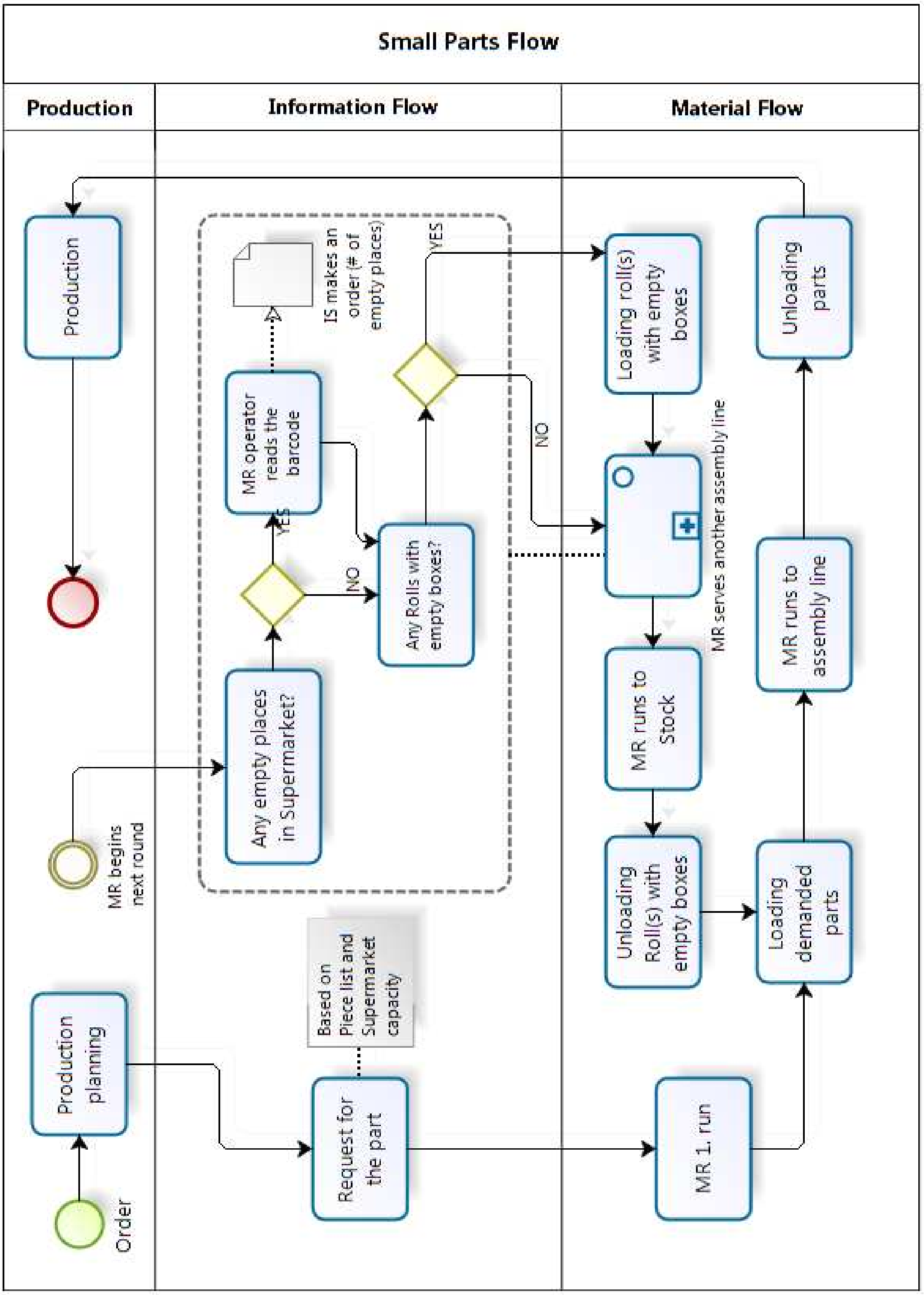


*Chart 5: Logical diagram of information and material flow for small parts (Own structure by BizAgi).*

The initial process in the chart is accepting the **order** of final product.

During the **first initial round** when the Supermarkets are empty, the milk-run brings parts according to Piece list and capacity of Supermarkets. During every after round the MR checks if there are any empty places for parts. If they are, the milk-run makes order by loading the e-Kanban number for later use in the stock.

When one operator manages more assembly lines, these are operated in a **parallel fashion**. Required parts' ID numbers are loaded at first and afterwards all parts are brought together to all production lines.

When all the parts from box are used, empty boxes are put together into the prepared Roller which, when full, is transported by operator to stock where the empty boxes are returned to **reuse** or are **recycled**.

There is also a backup possibility. When the part is **urgent**, the milk-run can make special round just to ensure needed piece. These situations are managed ad-hoc with possible use of a **cell-phone** to make an urgent order and it can be done during every process.

### 3.4.2 Supermarket Capacities

The capacity determines how many boxes can be kept in Supermarket shelves.

For the following parts the capacities are **two boxes**:

- 159.924-37
- 155.665-00
- 153.873-00
- 144.952-00
- 006.841-14
- 003.594-16
- 153.092-37

For the light bulbs 007.157_12 and 007.157_14 the capacity is **10 boxes** for each. The headlamps are stored in six packages for each variation.
For the **empty boxes** is prepared one Roller which is transported when is full.

### 3.4.3 Time analyses

Since we have understood the logic of material and information flow we need to focus on timing of each process in model.

In the small parts delivery they are always served at least **two assembly lines** together, sometimes it can be three lines. Thus we need to cover also these lines into the time scheme.

The metering was undertaken directly on workplace by using the regular **chronometers** and also by **interviewing** the operators and delivery men. The times were **averaged** from several measuring. The small parts have following times during the processes:

- ***The way to the stock*** *– 2.5 min*
- ***Loading*** *– this time depends on how much different parts are to be loaded. Because the operator needs to collect parts from different places in Kardex racks, the time unwinds directly from the number of part types demanded. The average time for each type is 2 min:*
  $Loading\_time = 2 * (\# of\ loading\ parts\ from\ 1^{st}\ assembly\ line + \# of\ loading\ parts\ from\ 2^{nd}\ assembly\ line)$.
- ***The way from stock to Assembly line*** *– 2.5 min*
- ***Unloading*** *– the same case as during the loading process. 0.5 min for each type of part. In this time is included the unloading time as well as time to read the barcode on the shelves. The time is the same also for other line.*
- ***Loading empty roller*** *– 0.5 min*
- ***Unloading empty roller*** *– 1 min*
- ***The way between two assembly lines*** *– 1.5 min*

These data are used later in the model.

## *3.5 Big parts flow*

The big parts flow is little bit different than the small parts flow.

### 3.5.1 Logic of flow

The big parts are prefabricated in manufactory at least 3 days in advance before the final assembly. Meanwhile they are not used they are stored in two possible places:

- *Most of the parts are stored in external stock called* ***Meriva****, which is located across the street.*

- *The situation is different for the part 171.223-01 and 02 variation. These prefabricates are kept in a* ***Remote pull area*** *which is located according to operating decision somewhere in the workshop. This is because Pull areas placed directly in the assembly lines have limited space and all the parts are unable to be stored there.*

The **capacity** of Supermarkets is **10 rollers** for all parts except the parts 171.223-01 and 02. For those two parts the capacity is just **2 rolls**.

