Next Generation Logistics: Technologies and Applications

Scientific Monograph

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Foreword

Logistics can be defined as a science managing the flow of resources through supply chains in terms of transportation mode, warehousing and third-party organization. Logistics is a complex operation due to involving the integration of several parameters: information flow, material handling, production, packaging, inventory, transportation, warehousing, and often security. In general, the aim of logistics is to provide a right management of the flow of things between the point of origin and the point of consumption in order to meet the requirements of customers.

Today's logistical system requirements evolve towards efficiency, correctness and robustness in the process of planning and control of the raw materials, products and people flows and the related information. Some current challenges within logistics include the dispersed nature of customers; the increased diversity in storage and transportation modes; the intense variability in customer demands; and the requirements for flexibility, security and sustainability. These challenges can be handled by the utilization of recent ICT and automation technologies, so that it gets possible to have the right resources in the right place at the right time what logistics target. For instance, by the the use of RFID tags and intelligent use of software, as well as data science and big data would enable the set of the future's powerful logistics system. The developments in machine-learning, M2M communications, data-mining, traceability of real-time information are improving the logistics operations as well as shaping the next generation logistics through a "Smart Logistics" resulting with transparency and control of the entire system, improved predictive analysis and risk assessment, real-time adjustment to the changed conditions (e.g. robustness).

Although the recent technological developments facilitate the implementation of future's smart logistics management, without the integration of the mathematical tools with these technologies it would be impossible to have efficient logistics operations and planning. This sceintific monograph includes next generation logistics technologies and applications and some modelling approaches. It includes studies on smart system modelling approaches to some logistics problems, models and sustainability applications on warehousing technologies as well as investment and management of logistics systems.

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Chapter 1

Intelligent Logistics Management

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Abstract

Target of this chapter is introduce CEIT Intelligent Logistic Management concept developed by CEIT a.s. (Central European Institute of Technology) and University of Zilina through common workplace ZIMS (Zilina Intelligent Manufacturing System). Developed solutions based on this concept are implemented in many industrial companies in Central Europe focused especially on automotive and electro technical production. All this solutions are primary focused on productivity increase, innovation application and effectivity increase. This concept brings more new potentials and challenges to decrease logistics costs and improve quality of logistics performance.

Keywords: logistic management, new concept of logistic, automated logistic, automated guided vehicles.

1.1 INTRODUCTION

The globalized economy is strongly influenced not only by economic cycles but also a rapid change in customer behaviour, which result in turbulences. Business community should continually find new ways to respond to these incentives. One of the effective solutions is the use of new technologies and advanced tools. In the world runs intensive research into future production and logistic systems. European Union has launched extensive research programs dedicated to Factory of the Future (FoF) and Intelligent Manufacturing Systems (IMS, Smart Manufacturing). Due this continental initiatives, one countries prepared own national manufacturing strategies. One of the most popular is German initiative Industry 4.0, which some authors call as 4th industrial revolution (Herčko et al., 2015a)(Herčko et al., 2015b). The goal of all these efforts is to develop a new production and logistic systems using advanced technology, which will enable to satisfy demanding customer requirements in the future.
Authors of this chapter describe concept of intelligent logistic management developed by CEIT a.s. (Central European Institute of Technology) and University of Zilina on common workplace ZIMS (Zilina Intelligent Manufacturing System).

1.2 LOGISTIC MANAGEMENT – CYCLE OF IMPROVEMENT OF LOGISTIC SYSTEMS

Logistic management is a closed circle, or better named as a spin of continuously improvement in the field of logistic (Fig. 1.1).

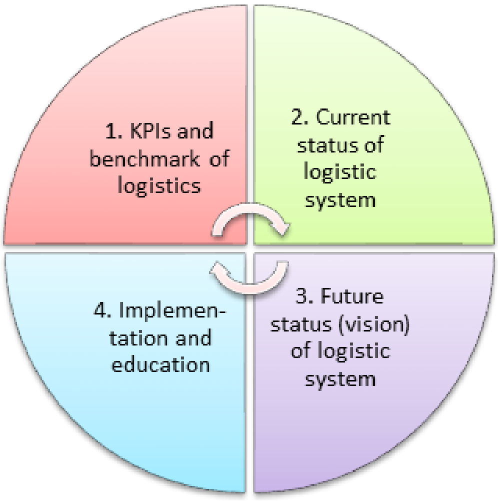


Fig. 1.1 Logistic management

Following cycle consists of 4 recurring steps:

1. Definition or actualization of Key Performance Indicators (KPIs) and benchmarking,
2. Analyses of current status of logistic system,
3. Definition of future status (vision) of logistic system,
4. Implementation and education of employees.

This circle is constantly repeating. That mean that after the implementation Indicators are updated, the current status is analyzed, and so on. Mentioned steps are tested by the methodic of the Flow value management and slightly edited (Mičieta and Biňasová, 2013). Similar steps can be found by all methods of improvements. Unique of mentioned steps is in the usability in the work with people, what is also a crucial. As follows from KPMG Automotive Innovation Survey 2014, more than 60 % of respondents consider continuous improvement as the most fundamental factor for development of innovation in enterprise (KPMG, 2014).

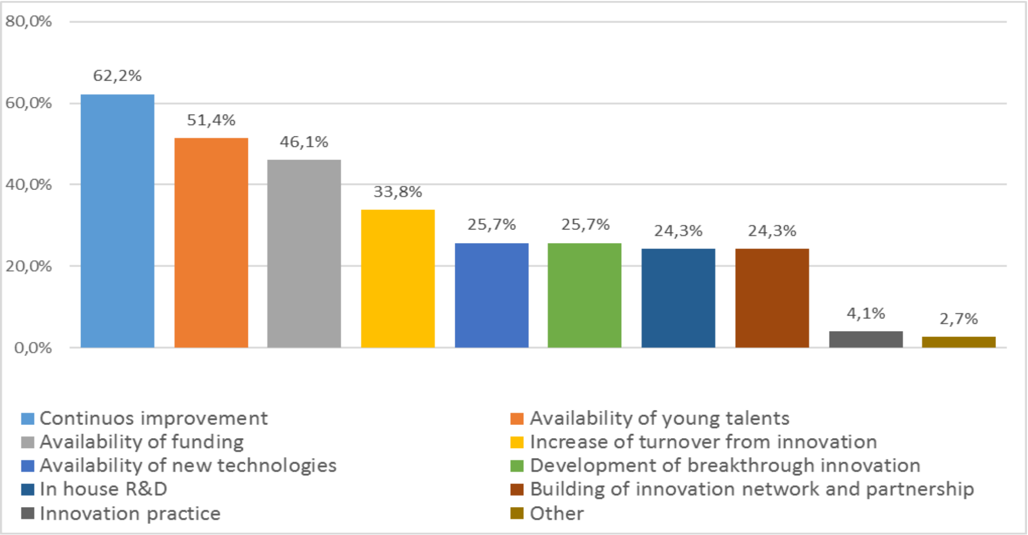


Fig. 1.2 The most fundamental factor for development of innovation in enterprise (KMPG, 2014)

1.3 CONCEPT OF CEIT INTELLIGENT LOGISTIC MANAGEMENT

Concept CEIT Intelligent Logistic Management is based on needs from industry and is based on artificial intelligence. Main contributors to this concept is many companies based in Slovakia and operated in automotive and electrotechnical industry. This companies defined they needs and CEIT a.s. with strong cooperation with University of Zilina completed this concept. Artificial intelligence that ensures autonomous tasks directionally through agent communication should be integrated into an enterprise system (Mičieta et al, 2014a) (Mičieta et al, 2014b). Principles of this concept is described in Fig. 1.3. Many of this solution has been awarded directly to CEIT, or to companies where has been solution implemented. For example CEIT has been awarded by Ministry of Economy as „Innovative Act of the Year“ for practice game. This game has been used for practice new logistic concept to thousands of employees and suppliers of Volkswagen Slovakia. Next awards achieve Volkswagen Slovakia as „most lean company“ in Volkswagen Group or „Lean & Green Efficiency Award“ for they activities in field energy efficiency. The biggest award achieved by Volkswagen Slovakia with strong contribution of CEIT Intelligent Logistic Management is “mach18.FACTORY Oscar”, which Volkswagen Slovakia achieved in 2015 as best plant of Volkswagen Group.

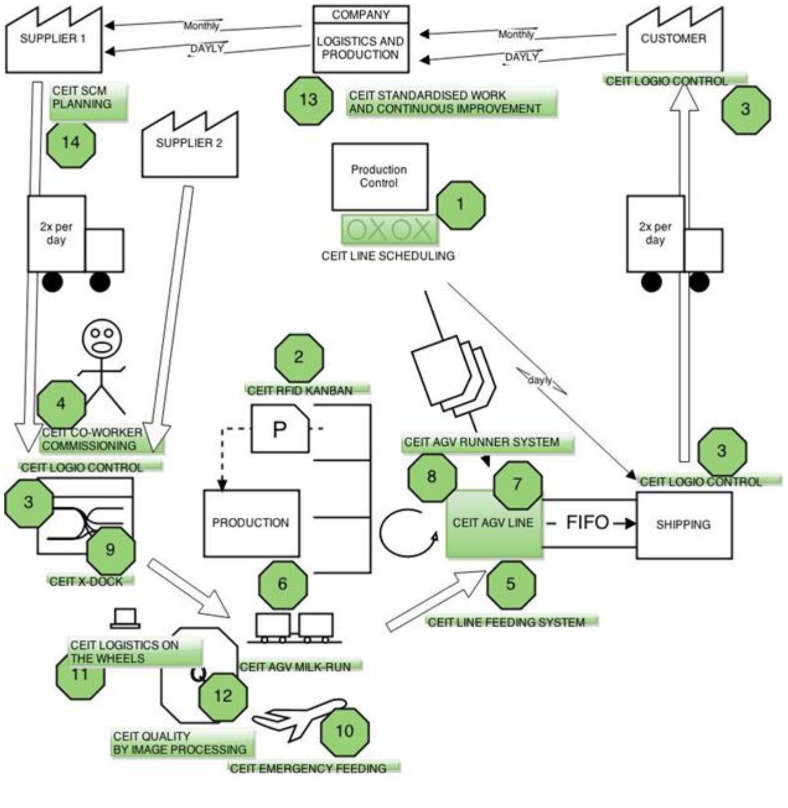


Fig. 1.3 Concept of CEIT Intelligent Logistic Management (CEIT, 2015)

Concept of CEIT Intelligent Logistic Management is based on 14 solutions, that are together connected and make common “logistics network”. At this time, not all of this solution are fully integrated and connected to IT infrastructure of companies. For the future is this concept facing big challenges like Internet of Things (Gregor et al., 2015), Internet of Service and Smart Factory.