On the following picture is shown the logical flow of information and material:

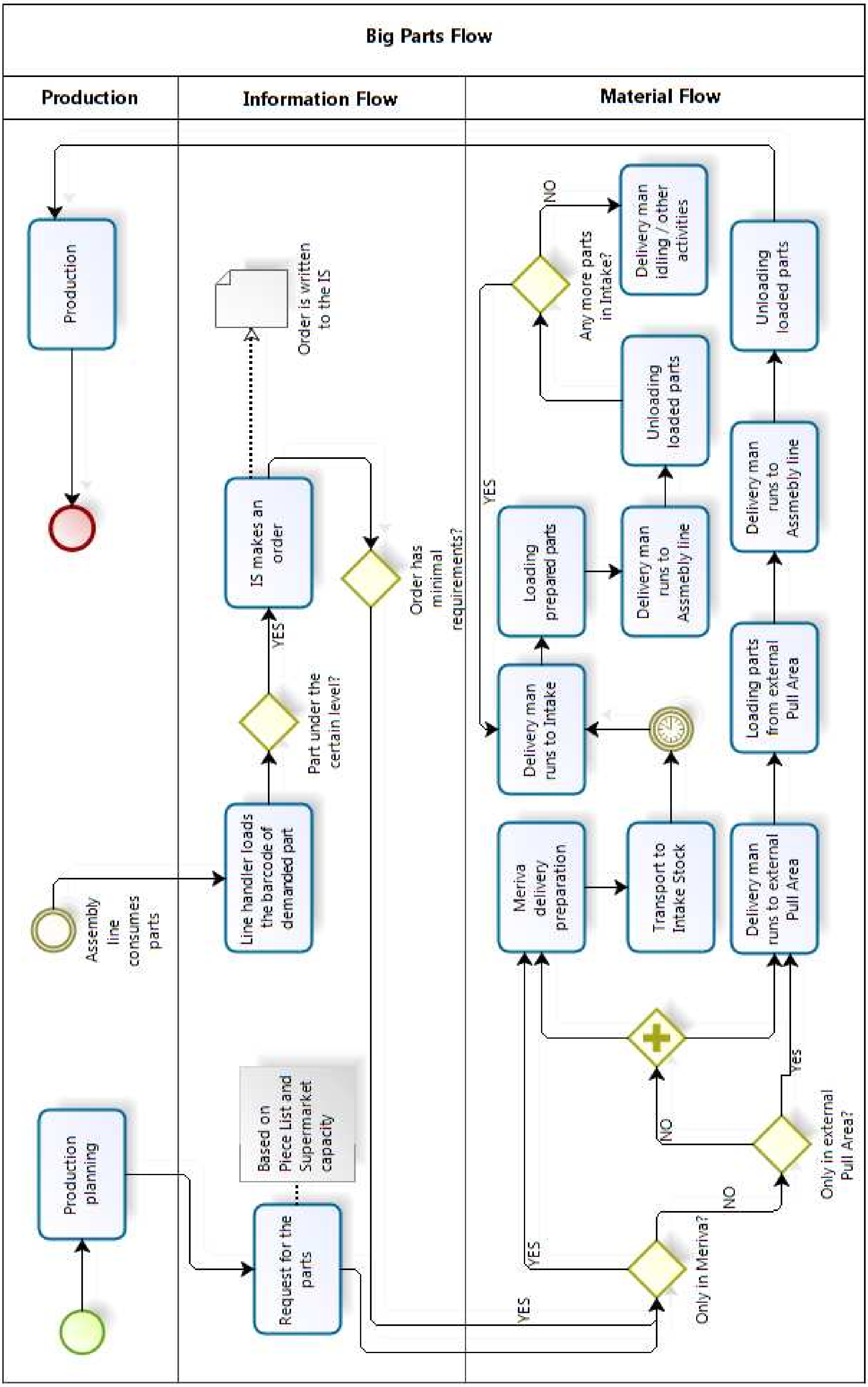


*Chart 6: Logical diagram of information and material flow for big parts. (Own structure by BizAgi)*

The scheme begins at production planning. According to Piece list are ordered needed parts. If some of them are in Remote Pull areas the cart operator brings them to the assembly line. If they are in Meriva, they are **ordered** by production line handler by use of **wireless reading device**. The ID is loaded by barcode to IS and the delivery is prepared in Meriva to be transferred to **Intake stock** in the plant. This process takes certain time which is in diagram represented by clock symbol.

After the delivery is prepared in the Intake, the delivery man begins to bring all the parts to the assembly line. Because of safety regulations and standards the maximum amount of transported rolls is **5 in a time**. That is why the delivery man usually has to go **more than once**.

Every time the line handler removes one roll from the Supermarket he **loads the barcode** and in IS it creates an order. After the order has certain volume the people in charge begin to prepare the delivery in Meriva.

Because the delivery from external stock to Intake takes from **30 min** to **2 hours** at most, the delivery man usually do other works in the stock. For the model we did not examined more deeply what the actual works are.

### 3.5.2 Time analyses

The logistic of big parts has also some specific rules to be respected. When ordering the parts from external stock, the delivery takes approximately **40 min**. Thus the assembly line needs to have enough stockpiles to manage this period. The times for each process are mentioned bellow.

For the parts 171.223-01 and 02 which are brought from Remote pull area:

- ***The way to Remote Pull Area*** *– 1.5 min*
- ***Loading*** *– 2 min when takes only one type of parts or 4 min when takes two*
- ***The way to the assembly line*** *– 1.5 min*

- ***Unloading** – 2 min*

For the rest of the parts brought from Meriva through Intake:

- ***The way to Intake** – 2.5 min*
- ***Loading** – 1.5 min*
- ***The way to Assembly line** - 2.5 min*
- ***Unloading** – 3 min*
- ***Loading of empty rolls** – 2 min*
- ***Unloading of empty rolls** - # Loaded empty rolls / 4*

# 4 PROPOSALS AND CONDITIONS OF APPLICATION

Before proceeding to the process modelling we need to clarify what is the aim of the model and which **simplifications** we can use.

## *4.1 Simplifications*

For the optimisation we need to **track** and **examine the activities** of each delivery carts and record their **activity states**. Thus the carts should be set and timed as properly as possible. On the other side, we can reduce the physical side of the model and some other characteristics:

- *The assembly line is just a **Black Box** which pulls parts according to time scheme based on finale machine cycle. No line handler is visualised.*
- *The next assembly line is created only **virtually**. It demands parts **randomly** according to set normal distribution which is close to averaged value of first line 2445 demand. The normal distribution has mean value set to 3 and standard deviation set to 1.*
- *The delivery from Meriva is **simplified** by the time which is necessary to bring parts from external stock. This time is around **40 min**. No other aspects are included.*
- *The physical side of the workshop and **logistical tracks** are **simplified** and do not correspondent with reality. That is why it is impossible to investigate and optimise the rides of carts and to find bottlenecks where the risk for the collision is. Deeper modelling and complexity would be needed to comprehend this feature.*
- *The times are **approximated** from measured times and can be sometimes different from reality where many other aspects interfere with the process. That is why it is added normal distribution to all processes.*
- *In the model are shifts set as **continuous flow** during the first **10 shifts**. This is divergent than the reality where the demand determines how many shifts will*

*take place in a week. Sometimes the line can be inactive for several days. This is the reason why the line is filled from the start-up* ***empty state*** *just* ***once****.*

## *4.2 Creating the model*

The model was created by software Witness Power with Ease 1.0. In the model are used several elements to realistically describe what is happening in the workshop:

- ***Machines*** *– primarily are used to assembly final product out of parts which are necessary. The secondary use of machine is for packing and unpacking parts to the and out of rollers to preserve the transportation logistic.*
- ***Buffers*** *– are used to contain parts before other process. They can represent pull rows, Kardex racks, Supermarkets in the production line etc.*
- ***Vehicles*** *– are the carriers of the parts. They are the main elements in this simulation because they are used for the optimisation. They can be adjusted for several conditions by using the inner code language.*
- ***Tracks*** *– are agents which broker the transportation of material by vehicles.*
- ***Variables*** *– ensures the logical functionality and statistical records.*
- ***Charts*** *– are used to capture the states of the vehicles for later analyses.*

### 4.2.1 Layout of the model

The basic layout of the model is visualised on the screenshot [Appendix 8].