1.3.1 Line scheduling

It is used to determine the optimal sequence of products for custom management. Custom management can be simplistically described as a sequence of steps (the process) between the adoptions of the order from the customer after receipt of payment for the realized product. Custom Management is a summary of financial, information and material flows, most of which are complex and time-consuming just financial and information flows. Custom management is the appropriate basis for optimizing the production system, because it is him we can accelerate cash flow and return on capital in the company, as delivery times, delivery reliability, capacity utilization and the level of stocks. These parameters mostly affecting planning and management.

Department of planning and management can identify targets with which the generated sequence. Timetable may have several objectives. For example schedule in order to maximize capacity; Reducing of stocks; continuity of supply; use of the bottleneck and so on.

In that case they are set for individual scheduling criteria (targets schedule) the scales. Scheduling criteria that is most has the highest weight.

Scheduling in terms of ISO 16949 is defined as “Production shall be scheduled in order to meet customer requirements, such as just-in-time supported by an information system that permits access to production information at key stages of the process and is order driven.” (ISO/TS, 2002)

Methodology for determining the optimal sequence for selected request

This methodology deals with setting a uniform schedule to minimize inventory and ongoing production times on the line, uniform load logistics, minimizing the sort order, or weighting such criteria and determine the mix according to all the rules together. Explanation of the above procedures outlined in the following topics.

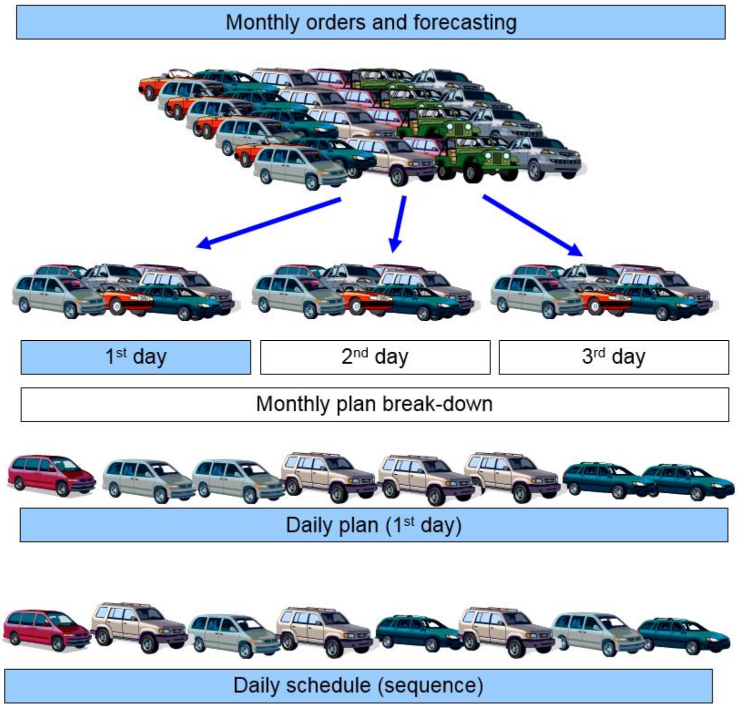


Fig. 1.4 Example of determination of the sequences (CEIT, 2015)

Table 1.1 Order coefficients for production lines (Botka and Mičieta, 2005)

	Operation “a”		Operation “b”		Operation “c”		Operation “d”		Order coeff. for line
	Priority: 90%		Priority: 3,3%		Priority: 3,3%		Priority: 3,3%		
Product	Time	Coeff.	Time	Coeff.	Time	Coeff.	Time	Coeff.	
A	4	8,78%	3	0,32%	2,5	0,32%	3	0,32%	9,74%
B	2	17,14%	1	0,55%	3	0,62%	2	0,60%	18,91%
A	4	17,56%	3	0,64%	2,5	0,63%	3	0,64%	19,47%
C	1	18,00%	4	0,78%	3	0,76%	2	0,73%	20,27%
A	4	26,34%	3	0,96%	2,5	0,95%	3	0,96%	29,21%
D	2,5	26,47%	2	0,94%	2,5	0,97%	4	1,02%	29,40%
B	2	34,29%	1	1,10%	3	1,24%	2	1,20%	37,82%
A	4	35,12%	3	1,28%	2,5	1,27%	3	1,28%	38,95%
C	1	36,00%	4	1,55%	3	1,52%	2	1,47%	40,54%
A	4	43,90%	3	1,60%	2,5	1,59%	3	1,60%	48,68%
B	2	51,43%	1	1,65%	3	1,86%	2	1,80%	56,73%
A	4	52,68%	3	1,92%	2,5	1,90%	3	1,92%	58,42%
D	2,5	52,94%	2	1,89%	2,5	1,94%	4	2,03%	58,80%
C	1	54,00%	4	2,33%	3	2,28%	2	2,20%	60,81%
A	4	61,46%	3	2,24%	2,5	2,22%	3	2,24%	68,16%
B	2	68,57%	1	2,20%	3	2,48%	2	2,40%	75,65%
A	4	70,24%	3	2,55%	2,5	2,54%	3	2,55%	77,89%
C	1	72,00%	4	3,11%	3	3,05%	2	2,93%	81,09%
A	4	79,02%	3	2,87%	2,5	2,86%	3	2,87%	87,63%
D	2,5	79,41%	2	2,83%	2,5	2,91%	4	3,05%	88,20%
B	2	85,71%	1	2,75%	3	3,09%	2	3,00%	94,56%
A	4	85,71%	3	3,19%	2,5	3,17%	3	3,19%	95,27%
A	4	8,78%	3	0,32%	2,5	0,32%	3	0,32%	9,74%
B	2	17,14%	1	0,55%	3	0,62%	2	0,60%	18,91%

Based on the coefficient ranking is able to complete order respectively the sequence of the products in relation to the times of operations. Result of this ranking is maximum output of the line.

On Fig. 1.5. you can see compare of two types of scheduling rules. One rule is focused of maximization of line capacities and second rule is focused on minimization of stocks on production line. On Fig. 1.5 is difference between this methodologies. Production line with implemented rule focused minimization of stocks on production line goes to lags, what results in lower production level.

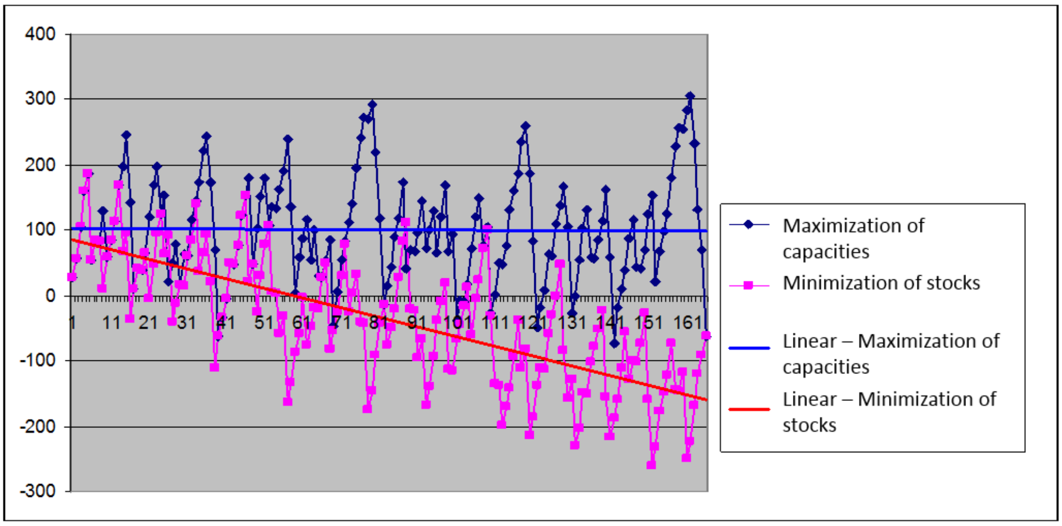


Fig. 1.5 Production lags based on line scheduling methodologies (CEIT, 2015)

The difference in percentage is in the maximum capacity methodology is 1.75%. This difference for example in automotive industry could mean increase of production about 7.8 vehicles per day, what is more than 6,900 vehicles per year in continuous operation.

1.3.2 RFID Kanban

Based on CEIT WORLD CLASS MANUFACTURING aimed at minimizing waste and delivering on the needs of the customer. It is applicable in all types of Kanban.

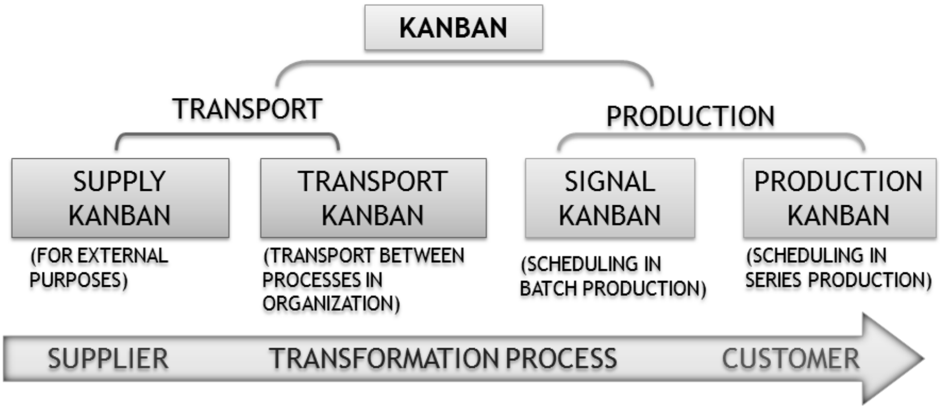


Fig. 1.6 Distribution of Kanban systems by way of use (Mičieta and Biňasová, 2013)

Sequential Kanban system is suitable for use in manufacturing based on the particular order. The system is useful for the types of production with a wide range of products. It ensures the production of parts in the required quantity, time and quality. The card is a replacement for production order. (Mičieta and Botka 2002)

Filling Kanban system - Kanban system of this type should be chosen in the workplace, where several produced parts are entering into the final product (eg a, b, c). If the chosen production cycle is 2 days, then in the first and the second day we will produce product that will be assembled to the final assembly in the third and 4 day.

Requesting Kanban system, according to its principles is one of the best-known pull systems that is usually described in most literature. The principle of its functions is best explained by the so-called saw diagram. The signal levels issue is closely described in the following section.

Features of the mentioned Kanban systems have become the basis for the design of model of pull system that is used for the implementation and improvement of other pull systems.

A complex model of pull system can be divided into few basic parts, which are shown in Fig. 1.7.

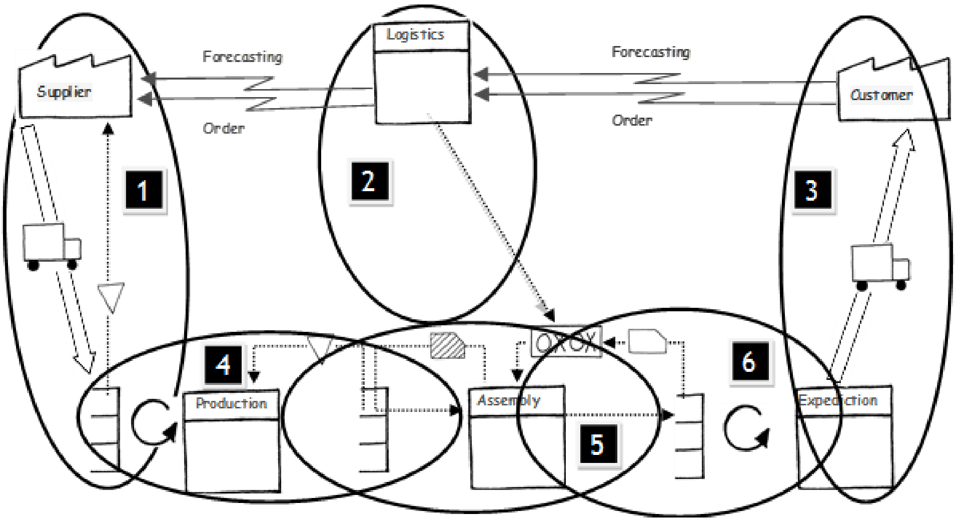


Figure 1.7 The distribution of a comprehensive model of pull system (Mičieta et al. 2014c)

Legend to Fig. 1.7.:

1 pull system - supply of materials,
2 planning and scheduling systems for pull system,
3 product ordering and shipping,
4 pull system in pre-production processes,
5 pull system in the workplace supplying,
6 pull system in production processes.

Main task of RFID is automated recording of materials flow. In this case are created Kanban cards and materials flows in materials packages. On Fig. 1.8 is example of RFID gates on warehouses.

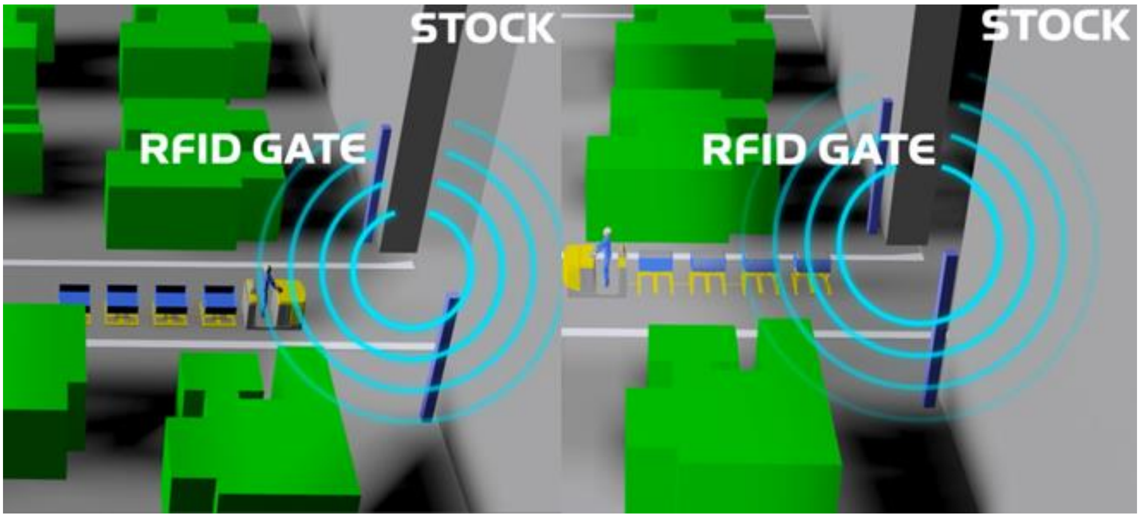


Figure 1.8 Example of scanning of empty / full pallets and Kanban Cards (CEIT, 2015)

Main advantage of RFID Kanban is automated record of materials flow and faster movement of materials based on integration of information systems.

1.3.3 LOGIO control (logistics inbound and outbund system)

The system for removing irregular loading of supplies and internal logistics. The system is based on supply capacity planning under the real capacity of the internal logistics. By introducing this system there is a waiting elimination of suppliers and also overloading the internal logistics.

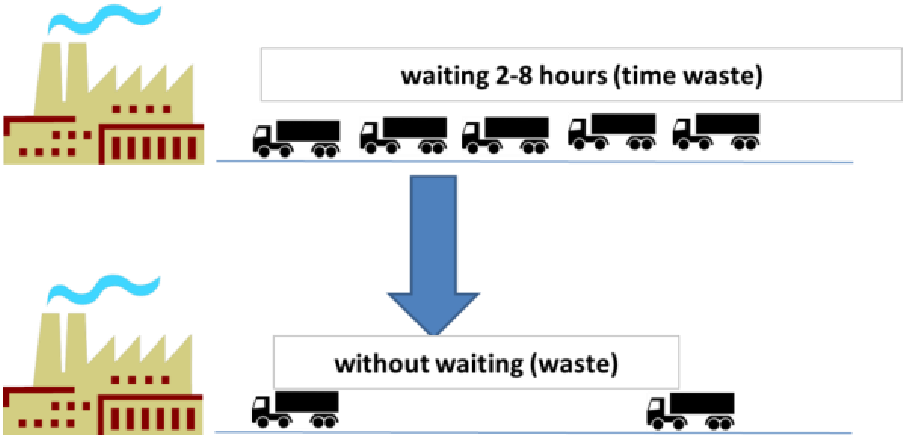
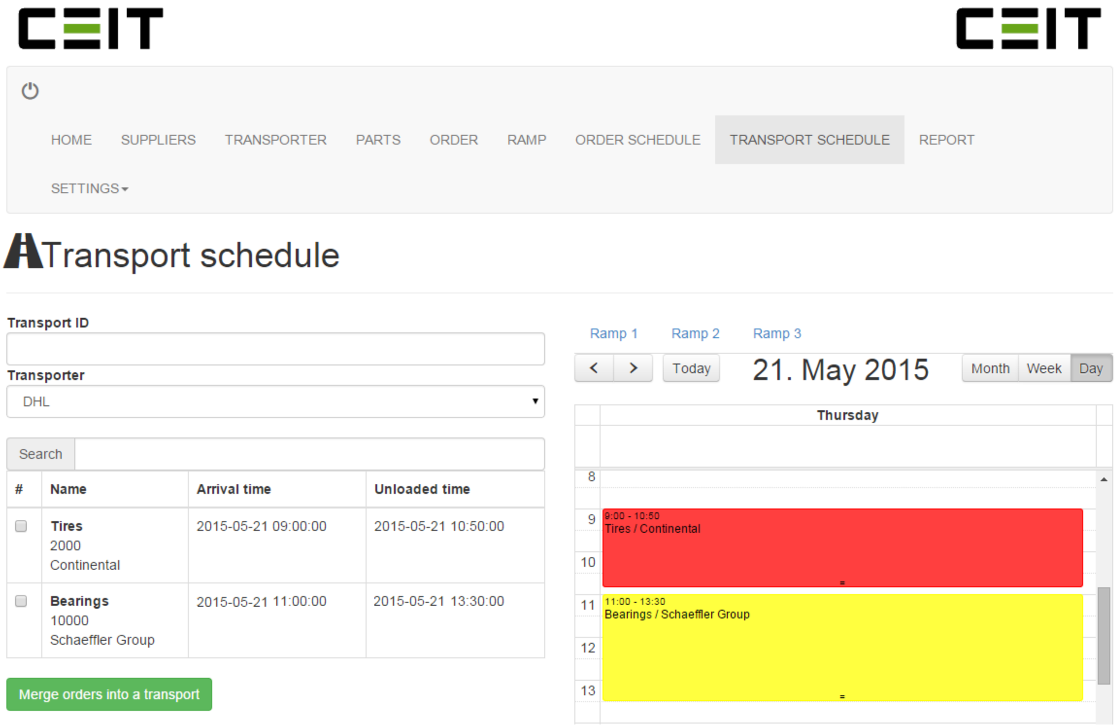


Fig. 1.9 Elimination of time waste at inbound and outbound logistic (CEIT, 2015)

Principle of LOGIO Control is planning inbound and outbound logistics. Individual suppliers are scheduled according to capacity of the internal logistics. Staff of internal logistics have an overview of the transportation schedule with a calendar, which sees information about the material and manufacturer. Transporter will receive the confirmation e-mail Planning and SMS confirming the exact date of delivery to the plant.