**Left side of the model**

On the left side are shown different types of stocks:

- *For the big parts* ***Meriva*** *together with* ***Intake stock*** *and* ***Remote pull areas****.*
- *For the small parts* ***Kardex racks****.*
- *For the final parts* ***Expedition stock****.*

Each rectangle signifies one part's storage area. The **parts** are named with **numbers** and a **letter** *P* on the beginning. It is because the Witness needs to put names beginning with letter. Also the dots are forbidden so they are replaced by **underscores**. In the rectangle is written **how many parts** are in a box and **how many boxes** are in the stock. The volume of boxes is set to be enough for 10 consecutive shifts.

**Right side of the model**

On the right side are shown the **assembly line** together with **Supermarkets** and **Pull areas** located directly next to the line.

For the big parts there are prepared **rows** for each type. They are located behind the assembly line and when the delivery man brings new parts, he pushes them from the farther side towards the line so the **FIFO** (First In, First Out) method is secured.

The small parts are stored in the racks so they occupy very little room. Each shelf has the label which means what part belongs to the exact place (Kanban).

In this section are showed also information about **empty places**, so it is clearly visible how many of them are missing and what is the total **capacity** of place. Also information about the **number of parts** in a box is included.

**Middle side of the model**

Between the left side (stocks) and right side (assembly line with supermarkets) there are **tracks with carts** and also **assistant tables**. These tables vividly display how many parts are **demanded** or **loaded**, what are **the sums** of them, how many empty or final rolls are taken back by Milk-runs etc. There are also **pie charts** which represents utilizations of single carts. These data are used later for the optimisation and improvements analysis.

In the model are contained also other machines, buffers and parts which are not present in a real life. They are used just for interstate operations to ensure the **proper behaviour** and **functionality** of the model. For example the machines are needed to pack parts to one package or unpack them what is in reality made by workers on assembly line. Other example is part *Pt_Box002*, which is used to substitute Rolls and other transportation cases. Other specific situation is for the next virtual assembly line where additional part *help_part_next_line* had to be created to imitate the demand.

### 4.2.2 Production

Final assembly of parts are made on two separates machines, one is for variation 247.051-017 and second for variation 027. Each has the cycle time set to 0.75 min. Before the final product is made, the pieces are **unpacked** from the boxes and pushed to the prepared buffers.

The input rule to the final assemble machine is:

```
MATCH/ANY
P168_327_01 out of Prep_parts01 #(1)P167_869_01 out of Prep_parts02 #(1)P167_877_01 out of Prep_parts03 #(1)P171_222_01 out of Prep_parts04 #(1)P171_223_01 out of Prep_parts05 #(1)P167_881_01 out of Prep_parts06 #(1)P168_326_01 out of Prep_parts010 #(1)P159_924_37 out of Prep_parts012 #(4)P155_665_00 out of Prep_parts013 #(1)P153_873_00 out of Prep_parts014 #(1)P144_952_00 out of Prep_parts015 #(2)P007_157_12 out of Prep_parts017 #(1)P007_157_14 out of Prep_parts021 #(1) P006_841_14 out of Prep_parts016 #(1)P003_594_16 out of Prep_parts018 #(1)P153_092_37 out of Prep_parts020 #(4)
```

The Match input rule connects **specified number** of each part with other parts. If the part is not accessible, the machine **waits** until the part is available again.

*Image 3 Detail window for machine Assembly.*

After the final products are made they are **packed** by machine Pack_final to a roll by **24 pieces**.

### 4.2.3 Big parts transportation

In the big parts flow the Meriva delivery is represented by two tracks and a vehicle which brings demanded parts to the Intake Stock. During the first **initial round** the demand is set to **fill** the supermarket capacities to **the full level**.

During other rounds the condition to order new parts from Meriva is set to 8 whichever parts or at least 4 rollers of part P171_222_01 or P171_222_02.

The *Vehicles001* begins the initial round from the Intake Stock. The start-up demand is set to fill.

The junction track *Tracks001* has the routing condition which routes the vehicle either to the Remote pull areas or to the Intake Stock.

The routing condition is the following:

```
IF Bin_Order_P171_223 = 1 AND Loaded_empty = 0 AND DESTOF1 (Vehicles001) = Tracks007
```

```
 PUSH to Tracks007
ELSE
 PUSH to Tracks003
ENDIF
```

- Variable *Bin_Order_P171_223* is equal to 1 when the capacity in supermarket is not full and it avoids the vehicle from going to the *Track007* if it is not needed.
- Another condition *Loaded_empty* ensures that the vehicle will not enter the track when it is loaded with empty rollers and it is going to unload them.
- If some of the condition is 0, the junction pushes the vehicle to the *Track003* towards the Intake stock or if there are no parts, the vehicle is parked.

When the delivery from Meriva is completed the action in the buffer Takein_stock triggers the *Vehicles001*'s demand. The code of the action is following:

```
IF ISTATE (Vehicles001) = 1 OR ISTATE (Vehicles001) = 8
 IF NDemands (Vehicles001) < 1
  IF NPARTS (intake_stock) > 0
   CALL Vehicles001,Tracks003,Tracks002,2
   VSEARCH Tracks003,Tracks001,Tracks002,Tracks007,Tracks008
  ENDIF
 ENDIF
ENDIF
```

When the conditions (the vehicle is idle or parked and is not already demanded and there are some parts in the Intake Stock) are positive, the vehicle is called to pick up the parts from the *Tracks003*. As mentioned in the section Analyses of the problem the vehicle can take 5 rollers at most. That is why the cart has to go multiple times to cover all Intake delivery.

Loading of parts in the Intake Stock is controlled by simple Rule:

```
PULL from intake_stock
```

The unloading is more complex because the parts are routed to the prepared buffers (pull rows):

PUSH P168_327_01 to Pull01(1),P167_869_01 to Pull02(1),P167_877_01 to Pull03(1),P171_222_01 to Pull04(1),P167_881_01 to Pull06(1),P168_327_02 to Pull07(1),P167_869_02 to Pull08(1),P167_877_02 to Pull09(1),P171_222_02 to Pull10(1),P167_881_02 to Pull12(1)

### 4.2.4 Small parts transportation

The small parts flow is modelled almost the same as in real. The only exception is other assembly line which is not covered in the model and thus it needs to be solved by using random variable which substitutes the number of demanded parts to be brought.

When the Milk-run comes to the Supermarket by the assembly line, the cart operator unloads all loaded parts, loads roll with empty boxes if there is any and finally fetch the Kanban labels. This information is stored in the assistant table as demanded part. When the MR goes to the Kardex racks, the demanded parts are loaded (in the assistant table the demanded number will be set to zero and loaded will be set as actual loaded part) and brought to the production line.

All the data from assistant table are **stored** for later statistical evaluation during the **validation**. Also the number of **MR rounds** is recorded.

## *4.3 Validation*

Validation serves as confirmation that model runs appropriately to the reality. It is necessary to compare data gained from simulation and from reality. First we need to adjust all the data to be normalized and synchronized with the model.

The model runs from the time 10 a.m. at Tuesday 2010-04-13. First 4 hours are filled Supermarkets by big parts. This time consumes transport from Meriva to Intake Stock as well as following transport to the line pull areas. After all pieces are on the place, the machine begins to work (labour is set to start after 240 min). Then all 10 shifts are simulated continuously ($4800\,min$), in other words from Tuesday 2 p.m. to Friday 10 p.m.

During the validation we also removed all the normal distributions in timing and we left only real numbers. This is for easier controllability of the model during the process of validation.