Transport ID:

Transporter: DHL

#	Name	Arrival time	Unloaded time
☐	**Tires** 2000 Continental	2015-05-21 09:00:00	2015-05-21 10:50:00
☐	**Bearings** 10000 Schaeffler Group	2015-05-21 11:00:00	2015-05-21 13:30:00

9:00 - 10:50 Tires / Continental

11:00 - 13:30 Bearings / Schaeffler Group

Fig. 1.10 Example of Transport schedule in LOGIO CONTROL (CEIT, 2015)

1.3.4 Co-worker picking systems

Automated order-picking system are commonly used in pharmaceutical, cosmetics and tabacco industries, but are also interested in other area where in need pick the small packages. Automated processes minimize the necessary manpower and increase the speed of delivery. Thanks to computer-controlled operations that ensure optimum capacity and static pallet operations using robotic technology can limit tha amount of damaged and lost goods. Due to maximum use of spatial layout can reduce the cost of energy and transportation. (Gabajová, 2013)

The most significant advantages of the automated picking systems are (Palajová and Gregor, 2013):

- high productivity,
- high efficiency achieved by eliminating difficult manual labor,
- efficient use of space due to high density products,
- easy maintenance thanks to an adjustable channel its product,
- easy integration into existing systems,
- expandable due to the modular design.

The basis for the solution of the CEIT is connection automated guided vehicle with co-worker robot. The modular connection provides the option of picking different materials in fully automatic mode. Thanks to the connection to the information systems by design picking is significantly faster, more efficiently and with certain materials safer (Mičieta et al., 2015).

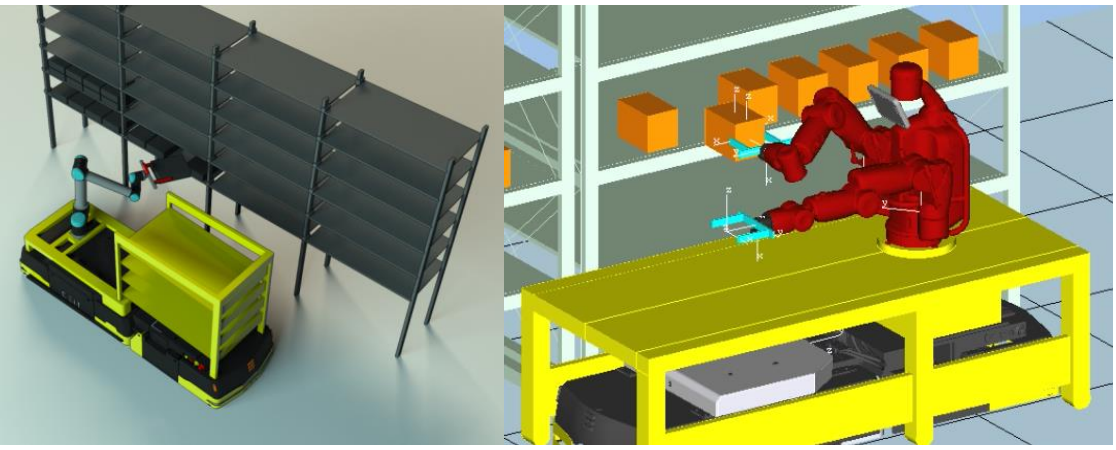


Fig. 1.11 Picking order with AGV connected with co-worker robot (CEIT, 2015)

1.3.5 Line feeding system

Material handling strategy in the context of World Class Manufacturing mostly manual or mechanical. Practically the supply system are a large variety of dimensions similar to euro-pallets and small containers 60x40 cm and smaller, which are handled manually. Therefore, their maximum authorized weight under many enterprises up to 15 kg. CEIT LINE FEEDING SYSTEM is mostly fully automated means of AGV (automated guided vehicle). Currently there are two types used AGV - run under version and towing version. CEIT AGV systems has this advantages:

- high speed - up to 2 m/s,
- high towable weight - up to 3 000 kg,

- brake energy regeneration,
- wireless monitoring and control system,
- automatic charging,
- safety scanners,
- towing and under-run version.
-

Under-run AGV system can be used as a movable mounting table. AGV broke through device supporting frame, catches him and pulls in any place where he left it. This type of device is used in particular for the transport of parts which are sensitive to handling, respectively during manipulation threaten to damage.

Towing AGV system is able to take more wagons and that mean take much more material at once. This advantage is able to use with material, which use in production is high (Gregor et al., 2009). This feature is supported with automatic system of connecting and disconnecting wagons by automatic system.

Fig. 1.12 CEIT AGV systems – under-run and towing version (CEIT, 2015)

Loading and unloading of pallets from/to AGV system is provided by peripheral devices. In case of big pallets it used “c-frame”. Principle of this pallet exchange is in exact stop of AGV in front of frame, mechanical part from wagon take the pallet on board and AGV continue in route. (Mleczko et al., 2014).

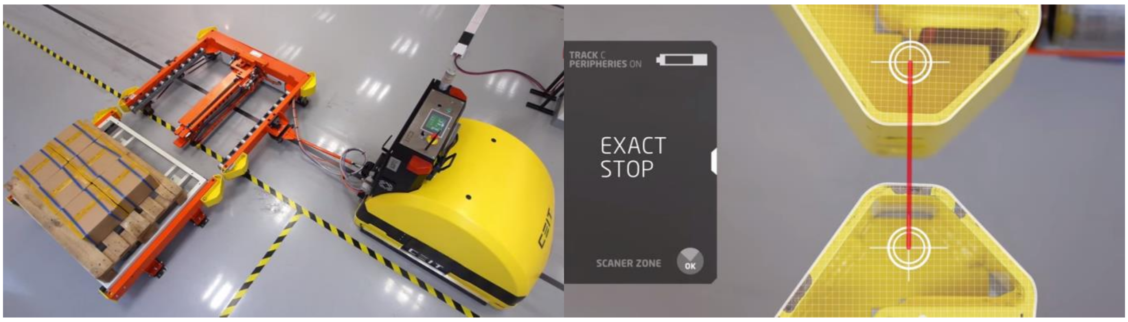


Fig. 1.13 AGV systems pallet loading or unloading (CEIT, 2015)

One of the main benefits of the AGV is reducing cost by reducing work-in-process, as well as cost savings for employees who are required to operate the truck by manual logistics. Calculations from a case study of researchers from University of Zilina show that the total annual costs of manual logistics are 182 160, 00 € while total annual costs of implementation AGV system are 89 456, 05€. The case study was conducted in conditions of subcontractors for the automotive industry, where for supplying was used three forklifts operated by employees (Grznár and Hnát, 2014)

1.3.6 AGV milk-run

The need to transfer small quantities of a large number of items between plants and inside plants, in short delivery times and predictable without increasing transport costs led manufacturers to slim the organization donations and supplies at fixed times along fixed routes, known as "milk runs". The term refers to a system used for delivering milk to homes in the United States until 1960. Milk run concept is applied in various forms for supply, marketing and internal logistics least for some items consumed or produced.

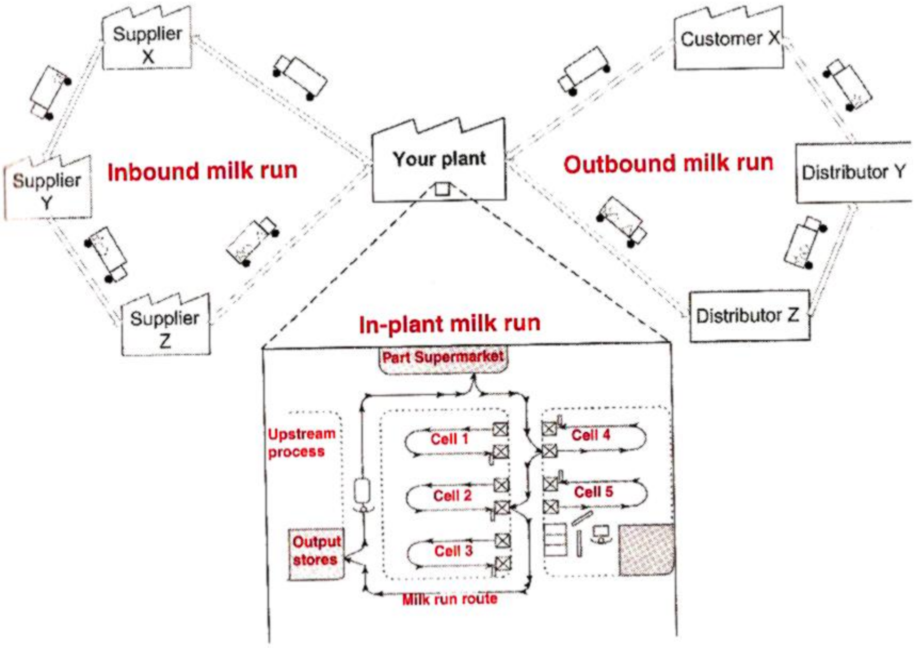


Fig. 1.14 Inbound, Outbound and In-plant milk runs

1.3.7 Runner system

Runner is a principle of continuous displacement of material flow in a certain tact based on the strength of central planning. Runner moves material in tact tightly bound to the cycle of production. This means that when it comes to a slow line, it is the logistics slowly, and vice versa. The main conversion is not over time, but over the number of units during the change. In practice this means that the truck does not switch off e.g. for example, the 6:30, 7:30, 8:30 etc., but when the dial is made with real vehicles, 30 pieces, 90 pieces, 150 pieces, etc.

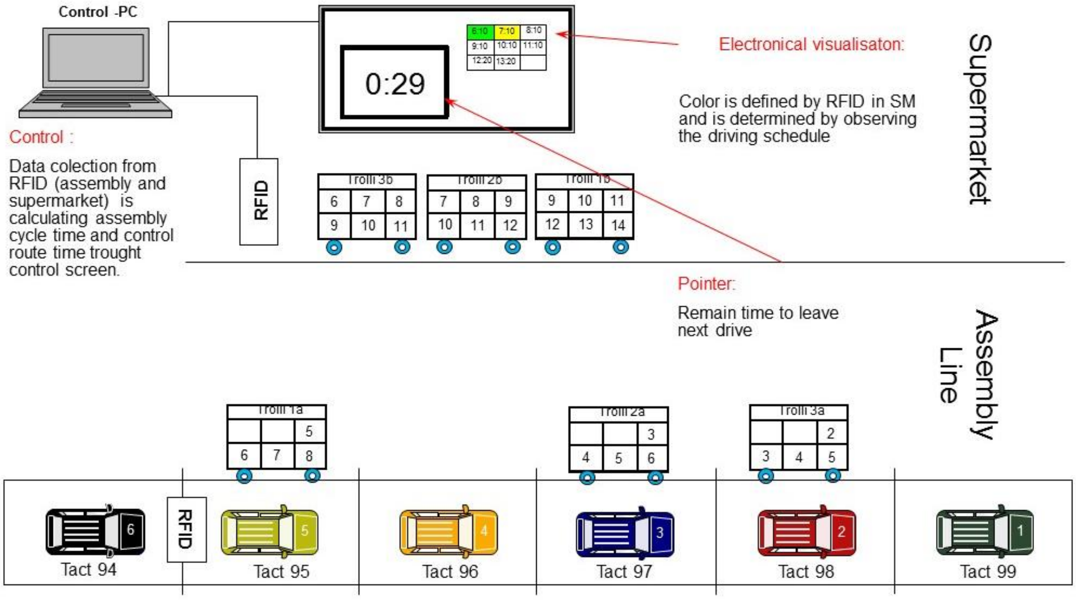


Fig. 1.15 Scheme of supply using Runner in order to synch logistics and production with minimum of stocks (CEIT, 2015)

1.3.8 AGV lines

AGV Assembly Lines principle is the use of under-run automated guided vehicles to move product between assembly stations. This transfer is the clearly defined path based manufacturing process. Transfers between different assembly stations can be synchronous, asynchronous or continuous automation. The asynchronous process allows independent movement of indexing between AGVs workstation. It is employed when workstation assembly times vary (Sásik et al., 2014).

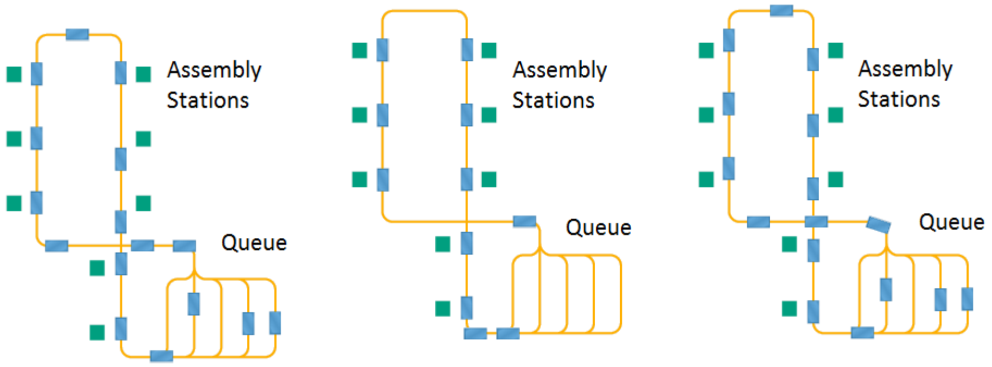


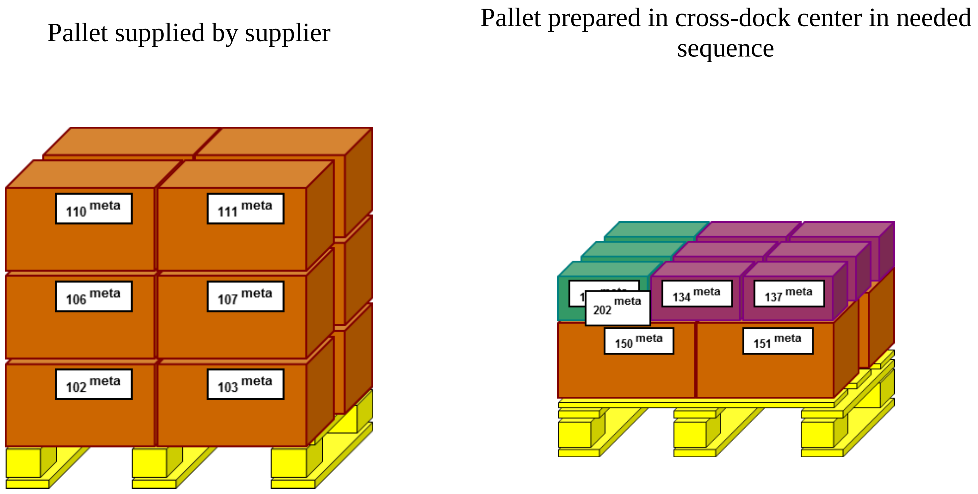
Fig. 1.16 Example of Asynchronous, Synchronous and Continuous Automation (AGV Systems, 2015)

This allows for more or less assembly time at a workstation for different SKU units. Synchronous AGV movement supports the assembly processes require all work pieces to index to the next station at the same time. The index can be controlled by time or activity such factors as a release when all stations have completed their tasks. Some assembly processes are better serviced by a continuous movement process. Savant AGVs can move very slowly replicating continuous chain driven assembly systems. With this 'virtual' towline, the AGVs will maintain a specific set spacing as needed.

Stopping one AGV will stop all AGVs and restarting the operator stopped AGV will restart all AGVs (Štefánik et al., 2008).

1.3.9 X-DOCK (cross-dock)

Mostly automotive industry is known to produce with minimal supplies. This objective is being fulfilled by the manufacturer mainly with local suppliers and supplier parks. These make it easy to supply parts only in sequence from the input store, but directly from suppliers, reducing inventory and handling difficulty. Not only in the automotive industry but also in logistics for the food industry are fully exploited cross-dock (x-dock). It's mostly a store for the transfer of material so that each customer gets the short time that he needs. In the most developed logistics system the goods "ticket" to the destination. According to this "ticket" can guide the container logistics personnel. At the "travel ticket" is as accurate flow warehouses and storage places that pack passes.



Pallet supplied by supplier

Pallet prepared in cross-dock center in needed sequence

Fig. 1.17 Example of x-dock pallets

1.3.10 Emergency feeding

Order picking centers and x-dock are usually far from the place of consumption. If the installation unit is damaged or damaged part of the supplier, the need urgent delivery, which can not only be directly and rapidly. As the supply of the components need to be as quickly as possible, the method of delivery is a significant cost for the manufacturer, so that their natural desire to minimize the use of emergency feeding. Most often used for this kind of air transport through cargo charter flight. Price of this operation depends on many factors – distance, time of delivery, cost for loading/unloading, type of transported components, weight of load, etc.

CEIT Intelligent Logistic Management is based on reduction of emergency feeding. This is realized on two main pillars – reduction of damages during processing and second on reduction of numbers of damaged part supplied by suppliers. First pillar is based on daily monitoring of damaged parts, finding reason of damage during processing and fix processes where part was damaged. Usually the bigger cost for emergency feeding is based on damaged parts supplied by supplier. Reduction of this cost is in CEIT Intelligent Logistic Management based on regular workshops between suppliers and producer (mainly in automotive industry), where both sides are brainstorming how to reduce this status. Sure, in this case all cost on emergency feeding is covering supplier (Gregor et al., 2011).

1.3.11 Logistics on wheels (packaging and material flow)

In industry there are a number of patents, supporting x-dock and ordering of the material under production sequences. Individual stacked boxes so no need to manually translate and manipulate pallet truck. Forklift unloads the pallet from the lorry onto the floor and any other operation takes place manually and efficiently (Krajčovič, 2015).

Fig. 1.18 Example of pallet with pallet truck

1.3.12 Quality control with image processing

Industrial image processing is a key technology for a 100% quality of input parts, which in most cases must be ensured logistics (Rakyta and Fusko, 2015). The intelligent modular system of quality control (InMoSysQC) of parts is a prototype intelligent modular system. Its task is to control the quality of parts. Under the quality measurement on the sample we mean measurements of its characteristics, such as outside dimensions, weight, surface finish, and others. One of the basic characteristics of modular equipment can perform easy, time-saving changes in the system, so that we may extension device with additional functions (in our case as an example, we can add other measuring devices at a lower level within one module or add a new module basal). (Marčan, 2013)

The control system of the intelligent modular system of quality control as automated inspection cell has been developed with emphasis on modularity, flexibility, re-configurability and adaptability. This system is designed to measure the quality of the wide spectrum of electro-technical and mechanical parts. The main control system in every holons is represented by the Mitsubishi Qx PLC. In the intelligent modular system, used for measuring of quality of electro-technical and mechanical parts (InMoSys QC), we can describe three types of the control systems, which support required tasks.