### 4.3.1 Entry data adjustment

Before the comparison we correlate the number of parts which run to the assembly line with machine cycle. Because the inflow of big parts is not constant, we use average values.

| | Σ | 20100413 | 20100414 | 20100415 | 20100416 |
|---|---|---|---|---|---|
| 168.327-01 | -4320 | -576 | -1584 | -1104 | -1056 |
| 167.877-01 | -4880 | -1120 | -1520 | -1200 | -1040 |
| 167.881-01 | -4322 | -1080 | -765 | -1080 | -1397 |
| 171.222-01 | -4416 | -704 | -1408 | -1280 | -1024 |
| 171.223-01 | -4872 | -672 | -1512 | -1344 | -1344 |
| | Ø - 4,562 | | | | |
| | | | | | |
| 168.327-02 | -4416 | -720 | -1536 | -1152 | -1008 |
| 167.877-02 | -4400 | -640 | -1520 | -1200 | -1040 |
| 167.881-02 | -4363 | -720 | -1440 | -1123 | -1080 |
| 171.222-02 | -4480 | -640 | -1472 | -1280 | -1088 |
| 171.223-02 | -4704 | -840 | -1344 | -1176 | -1344 |
| | Ø -4,472 | | | | |

*Table 5: Table of parts volume brought to the line. Distributed by days and parts. (Own structure)*

They were examined all big parts except 167.869-01 because this part has close-to-zero volume during first three days and thus the deviation is too big. The table shows how many pieces were brought each day to the assembly line. In the blue column are summarized values and in the dark blue cell is averaged value.

To match the machine cycle and number of inflow parts we need to calculate how long it would take to the machine to produce certain number of parts during offered 4800 $min$:

$$Machine\_cycle = -4800 / ((4562 + 4473) / 2)$$

$$Machine\ cycle = 1.062\ min$$

Even the real machine cycle is $0.75\ min$ the analysed data respond with cycle $\mathbf{1.062\ min}$.

### 4.3.2 Validation of big parts flow

When we put above mentioned machine cycle value to the simulation model and let if run for 10 shifts we get following data:

| 20100413 | Day 1 | 20100414 | Day 2 | 20100415 | Day 3 | 20100416 | Day 4 |
|---|---|---|---|---|---|---|---|
| **140304** | 160612 | **12230** | 12612 | **23914** | 11036 | **13117** | 436 |
| **141621** | 162636 | **25613** | 14636 | **30636** | 25236 | **23556** | 2500 |
| **143952** | 183900 | **55759** | 35836 | **60723** | 43412 | **33557** | 23700 |
| **150310** | 185924 | **84544** | 41900 | **74133** | 45436 | **55250** | 41900 |
| **154104** | 211148 | **91824** | 63124 | **92347** | 70700 | **71309** | 43924 |
| **165202** | 213212 | **102126** | 81300 | **120833** | 72724 | **80428** | 65124 |
| **183600** | 234412 | **110624** | 95500 | **121951** | 93924 | **83846** | 71148 |
| **185538** | | **122237** | 101524 | **141836** | 112124 | **103329** | 92412 |
| **190856** | | **132128** | 122724 | **153235** | 114148 | **120022** | 110548 |
| **195043** | | **142208** | 140924 | **160822** | 135348 | **141058** | 124748 |
| **201301** | | **152757** | 142948 | **163950** | 153548 | **150113** | 130812 |
| **211601** | | **173902** | 164148 | **174513** | 171724 | **160004** | 152012 |
| **220852** | | **195520** | 170212 | **182952** | 173748 | **170858** | 170212 |
| **225826** | | **212459** | 191436 | **190056** | 195012 | **172239** | 172236 |
| **233449** | | **221530** | 205612 | **193022** | 201036 | **184654** | 193436 |
| | | **232717** | 223812 | **222202** | 222236 | **191032** | 195500 |
| | | | 225836 | **233223** | | **204444** | |
| 15 | 8 | 16 | 17 | 17 | 16 | 17 | 16 |

*Table 6: Validating data for the big parts for 10 shifts.*

The values represents when the delivery from Meriva took place. By bold type are shown real values and by normal type are values from the simulation. When we analyse the situation we can elicit the *Day 1* does not match with the reality. It is because the first four hours (these hours are not shown in the table) the assembly line was filled to the full capacity, so afterwards there is visible decreased demand for the parts. The contrast is visible especially when compared to data from reality when the shift continued fluently after previous shift. In the chart [Appendix 7] is visible how distributed the usage of *Vehicles001* was during first four hours (from 600 to 840). At first it was idle by $1/3$, afterwards it declined to 4 % and finally it stabilised at level of 23 % (in other words very fluctuant data).

If we consider only Days 2 to 4 we get the total number of rounds which is $\mathbf{49}$. In the real data the count is $\mathbf{50}$. That means in this circumstances the validation is successful with probability of $\mathbf{98}$ %.

Other comparison can be found in number of transported parts during one run. In the model the average is $\mathbf{11.1}$ parts per one ride and in reality it is $\mathbf{10.5}$. The difference is made by few rides in a real data when the delivery was just in size of 1 part. This has quite big effect on final value. The result is within the accepted limits.

### 4.3.3 Validation of small parts flow

Small parts are picked up by Kardex-er who can take all of the parts in a one round because the parts are not so bulky. That is why the timing is not as responsive as in the big parts flow. The validation was based on number of rounds took during two days.

From the table [Appendix 6] is visible that the distribution of real and simulation data is comparable. Summarized values of rounds per day are in the following table. In total the difference is about $\mathbf{4}$ % .

| | Day 2 | Day 3 |
|---|---|---|
| **Reality** | 32 | 41 |
| **Model** | 34 | 40 |

*Table 7: Table shows the number of rounds of Kardex delivery cart during two days in reality and in simulation.*

Other comparable data are the sets of difference times from real world and the model when the deliveries took place. They can be seen in the next chart:

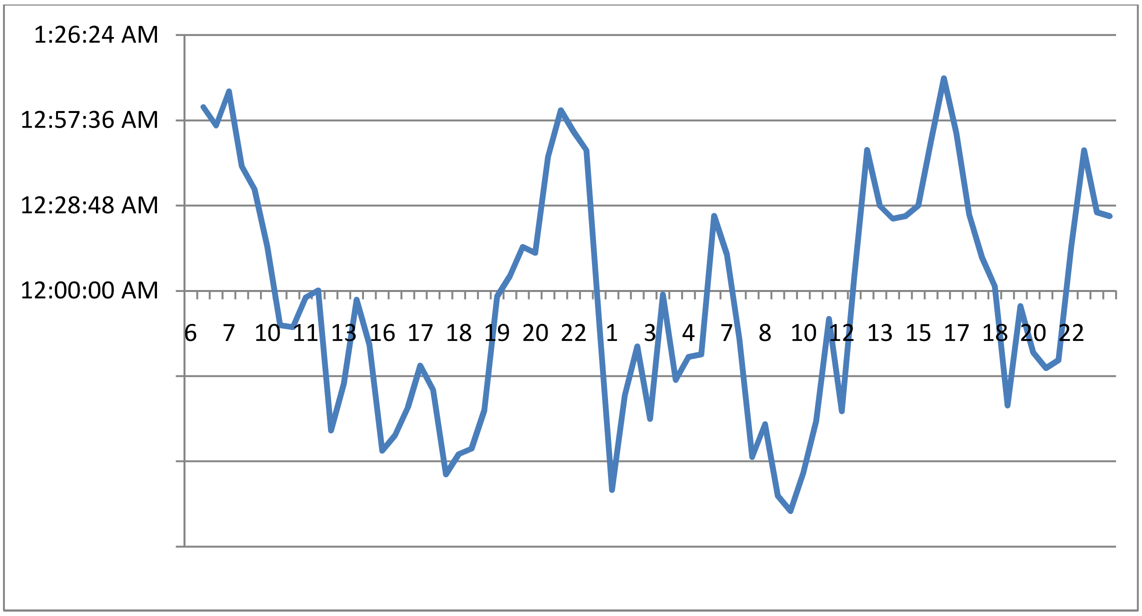


*Chart 7: Chart describes the differences of real data and simulation data in the small parts flow.*

In the chart we can see the differences between real times and times obtained from the simulation. On the horizontal axis are times during two days when the differences were recorded. These divergences are between close-to-zero values to approximately 1.25 hour. This result is reasonable because more crucial fact is the distribution incline and keeps the zero level which means the timing is correspondent.