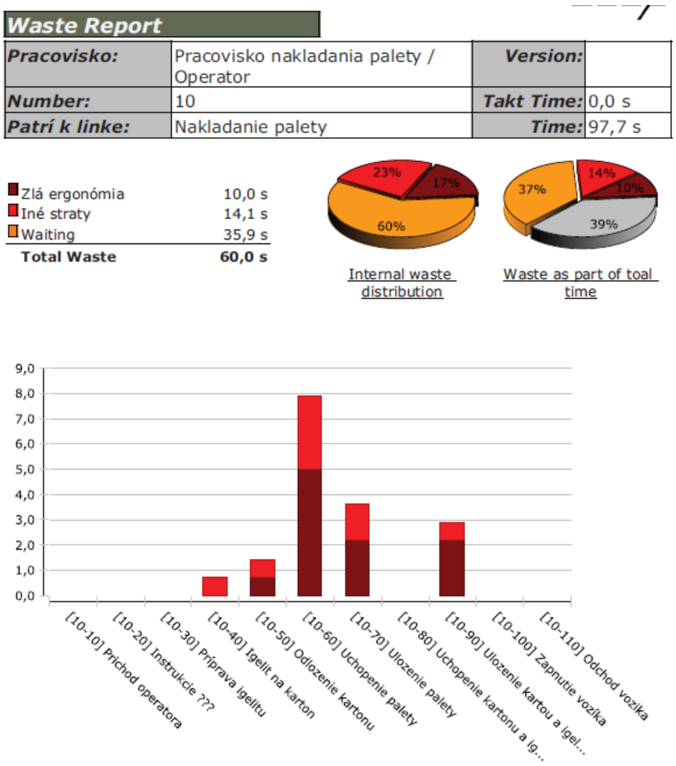
1. The Integrating Control System (ICS)
2. The Quality Control System (QCS)
3. The Manipulation Control system (MCS)

Each module represents the holon in the holarchy, which is simultaneously considered as a whole and as an element of the whole. It means that every module is capable of autonomous activity and simultaneously capable of cooperation with other modules. Considering the standard IEC61499 – Function blocks, every holon is characterized by a group of input (output) events and group of input (output) data signals. Algorithms, defined by standardized tools dedicated to programming automation's systems, are in progress in every holon. In the given project, the standard IEC 61499 (tools from IEC 61499) was not directly used. Only the concept of this standard was actually used. But the concept helps us to describe a formal description of the system and then to design the whole system. (Rofár and Macek, 2013)

Fig. 1.19 Prototype of InMoSysQC (Marčan, 2013)

1.3.13 Standarized work and continuous improvement

Continuous improvement is possible only if there are standards or the improvement achieved quickly degenerates. Also it is not possible to quantify the improvement and reward. Essential for improving the removal of waste. On Fig 1.19 is a sample wasting analyzed in software AVIX. AVIX is used to optimize the timing of the economy and is composed of several modules that can be optimized work involved. It Includes DFX as the methodology by which it is possible to design an optimal design for manufacturing and thus the optimal cost of the product.



Waste Report

Pracovisko:	Pracovisko nakladania palety / Operator	**Version:**	
Number:	10	**Takt Time:**	0,0 s
Patrí k linke:	Nakladanie palety	**Time:**	97,7 s

Zlá ergonómia	10,0 s
Iné straty	14,1 s
Waiting	35,9 s
Total Waste	**60,0 s**

Fig. 1.20 Waste report produced by AVIX (CEIT, 2015)

Standards are part of the job description of positions. The standards to determine the required number of operators and logistics capacity. The standards are for the personnel department helping you to choose the right people for particular positions (Fig 1.20).

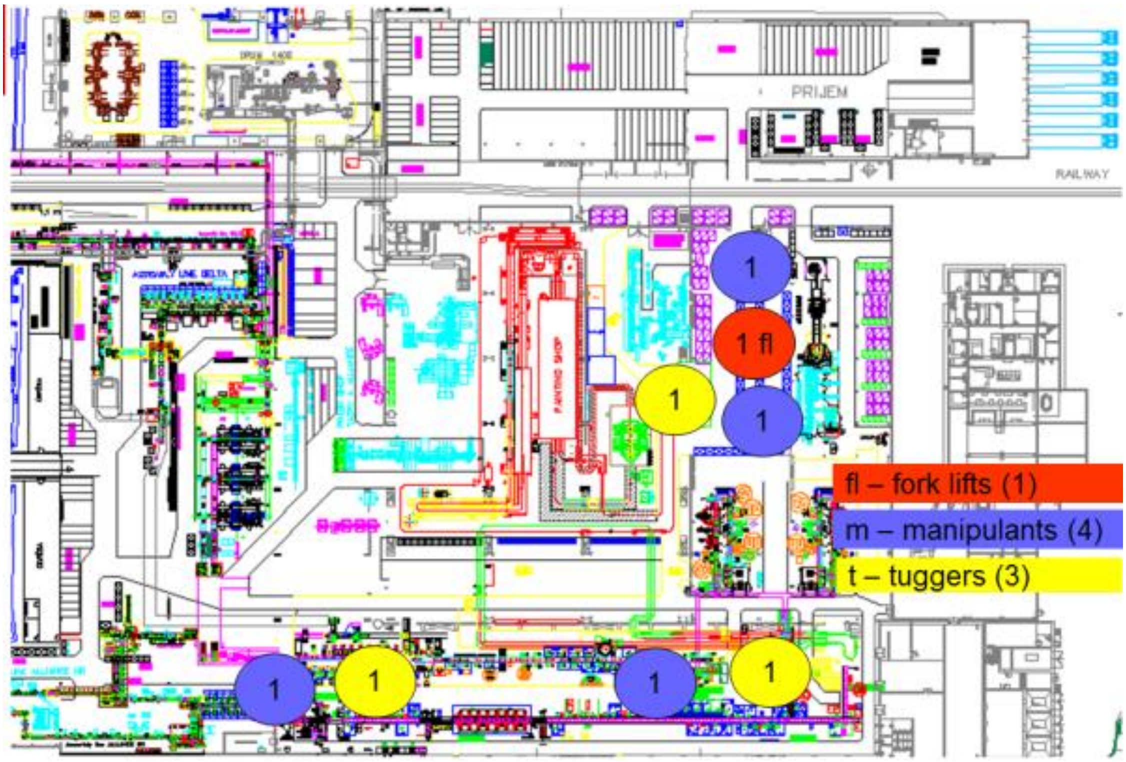


Fig. 1.21 “Dot” system for visualization of particular positions (CEIT, 2015)

The number and capacity of operators is determined by the time of analysis, or methods before camping times. The most used methods of predetermined times are in Central Europe thanks to the automotive industry methods MTM1, MTM2 and MTM UAS. MTM also worked there for logistic processes. It is a set of data which make it possible to determine the time consumption for manipulation. These spreadsheets times are used routinely in practice. They are excellent for estimating consumption of time in the planning of logistics processes.

1.3.14 Supply chain management optimization and planning

Top-saving logistics costs and inventory reduction can be achieved with good management of supply chains. On Fig 22 is a sample of simple visualization in planning logistics route. The scheduler uses different bands, height for optimum planning of transport (Dilský et al., 2014a) (Dilský et al., 2014b). Principle of CEIT planning optimal logistics route is based on calculation of optimal route taking into account the quantity of the material, the distance between the supplier and factory, just in time aspect and etc.

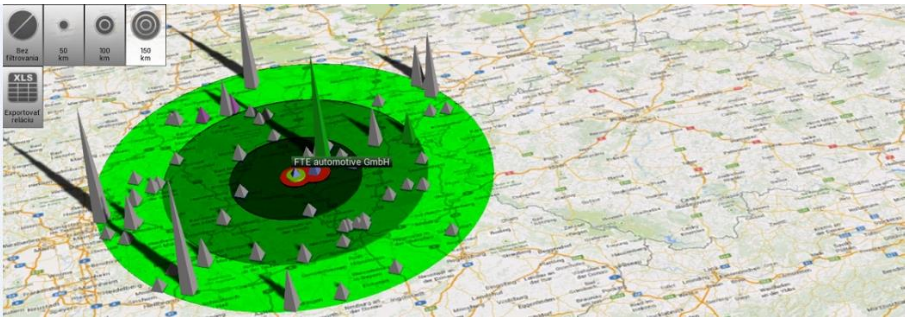


Fig. 1.22 Visualization system for planning optimal logistics route (CEIT, 2015)

Features of application:

- Visualization supplier position through GPS co-ordinates on a map,
- Visualization weekly volume of material by volume and height of the pyramid,
- The capability to filter the suppliers of the relative position according to the size of perimeter 50 to 150 km,
- Grouping of suppliers to sessions,
- Categorization sessions,
- Generating driving schedules.

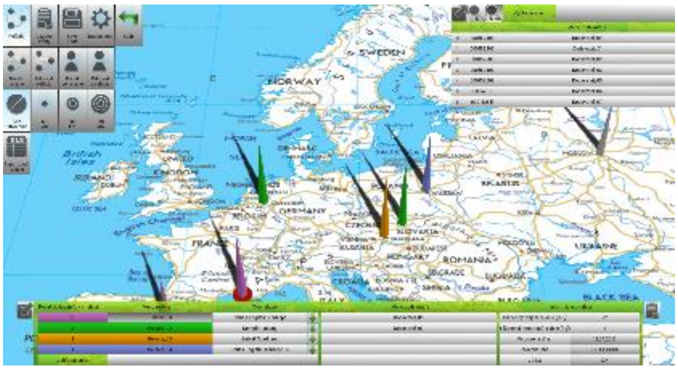


Fig. 1.23 Visualization volume of material (CEIT, 2015)

1.4. CONCLUSION

The aim of this chapter is to introduce the individual components of CEIT Intelligent logistics system. The basis of this concept are automated guided vehicles accompanied by other components of the system. Interconnection of components brings a wealth of technical and process innovation. It is these aspects directly in the reduced costs of internal logistics. For example, the introduction of automated logistics brings out significant time savings when transferring material even guarantee delivery of material to the production line at the right time and quantity without potential human errors. The creation and implementation of such a concept provides new opportunities for the introduction of smart manufacturing, which forms the basis for building Factories of the Future. At the same time innovations of existing solutions will bring further potential to reduce costs, increase productivity and competitiveness of factory. The introduction of this concept is directly dependent on the conditions and needs of the company, its modularity allows efficient logistics operation without the need of introducing the concept as it was presented. The ideal environment for introducing this concept as the automotive and electrical industry.

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Chapter 2

Intelligent Intermediaries for Multiple Logistics Parties

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Abstract

Logistics parties are usually introduced to represent different layers to logistics services in supply chain management. Recently they have become a challenging subject of research for managers and software developers in respect of implementing different aspects of outsourcing. For example, third party logistics (3PL) resources need special approaches of scheduling in transportation logistics, and fifth party logistics (5PL) is totally based on information technology (IT) infrastructure, which requires new technology of management considering the principles of group behaviour and self-organization. IT plays the general role in 5PL business. Customer representatives, transport managers, shippers, carriers, and even drivers become the users of a certain web site. The purpose of this site is to allocate incoming orders to appropriate resources, consolidate them improving consolidation and reducing idle time, generate efficient schedules for drivers and vehicles.

In this chapter we propose to discuss and explore the features of managing logistics services delivery based on dynamic interaction in integrated information space, provided by web-based platform or online scheduling system. There is introduced a new concept of Intelligent Intermediary Service Provider (IISP) to improve the efficiency of actors cooperation in business-to-business networks. New model is formalized for intermediary service provider that owns no transportation resources itself but makes available special services able to link suppliers and consumers.

IISP is a software platform with Internet portal able to match customers and service providers and generate profitable options of integrated services. Intelligent intermediary represents a new concept for multiple logistics parties. Targeting effective interaction between services providers and consumers it meets the challenge to find a balance of service cost accessible for all parties. To make this possible IISP should analyse possible opportunities and provide a list of options enforcing the autonomous actors to make own decisions. Considering the introduced approach there are analysed the capabilities of multi-agent technologies that are successfully used for intelligent scheduling in transportation logistics nowadays. Possible solutions are given in comparison to web-based optimization technique. The resulting solution is developed for transportation logistics and illustrated by software solution powered by Magenta Technology.

This research appeals to all the users of new IT technologies for multiple logistics parties who gain to increase the efficiency of interaction in integrated information space and should be of interest for developers of emerging multi-agent technologies and next generation software solutions.

Keywords: logistics parties, intermediary service provider, multi-agent technology, transportation logistics, scheduling, decision making support.

2.1 LOGISTICS PARTIES AND MULTI-AGENT TECHNOLOGIES

2.1.1 Definitions and viewpoints

Extensive implementation of information technologies at different stages of supply chain management is one of the challenging trends in modern logistics. Starting with an intensive use of distributed data bases and RFID technologies (Bessis and Dobre, 2014) the forthcoming software and hardware systems delivered by lots of scientific and commercial software development companies provide intelligent decision making support and give considerably new opportunities for logistics management. One of these opportunities is based on organization of logistics actors' interaction in distributed information space based on the implementation of Internet services.

Under the "Actor" term hereinafter we shall basically mean any participant of logistics' management: a company, business party or private person acting in the face of customer or supplier. Actors represent the number of decision makers that interact in order to meet personal goals and need to compete and cooperate in real time. Therefore different actors play various roles in the process of planning, implementing and controlling procedures for the efficient and effective transportation and storage of goods including services and related information, as part of logistics glossary according to the Council of Supply Chain Management Professionals (CSCMP glossary, 2013).

In a distributed supply chain, actors have predominantly autonomous behaviour determined by different business roles, goals and constraints. The process of actors' interaction and negotiation on logistics market is a challenging subject of research from economical and management point of view, and gives new opportunities for computer science to introduce intelligent decision-making support. With respect to high complexity and autonomy of actors' negotiation most of intelligent software systems provide the simulation of this process in virtual world.

Under the "Agent" term hereinafter we shall basically mean actor's substantiation in virtual world used to represent its logic and simulate its behaviour. Agents stand and act for actors that observe an environment and direct their activity towards achieving the goals. Agent-based computational model simulates the actions and interactions of autonomous entities with a view to assessing their effects on the system as a whole. Each agent acts on a "scene" – a snapshot of virtual multi-agent environment that represents the current citation of agents' interaction.

Popular interaction models like auctions, round tables, gaming, cooperation, and competition, etc. describe a wide variety of business relations and their evolution in time. Within the context of this theory and as a part of it there should be emphasized the models of outsourcing that play an important role in actors' interaction specification nowadays.

Logistics outsourcing involves a relationship between a company and logistic service provider (LSP), which, compared with basic logistics services, has more customized offerings, encompasses a broad number of service activities, is characterized by a long-term orientation, and thus has a strategic nature (Mallik, 2010). The principles of outsourcing introduce a new design factor and metric that initiates a popular classification for supply chain actors as logistics parties (see Fig. 2.1).

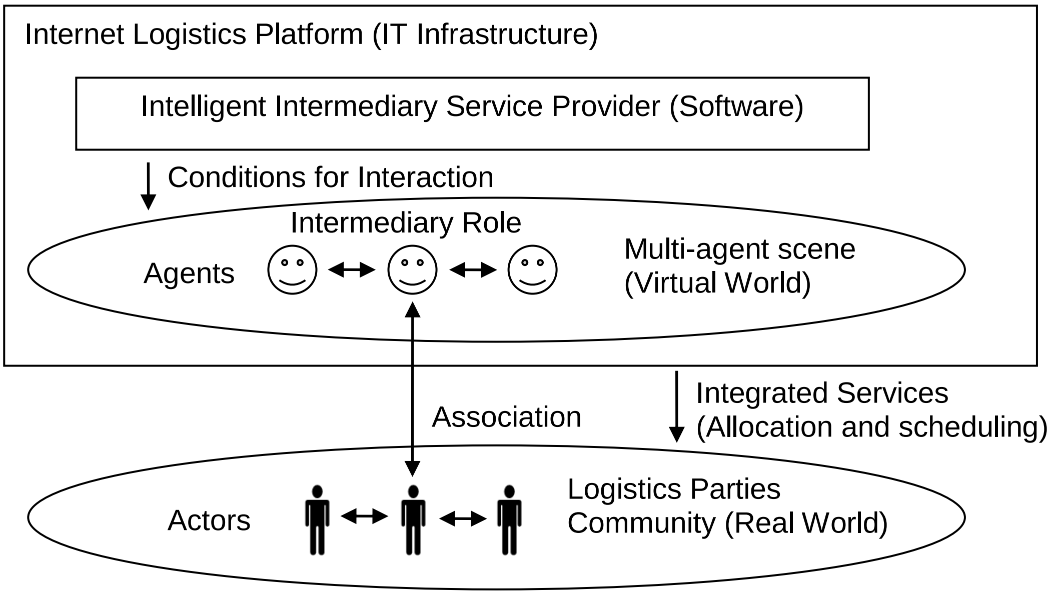

Fig. 2.1 IT solution for multiple logistics parties

"Logistics parties" are usually introduced to represent different layers to logistics services in supply chain management. Recently they have become a challenging subject of research for managers and software developers in respect of implementing different aspects of outsourcing. For example, third party logistics (3PL) resources need special approaches of scheduling in transportation logistics, and fifth party logistics (5PL) is totally based on information technology (IT) infrastructure, which requires new technology of management considering the principles of group behaviour and self-organization. Customer representatives, transport managers, shippers, carriers, and even drivers become the users of a certain web site, which helps them to allocate incoming orders to appropriate resources, consolidate them improving consolidation and reducing idle time, generate efficient schedules for drivers and vehicles. IT software solution being easily available on Internet makes it possible for all the above mentioned users to become actors and participate in group decision making.

2.1.2 Logistics Parties Overview

Considering the role and degree of outsourcing there are classified the following types of party logistics providers (Hickson et al, 2008):

- 1PL – is the autonomous logistics with the two parties who benefit from the transaction. The term first-party logistics provider is used both for cargo sender and cargo receiver. It can be any person or company that needs goods to be moved from place A to place B.
- 2PL – the carriers of goods are involved for the transaction. We deal with the owners of transportation means (air, rail, road, sea), who own, lease or charter transport.
- 3PL – apart from transportation goods from supplier to buyer, additional outsourced services can be involved in the supply chain. The example of possible services: warehousing, IT track and trace, supply chain management, etc.
- 4PL – the provider is a head administrator of supply chain management (non-asset based). An integrated electronic interface system addresses the requirements of logistic sections, provides the analysis due to the established key performance

indicators (KPIs). 4PL provider manages other contracted 3PLs and provides feedback, comprehensive solutions and recommendations for increasing the efficiency.

- 5PL – the providers plan, organize and implement logistic solutions with an extensive e-business focus. Updated information on the shipment process can be constantly provided. Favourable rates are negotiated to cut costs and achieve savings, the best possible solutions are provided. The activity of provider is based on the use of modern IT technologies.

The difference between the introduced logistics parties can be illustrated by the following example given for industrial problem domain. In 1PL industrial enterprises specialize on several production types and as a rule work with a number of buyers. Enterprises act independently, and have their own warehouses and transport. In 2PL enterprises have a wide range of products, broader geography of customers' location in comparison to 1PL (one or several countries), can have their own warehouses. In 3PL model enterprises introduce a more developed logistics: they have their own fleet that can be distributed on the territory or use the service of contractor-companies. Therefore, 3PL enterprise has good opportunities for outsourcing of his own and external fleet. Having a well-developed infrastructure, 3PL enterprises provide the warehousing and transportation services.