# 5 IMPROVEMENT ANALYSIS AND EVALUATION

While in Validation we used adjusted data to fit with available data set, from now we will use fully adequate data which are in addition normalised to achieve realistic behaviour of the model by implementing random variables. For the analyses will be used pie charts produced by Witness. These charts represent usage of vehicles in the model.

## 5.1 The present state

After 10 continuous shifts the number of final produced parts is 12,864 in total (6,432 $parts$ per each variation). These lights are packed in total 530 $boxes$ (each box has 24 $parts$). All the final boxes were transported to the Stock, just 28 more were left in the production line. Also all of empty boxes were transported. All the supermarkets are at **sustainable level** and all three vehicles are on their ways to satisfy the current demand. There are **no blackouts** recorded when the final assemble machine would have to wait for the parts.

Utilisation of *Vehicles001* shows the next Pie Chart:


*Chart 8: Statistical data for Vehicles001 after 10 shifts of supplying.*

We can see **23** % of time the vehicle was **idle** which means it was parked and unused for analysed line. At the same time this does not mean that the vehicle was **unused**. Maybe it was necessary for other line but within the framework of simulation we record this time as idle and free for other needs.

Other activities as *Loading* and *Unloading* are quite balanced and they do not show any abnormalities. Analogical situation applies for *Demanded* and *Loaded* section.

Other statistical Pie Chart indicates how busy *Vehicles002* operating within small parts delivery:


*Chart 9: Pie Chart for the Kardex delivery cart showing its good usage.*

The idle time is lower then in previous case, just **12** %. Most of the time takes *Loading* (40 %) because it is very time-consuming to get specific parts from Kardex racks. Other segments do not yield any uncommon values.

Last pie chart shows the *Vehicles003* usability:


*Chart 10: Graph for the cart transporting final products to the Stock.*

There is a slight difference in this chart compared with two previous ones. This pie chart does not have *Demanded* segment, which is logical because the delivery man simply takes every time the same amount of rollers and transports them to the stock. There is no need to create the demand. The *Unloading time* (in the stock) forms half of the total time which is given by necessity to unload full rollers, store them and prepare empty rollers (mentioned above in Section 3.3.2). The rest of the time is distributed among Loading and ways to assembly line and back.

In the graph is visible **0 % idle time** which comes from continual serving of production line. The question is how big reserves are in the activities within the stock. It is difficult to estimate the actual time which is necessary to change the rollers. If there are small reserves it can seems like the transportation is very efficient but on the other side there are certain risks related with this situation.

If there is no reserve capacity, problem can occur with the supply of the line. This can result to breakdown on the assembly line which has very deep economic implications and is the worst scenario imagined. Because the cart has to come approximately every 18 min, if something happens for longer period than that and there is no backup, the drop-out of delivery will result in production stop.

If we simulate how long the dropouts can be we find the following values:

- *If the unloading/loading time in stock increase by 1 min (from 9 to 10) compared to regular times, the problem will occur after 2.25 hour when the capacity in final assembly line will be surpassed. This little increase in time can be caused by difficulties in the stock or the problem on the way towards the line.*
- *From the best possible state when the rolls are empty there is reserve only 18 min before the collapse will occur. In other cases this time is even smaller.*

.

These times can be concerning and in the next chapter we will try to deal with this issue.

From the simulation arose the fact that Hella does not record all the data in sufficient way. For example the timing about Kardex delivery man is indexed only when he loads the barcodes in the assembly line's supermarket. It is advisable to store also data when he takes the parts directly from Kardex racks and when he leaves the stock to go to the line. By using these times they can be found more inefficiency activities in the logistical flow.

## 5.2 Improvement proposal

Our suggested improvement consists in transfer of duties from delivery man who carries final parts to **Kardex delivery man** who is already running rounds every 30 min or so. The presumption for this variation is to extend the place for rollers with final products **by 2 places** – in total 4 places (2 for variation 247.051-017 and 2 for variation 027). In that case the approximate one round per 30 $min$ is sufficient to transport all rollers with final products.

### 5.2.1 Step 1

After the joining the works to Kardex cart the idle time is lowered to minimum (less than 1 % - mostly because the beginning four hours period when the assembly line was waiting for the big parts).

Because the carrier does not have enough capacity to reckon with this rush the **blackout** of the final assembly line appears. This is caused by the **lack of parts** on input to the line. The consequence of this failure is reduction of final products quantity to only 502 $boxes$ (28 less than during normal operation).

This situation has to be **farther solved**.

### 5.2.2 Step 2

As the answer for the insufficient capacity of Kardex carrier we will simulate assigning the final rollers preparation to **other worker**. This worker will be located directly in the Stock where he will be setting up the empty rollers and storing the full ones, while the delivery man will simply just unplug and plug ready-made rolls.

If we assume the former time took 9 $min$ for the activities in the stock, now the main portion would take the stock keeper – approximately 8 $min$ and the remaining 1 $min$ would provide delivery man. All other settings are kept the same.

When we put these settings to the simulation we get the following outcomes:

- ✓ ***530*** *manufacture boxes with* ***final products***
- ✓ *Idle time of the machine* – 0 % -> ***no blackouts***
- ✓ *Vehicles idle time* = $\mathbf{1,17}$ % - *there is still some* ***safety capacity***


***Chart 11: Pie Chart showing the usability of Kardex carrier after acquiring of additional duties.***

This step solved the issue with insufficient capacity of Kardex delivery man and in overall it proposed the solution of this paper work.

## 5.3 Economic implications

As the result of above mentioned proposal we will **save one complete element** of inner logistics – final products delivery flow. Due to this reduction we will save the financial resources for one employee and his transportation equipment.

On the other side we have to **subsidise** this person by one man working in stock where he will do the preparation work for the Kardex delivery man. In final consequence the savings for the man-power will be following:

- *Former preparation in stock took 9 min in total*
  - $\mathbf{8}\ \boldsymbol{min}$ *will now* ***undertake*** *the special-purposed worker*
  - *1 min will still have in charge delivery man*
- *Number of rounds when the delivery man changes the rolls for final products is* $\mathbf{182}$ *(per 10 shifts).*
- *Total time spent on preparation work:* $182 * 8 = \mathbf{1,456}\ \boldsymbol{min}$
- *Total usable time during 10 shifts is* $\mathbf{4,800}\ \boldsymbol{min}$
- *Saved time:* $4{,}800 - 1{,}456 = 3{,}344\ min \approx \mathbf{56}\ \boldsymbol{hours}$
- *Ratio of saved time / total time:* $3{,}344\ /\ 4{,}800 = 0{,}6966 \approx \mathbf{69,6}\ \%$
- *Total costs (insurance, taxes, safety utilities and other costs included) for one employee are* $\mathbf{250}\ \boldsymbol{CZK/hour}$
- <u>*Savings in monetary expressions:* $56 * 250 = \mathbf{14,000}\ \boldsymbol{CZK/month}$</u>

Regarding to costs of transportation equipment they are numerated as:

- *Cart (brand Still) – towing unit costs* $\mathbf{13,000}\ \boldsymbol{CZK/month}$ *(exluding tax)*
- *Even we spare one complete cart; it is improbable and incorrect to take into account full costs. Because there are situations when the cart can be needed (breakdown, increased production and other complications) it is logical to keep the cart and share its usage with more assembly line. In this sense we can say 20 % of the cart can be kept for analysed assembly line and remaining 80 % can be split to other lines. In our model, we do not include with external elements, so 80 % appears as cost savings.*
- *Final savings of machinery are:* $0{,}8 * 13{,}000 = \mathbf{10,400}\ \boldsymbol{CZK/month}$

Final cost savings for our proposed situation are $\mathbf{24,400}\ \boldsymbol{CZK/month}$.

## 5.4 Costs of the analysis and the simulation

To perform the simulation they are necessary two key elements, software equipment and expert who can model the analysed situation and carry out the simulation.

The program Witness MPE (Manufacture Performance Edition) suitable for manufacturing companies costs $\mathbf{559,980}\ \boldsymbol{CZK}$. The maintaining services are for $93{,}980\ CZK\ per\ year$. [5]

The expert carrying out the simulation can be obtained by many ways:

- *The company can hire* ***graduate*** *with some experience from studies and pay him the training – approximately* $45{,}000\ CZK/month$*. The benefits are low costs*

[5] http://www.humusoft.cz/produkty/witness/cenik

*but on the other side there are risks the collaboration will not be enough efficient and the project will be dismissed which is the worst result ever.*

- *The company can hire* ***experienced professional*** *who did similar projects before and has good simulation record. The drawback is the expert costs quite a lot of money (let us say* $60{,}000 - 100{,}000\ CZK\ per\ month$*), on the other side there is certain reliance that the project will be successfully accomplished. This option is especially good for long-running projects and fluent optimisation of production and logistics.*
- *Probably the last option is to outsource the service by some external firm. This possibility is the easiest, there is almost no need to consume company's resources, the proper external company will smoothly drive through the process with advices which can highly increase the effect of final solution and last but not least it has quick realization time. Contrariwise this option is also very expensive; approximately* $200{,}000$ *to* $400{,}000\ CZK$ *for the project*[6]*, there is a risk of information leakage towards the competition and loosing the competitive advantage. In this option are already included costs for the software. This tender is good if the company needs to fix some critical problem which can be solved in short period.*

[6] http://www.logio.cz/reseni-a-sluzby/reseni/dynamicka-simulace/

# CONCLUSION

In the thesis we analysed which possibilities are available by using advanced controlling methods. We found out there are many principles to manage production and other associated activities in a more efficient way. Some of the systems refer to information technology some other to assume complete management philosophy.

One of the useful tool for achieving high quality products, and cost reductions is computer simulation by using professional software. We deal with this issue in this thesis by using the program Witness Power with Ease created by English company *Humusoft.com*.

The final results which unwind from the thesis are cost reductions in terms of elision one delivery man together with his machinery. On the other side we took into account also the necessity of adding one workman to the stock and retaining the fraction of machinery. The total savings are worth $\mathbf{24,400}\ \boldsymbol{CZK\ per\ month}$ which can be comprehended as the *successful accomplishment* of the *main goal*.

By using this discrete simulation we were modelling the inner logistics. Through the consequent simulation we realized many new facts:

- *which data are necessary to create a model and what other recordings should be implemented to the system*
- *statistical usability of each carrier*
- *unfolding the bottleneck and its accompanied risk related with vulnerability of final parts flow, which is critical for fluent production*

There are several prerequisites to successfully implement the suggested proposals such as extension of place next to the assembly line to keep more transportation boxes or allocation of activities between two people, when one is located in stock and other is in charge of delivering the material to its destination.

Beside the monetary savings we did by using simulation software we also clarified the logic structure of inner transportation. It is always helpful to see clearly how things work and which process collocates with the other one. For the future it is advisable to create more complex model of workshop and cover also successive and preceding processes to gain very forcible tool for the management.

The discrete simulation can do even more things than we showed in this thesis and it can be very powerful tool for enhancing the business performance. In my opinion every manufacturing company should give it a try.

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# LIST OF ATTACHMENTS

[Appendix 1] Lay-out of factory (layout.pdf - *electronic attachment)*

[Appendix 2] POLO-BOM.xls *(electronic attachment)*

[Appendix 3] Table - stock transports

[Appendix 4] Table: Parts_deliveries.xls *(electronic attachment)*

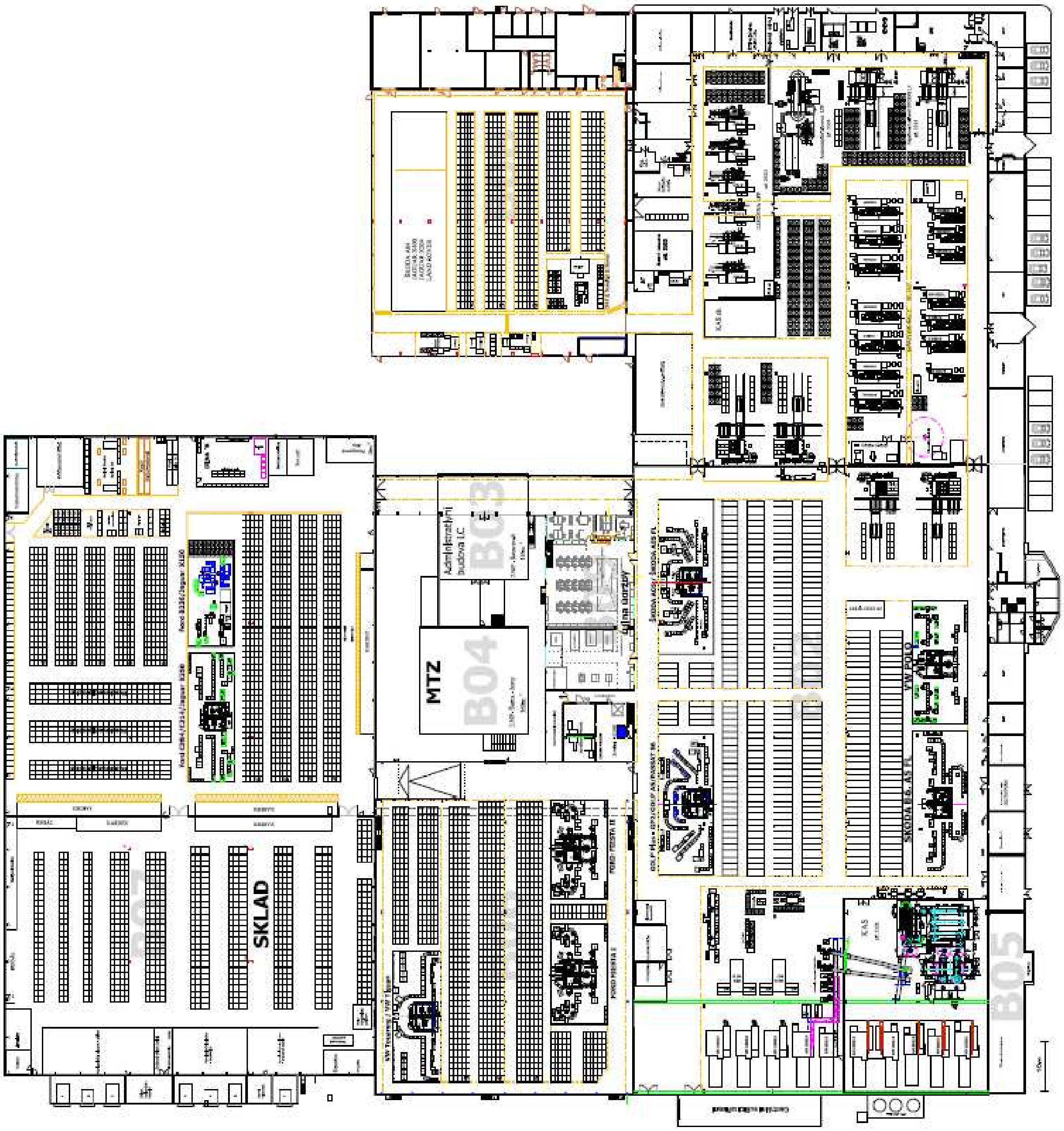
[Appendix 5] Table: final_parts.xls *(electronic attachment)*

[Appendix 6] Table: validation of small parts: Differences

[Appendix 7] – Usage of Vehicles001

[Appendix 8] – Lay-out of the model.

[Appendix 1] Lay-out of factory (layout.pdf - *electronic attachment)*



[Appendix 2] POLO-BOM.xls *(electronic attachment)*

| 247.051-017 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pos | Číslo dílů | Označení MB TA | Množs | typ | mnozstv | jednotky | jakČast(mi | kolik denně |
| .1 | 157.130-00 | STITEK BILY 60X40 | 1 | nákup | 1500 | KAT | 1125,0 | |
| .1 | 824.010-02N | FOLIE TERMO.60X500 T001SCH | 0,145 | nákup | | | 0,0 | |
| .1 | 168.327-01 | POUZDRO L SKUP. POLO | 1 | koopera | 36 | ROL | 27,0 | 17,777778 |
| ..2 | 155.319-37 | CEP KULOVY | | nákup | 1500 | KAT | 1125,0 | 0,4266667 |
| ..2 | 156.362-00 | DIL POHONU SK. | 3 | nákup | 5000 | KAT | 1250,0 | 0,384 |
| ..2 | 173.900-00 | SROUB NASTAVENI | 1 | nákup | 850 | KAT | 637,5 | 0,7529412 |
| ..2 | 981.019-00 | SROUB NASTAVENI SK. | 1 | nákup | 650 | KAT | 487,5 | 0,9846154 |
| ..2 | 254.058-00 | KOLO POHONU VW TOUARE | 1 | nákup | 7000 | KAT | 5250,0 | 0,0914286 |
| ..2 | 156.594-00 | SROUB NASTAVENI SK. | 1 | nákup | 700 | KAT | 525,0 | 0,9142857 |
| ..2 | 175.768-00 | SPONA POLO | 1 | nákup | 2000 | | 1500,0 | 0,32 |
| ..2 | 164.686-44 | SROUB KUL.PT-DG 6X65X42,5 | 1 | nákup | 1300 | KAT | 975,0 | 0,4923077 |
| ..2 | 172.209-01 | PLECH TEPELNY L FL POLO | 1 | nákup | 300 | | 225,0 | 2,1333333 |
| ..2 | 239.321-44 | KT-SROUB 4X14 | 4 | nákup | 10000 | KAT | 1875,0 | 0,256 |
| ..2 | 167.923-00 | VODICE SK. POLO | 1 | nákup | 50 | | 37,5 | 12,8 |
| ..2 | 008.830-00 | LWR PRVEK EL.12 V | 1 | nákup | 240 | KAT (PH | 180,0 | 2,6666667 |
| .1 | 171.930-01 | SKLO+RAM L SKUP. POLO | 1 | výroba | 120 | =? | 90,0 | 5,3333333 |
| ..2 | 167.869-01 | SKLO KR. L POLO | 1 | výroba | 120 | ROL | 90,0 | 5,3333333 |
| ...3 | 065.120-12N | PC WIE LEXAN LS1 111H | 47,07 | surovina | 19400 | EUR | 309,1 | 1,5528577 |
| ...3 | 600.013-63N | LACK UVHC 3000 | 0,77 | nákup | 180 | | 175,3 | 2,7377778 |
| ..2 | 167.877-01 | RAM VNEJSI L POLO | 1 | výroba | 80 | ROL | 60,0 | 8 |
| ...3 | 065.269-02N | PC-HT WIE APEC 1695 | 16,72 | surovina | 1000 | EUR | 44,9 | 10,7008 |
| ...3 | 824.001-76N | PE VAK 1350X950X2350X0,020 | 1,14 | nákup | 900 | GBO | 592,1 | 0,8106667 |
| ..2 | 162.303-03 | SPONA 4 MM | 3 | nákup | 15000 | | 3750,0 | 0,128 |
| .1 | 171.222-01 | RAM L VNITRNI POLO | 1 | výroba | 64 | ROL | 48,0 | 10 |
| ..2 | 065.269-02N | PC-HT WIE APEC 1695 | 20,4 | surovina | 1000 | EUR | 36,8 | 13,056 |
| ..2 | 824.001-76N | PE VAK 1350X950X2350X0,020 | 0,21 | nákup | 900 | GBO | 3214,3 | 0,1493333 |
| .1 | 171.223-01 | RAM /KRIDLO/ L POKOV. POLO | 1 | výroba | 168 | ROL | 126,0 | 3,8095238 |
| ..2 | 171.223-11 | RAM /KRIDLO/ L LISOV. POLO | 1 | výroba | 168 | ROL | 126,0 | 3,8095238 |
| ...3 | 065.359-58N | CO-PC APEC 1795 | 12,4 | surovina | 900 | EUR | 54,4 | 8,8177778 |
| .1 | 168.326-01 | REFLEKTOR L BL SKUP. POLO | 1 | koopera | 36 | PHM | 27,0 | 17,777778 |
| ..2 | 171.925-01 | PLECH TEPELNY L POLO | 1 | nákup | 400 | | 300,0 | 1,6 |
| ..2 | 239.321-44 | KT-SROUB 4X14 | 1 | nákup | 10000 | KAT | 7500,0 | 0,064 |
| ..2 | 491.311-06 | FOLIE NOPA 600X340X0,8 | 0,5 | nákup | 1000 | KAT | 1500,0 | 0,32 |
| .1 | 167.881-01 | REFLEKTOR L PS ABBL POLO | 1 | výroba | 360 | ROL | 270,0 | 1,7777778 |
| ..2 | 167.881-21 | REFLEKTOR L PS ABBL POLO | 1 | výroba | 360 | | 270,0 | 1,7777778 |
| ...3 | 167.881-41 | REFLEKTOR L PS ABBL POLO | 1 | výroba | 180 | | 135,0 | 3,5555556 |
| ....4 | 051.020-01N | UP-GF (BMC) HELLA N 37015 | 9,5 | surovina | 900 | EUR | 71,1 | 6,7555556 |
| ....4 | 824.001-76N | PE VAK 1350X950X2350X0,020 | 0,03 | nákup | 900 | GBO | 22500,0 | 0,0213333 |
| ...3 | 600.013-55N | LAK LPP QN11-0880 | 0,083 | nákup | 20 | | 180,7 | 2,656 |
| .1 | 159.924-37 | SROUB-PT 4X14 DELTA | 4 | nákup | 10000 | KAT | 1875,0 | 0,256 |
| .1 | 155.665-00 | KRYTKA SVETL. | 1 | nákup | 400 | KAT | 300,0 | 1,6 |

[Appendix 3] Table - stock transports

| | 20100411 | 20100412 | | | 20100413 | | | 20100414 | | | 20100415 | | | 20100416 | | | 20100417 | | | 20100418 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ROSUMI1N | 22 | 6 | 14 | 22 | 6 | 14 | 22 | 6 | 14 | 22 | 6 | 14 | 22 | 6 | 14 | 22 | 6 | 14 | 22 | 6 | 14 | 22 |
| 2443 | | | | | | | | | | | | | | | | | | | | | | |
| 2445 | | | | | | | | | | | | | | | | | | | | | | |
| 2420 | | | | | | | | | | | | | | | | | | | | | | |
| 2435 | | | | | | | | | | | | | | | | | | | | | | |
| 2437 | | | | | | | | | | | | | | | | | | | | | | |
| 2444 | | | | | | | | | | | | | | | | | | | | | | |
| 2325 | | | | | | | | | | | | | | | | | | | | | | |
| 2446 | | | | | | | | | | | | | | | | | | | | | | |
| 2434 | | | | | | | | | | | | | | | | | | | | | | |
| 2441 | | | | | | | | | | | | | | | | | | | | | | |
| NEDVJA1N | | | | | | | | | | | | | | | | | | | | | | |
| 2445 | | | | | | | | | | | | | | | | | | | | | | |
| 2443 | | | | | | | | | | | | | | | | | | | | | | |
| 2437 | | | | | | | | | | | | | | | | | | | | | | |
| 2435 | | | | | | | | | | | | | | | | | | | | | | |
| 2444 | | | | | | | | | | | | | | | | | | | | | | |
| 2446 | | | | | | | | | | | | | | | | | | | | | | |
| 2325 | | | | | | | | | | | | | | | | | | | | | | |
| 2420 | | | | | | | | | | | | | | | | | | | | | | |
| HELLPA1N | | | | | | | | | | | | | | | | | | | | | | |
| 2443 | | | | | | | | | | | | | | | | | | | | | | |
| 2445 | | | | | | | | | | | | | | | | | | | | | | |
| 2420 | | | | | | | | | | | | | | | | | | | | | | |
| 2325 | | | | | | | | | | | | | | | | | | | | | | |
| KREJTO1N | | | | | | | | | | | | | | | | | | | | | | |
| 2435 | | | | | | | | | | | | | | | | | | | | | | |
| 2444 | | | | | | | | | | | | | | | | | | | | | | |
| 2446 | | | | | | | | | | | | | | | | | | | | | | |
| 2325 | | | | | | | | | | | | | | | | | | | | | | |
| 2443 | | | | | | | | | | | | | | | | | | | | | | |
| 2445 | | | | | | | | | | | | | | | | | | | | | | |
| 2437 | | | | | | | | | | | | | | | | | | | | | | |
| 2420 | | | | | | | | | | | | | | | | | | | | | | |
| SISMVL1N | | | | | | | | | | | | | | | | | | | | | | |
| 2420 | | | | | | | | | | | | | | | | | | | | | | |
| 2437 | | | | | | | | | | | | | | | | | | | | | | |
| 2435 | | | | | | | | | | | | | | | | | | | | | | |
| 2444 | | | | | | | | | | | | | | | | | | | | | | |
| 2443 | | | | | | | | | | | | | | | | | | | | | | |
| 2445 | | | | | | | | | | | | | | | | | | | | | | |
| 2446 | | | | | | | | | | | | | | | | | | | | | | |
| 2434 | | | | | | | | | | | | | | | | | | | | | | |
| 2325 | | | | | | | | | | | | | | | | | | | | | | |
| 2519 | | | | | | | | | | | | | | | | | | | | | | |
| NESEBL2N | | | | | | | | | | | | | | | | | | | | | | |
| 2445 | | | | | | | | | | | | | | | | | | | | | | |

[Appendix 6] Table: validation of small parts: Differences

| 20100413 | Day 2 | Difference | 20100414 | Day 3 | Difference2 |
|---|---|---|---|---|---|
| 0:00:00 | 6:19:18 | 0:00:00 | 1:27:14 | 0:19:54 | 1:07:20 |
| 6:14:21 | 7:16:30 | 1:02:09 | 2:00:46 | 1:25:30 | 0:35:16 |
| 6:50:28 | 7:46:18 | 0:55:50 | 2:26:36 | 2:07:48 | 0:18:48 |
| 7:01:44 | 8:09:12 | 1:07:28 | 3:10:33 | 2:27:12 | 0:43:21 |
| 7:52:28 | 8:34:36 | 0:42:08 | 3:38:33 | 3:37:18 | 0:01:15 |
| 8:30:33 | 9:04:54 | 0:34:21 | 4:28:16 | 3:58:12 | 0:30:04 |
| 9:22:50 | 9:37:42 | 0:14:52 | 4:41:25 | 4:19:06 | 0:22:19 |
| 10:17:40 | 10:06:00 | 0:11:40 | 4:59:56 | 4:38:30 | 0:21:26 |
| 10:33:39 | 10:21:24 | 0:12:15 | 5:22:15 | 5:47:36 | 0:25:21 |
| 10:45:28 | 10:43:18 | 0:02:10 | 6:24:29 | 6:36:48 | 0:12:19 |
| 11:53:14 | 11:53:24 | 0:00:10 | 7:19:01 | 7:02:42 | 0:16:19 |
| 13:16:26 | 12:29:12 | 0:47:14 | 8:30:10 | 7:34:00 | 0:56:10 |
| 13:27:33 | 12:56:06 | 0:31:27 | 8:57:17 | 8:12:18 | 0:44:59 |
| 13:47:18 | 13:44:18 | 0:03:00 | 9:45:57 | 8:36:42 | 1:09:15 |
| 14:19:23 | 14:01:12 | 0:18:11 | 10:07:00 | 8:52:36 | 1:14:24 |
| 15:30:59 | 14:37:00 | 0:53:59 | 10:18:33 | 9:17:00 | 1:01:33 |
| 16:05:06 | 15:16:18 | 0:48:48 | 10:56:06 | 10:12:06 | 0:44:00 |
| 16:17:39 | 15:38:12 | 0:39:27 | 11:03:21 | 10:53:54 | 0:09:27 |
| 16:54:06 | 16:28:54 | 0:25:12 | 12:10:57 | 11:30:12 | 0:40:45 |
| 17:14:43 | 16:41:18 | 0:33:25 | 12:24:33 | 12:29:24 | 0:04:51 |
| 18:03:15 | 17:01:12 | 1:02:03 | 12:27:35 | 13:15:12 | 0:47:37 |
| 18:15:49 | 17:20:36 | 0:55:13 | 13:09:55 | 13:38:36 | 0:28:41 |
| 18:46:46 | 17:53:24 | 0:53:22 | 13:30:07 | 13:54:30 | 0:24:23 |
| 19:10:03 | 18:29:42 | 0:40:21 | 14:21:25 | 14:46:42 | 0:25:17 |
| 19:17:46 | 19:15:54 | 0:01:52 | 14:33:14 | 15:02:06 | 0:28:52 |
| 19:33:18 | 19:38:18 | 0:05:00 | 14:37:14 | 15:28:00 | 0:50:46 |
| 20:13:41 | 20:28:30 | 0:14:49 | 14:56:56 | 16:08:48 | 1:11:52 |
| 20:33:04 | 20:45:54 | 0:12:50 | 15:31:24 | 16:24:42 | 0:53:18 |
| 20:36:30 | 21:21:42 | 0:45:12 | 16:34:43 | 17:00:30 | 0:25:47 |
| 20:41:01 | 21:42:06 | 1:01:05 | 17:31:33 | 17:42:48 | 0:11:15 |
| 21:13:41 | 22:07:30 | 0:53:49 | 18:02:38 | 18:04:12 | 0:01:34 |
| 22:24:13 | 23:11:42 | 0:47:29 | 19:01:54 | 18:23:06 | 0:38:48 |
| 23:41:15 | 23:30:36 | 0:10:39 | 19:04:33 | 18:59:24 | 0:05:09 |
| 23:59:59 | 23:50:30 | 0:00:00 | 19:42:04 | 19:21:18 | 0:20:46 |
| | | | 20:26:14 | 20:00:06 | 0:26:08 |
| | | | 20:45:52 | 20:22:30 | 0:23:22 |
| | | | 21:19:38 | 21:34:36 | 0:14:58 |
| | | | 21:21:50 | 22:09:24 | 0:47:34 |
| | | | 22:26:41 | 22:53:12 | 0:26:31 |
| | | | 23:18:06 | 23:43:24 | 0:25:18 |
| | | | 23:37:37 | 23:59:59 | 0:00:00 |
| 32 | 34 | | 41 | 40 | |

[Appendix 7] – Usage of Vehicles001

[Appendix 8] – Lay-out of the model.