4PL providers work with various types of companies (transportation, industrial, warehousing). With a well-developed customer base the companies provide consulting services on developing the new supply chains or optimizing the already existing ones taking into account the present market situation. 5PL provider uses the Internet portal to organize activity. Suppliers and consumers are grouped as customers and contractors. In this case the integrated information space formed in 5PL is divided into two categories with no interaction inside each category. Contractor can register as a customer and act accordingly, but there will be hardly any connection between the two roles of one actor. A community of consumers and suppliers providing their services to the market is formed in 5PL. The quantity of transportation and production variants is much bigger, that leads to saving costs.

In 4PL consulting services for supply chain management employ outsourcing with a lightly complicated configuration. In 4PL we deal with heterogeneous actors negotiating in a broader information space (not only transport resources providers, but production, warehousing, etc.). Actors gain higher autonomy. Heterogeneous participants of supply chain, coherence of operations, territorial distribution characterize the complexity of 4PL outsourcing that is based on a certain IT infrastructure. In relation to this 4PL can be treated as the logical development of 3PL.

It can be noticed that with the transfer from 3PL to 5PL there is an up-grade in the development of information space. 5PL actors use portal for the cooperation of their resources. With two categories: customers and contractors being formed, we have a bigger scope of possible decisions and consequently more chances to find the more effective ones. The participants of such information space are free to interact, communicate and exchange the necessary information.

5PL concept is one of the most up-to-date trends in transportation logistics (Hosie 2012, Ivaschenko, 2014), which is based on the implementation of a number of services for customers and shippers provided by the specially designed software platform. 5PL platform is open for new transportation companies and even drivers, it helps them negotiating with customers in integrated information space. For example, a new coming taxi driver can use a handheld device to register and start receiving new orders according to his current position and capabilities. One of the main features of such an approach is high flexibility in number and time of resources available. Each transportation company or even driver becomes an independent actor with its own objectives and constraints and is highly motivated mainly by his own interest.

In (Ivaschenko and Andreev, 2015) we have introduced a new concept for 6PL provider that extends the functionality of 5PL by capturing and operating the network of contract relations that define long-term cooperation and competition between the actors. In contrast to the 5PL provider logic that does not change the conditions of interaction and does not limit decision making by the actors, 6PL provider can generate new contract relations that are used in real time scheduling and decision making support. 6PL provider is also based on the software that realizes system management of interaction based on the analysis of interaction statistics. On the level of 6PL there are formed the conditions of logistics supply chain members interaction in integrated information space that are being expressed in the form of contract agreements that reflect the cases of permanent cooperation between the actors.

Table 2.1 illustrates the features of party logistics in the aspect of outsourcing. 6PL operator provides both high autonomy of resources together with high reliability, which makes it reasonable for transportation logistics.

Table 2.1 Features of logistics parties

Logistics type	**1PL**	**2PL**	**3PL**	**4PL**	**5PL**	**6PL**
Resources	Own resources	Separated department	Outsourcing	Long term cooperation	Mobilization of new resources by Internet	Web-based cooperation with shippers
Interaction with resources	No autonomy	Low autonomy	High autonomy	High autonomy	Variety of available resources, multiple possible options, low predictability	Variety of possible allocation options, high autonomy, high reliability

Conspicuously the **next generation trends** in logistics parties' management are closely related to interactive and proactive involvement of actors into the process of distributed decision making. The value, proportion and time of outsourcing should be established by each actor individually considering the current resources utilization, contract commitments and future plans. Giving the actors high autonomy in decision making we provide the corresponding flexibility of cooperation and problem solving. The actors that are able to coordinate their behaviour in real time become adaptive to incoming events and provide enough level of self-organization for distributed intelligence.

In such a way wide use of information technologies increases the effectiveness of managing orders scheduling and executing, resources monitoring and organizing an efficient interaction of parties in integrated information space. New opportunities for suppliers and consumers of logistics services force the appearance of the new forms of virtual cooperation and competition that consequently stipulate special requirements to the software of the corresponding services.

The number of PL models is not limited to the above-mentioned list and is continuously discussed by logistics community. E.g. there is a suggestion to introduce 6 – 10PL, where 6PL stands for artificial intelligence driven supply chain management, 7PL –

autonomous competitor created to test alternative supply chain strategies, 8PL – super committee created to analyse competitor's results, 9PL – crowd sourced managed logistics strategy, 10PL – supply chain becomes self-aware and runs itself (Narasimhan, 2015)

Another suggested idea is to treat 7PL as the combination of 3PL and 4PL into one (3PL + 4PL = 7PL), where the PL provider organizes both 3PL and 4PL services under one roof. 'One contract, one bill' concept is introduced as a variant of optimization to make it comfortable for the client to deal with one provider (Snapp, 2010, Matyas, 2014). However, the above-mentioned ideas are not well grounded and are under design and construction yet, although demonstrate how popular the subject is.

Let us use these definitions as a background to study intelligent intermediaries for multiple logistics parties. One of the basic features of the introduced viewpoints is that they are primarily based on the implementation of actors' negotiation in integrated information space by means of software agents. High autonomy and distributed logic of decision-making motivate logistics management actively to implement, deploy and use multi-agent technologies that present good results in various logistics problem domains. This makes it reasonable to study multi-agent models and algorithms for multiple logistics parties' management thoroughly.

2.1.3 State of the Art

The concept of Fifth Party Logistics (5PL) is introduced by analogy with 3PL that provides the process of outsourcing the transportation resources and 4PL that describes a concept of Lead logistics integrator (still there is no general definition of it in business world). 5PL provider owns no transportation resources itself but makes available a special service able to link suppliers and buyers. This service is based on the IT infrastructure, which plays the general role in 5PL business. Customer representatives, transport managers, shippers, carriers, and even drivers become the users of a certain IT platform.

This idea is close to the popular SaaS (Software as a Service) business model, according to which software and associated data are centrally hosted on the cloud. Such service becomes attractive for small logistics companies and allows outsourcing dispatching functions for large logistics operators consolidated by the integrated information space. This feature gives the users a new opportunity to get access to related services that are consolidated together to better fit the customer's requirements (Machiraju et al, 2002).

Modern integrated information space is a complex system with heterogeneous structure that includes various databases, pieces of software, tools and systems for a support of decision making. The users of all these components form a certain virtual community that has access to all information items and change its behaviour in real time to react adaptively to the events that happen in a process of enterprise functioning. The process of decision makers' interaction is based on information, tasks and reports exchange and results in appearance of new knowledge, tasks, schedules, and reports that in turn initiate new waves of interaction.

One of the solutions can be close to subject-oriented approach for business processes management (S-BPM), which conceives a process as a collaboration of multiple subjects organized via structured communication (Fleischmann et al, 2013). There can be proposed a model for the interaction of actors (subjects) in integrated information space, which can be implemented using multi-agent software. In this paper we describe one of the possible solutions of this problem.

Still to ensure high efficiency of logistics service both for customers and executors in terms of time and costs there is a request to implement modern technologies of business processes management based on decentralized architectures, distributed intelligence and multi-agent technology. This happens because of the increasing number of decision makers, high uncertainty and dynamics of changes, and flexibility of decision making logic. The example of using multi-agent technology for business processes simulation can be found in (Onggo, 2013).

Nowadays multi-agent technologies (Wooldridge, 2002) are being successfully applied in intelligent systems for resources scheduling and allocation. Especially good results are demonstrated in transportation logistics (Andreev et al, 2009, Glaschenko et al, 2009), where geographical constraints can be used for the limitation of a number of iterations of agents' negotiation.

As soon as the information space provided by 5PL software platform can be treated as a complex network of continuously running and co-evolving actors or agents, the whole solution can be based on holons paradigm (Leitao, 2009) and bio-inspired approach (Gorodetskii, 2012). This paradigm and approach offer a way of designing adaptive systems with decentralization over the distributed and autonomous entities organized in hierarchical structures formed by intermediate stable forms. Its implementation in practice requires the development of new methods and tools for supporting fundamental mechanisms of self-organization and evolution similar to living organisms (colonies of ants, swarms of bees, etc.).

The actors compete and cooperate, coordinate and adapt their behaviours, aggregate their services to users and take various requirements individually. Each event that occurs here can influence the whole network and needs a collaborative reaction from all the subjects that take into account personal objectives and constraints of each decision making member. Another requirement for the decision making process based on subject' negotiation is that the final decision can require a complicated and time consuming process of data exchange between the actors. That's why it should be managed to consider time factor and assure functioning in real time.

Due to group behaviour and to be able to function in real time this network of intelligent systems and their users should be considered as a complex system with evolvable dynamics and investigated from statistical point of view. Another requirement for a decision making process based on the agents' negotiation is that the final decision can require a complicated and time consuming process of data exchange between the agents. This process should be treated as self-organization of software agents and human operators, which form a heterogeneous information space. That's why it should be managed to reduce the negative effects of human and time factor and assure functioning in real time.

One of the recent developments in this area (Kalina et al, 2013) introduces featuring a clear separation between the local planning performed by the individual vehicles and the global coordination achieved by negotiation. To solve such kind of problems there can be implemented a special functionality for a statistical analysis based on recent developments in cross-correlation analysis of non-equidistant time series (Prokhorov, 2007). The models and methods of such analysis were successfully probated in social - management and can be reused for managing the multi-agent negotiations.

Also in this area there can be used the event processing techniques (Anicic et al, 2012) for an effective continuous processing of time sensitive data in control centres. This technology deals with the analysis of the streams of continuously arriving events focused to identify the instances of the predefined meaningful patterns (complex events). Event processing offers a variety of special operations that are applied on events (e.g., event filtering, projecting, aggregating, splitting, transforming etc.) and enables a special (the event-driven) interaction model.

In many cases however, real-time awareness provided by event processing is not sufficient; real time actions need to be triggered not only by events, but also upon the evaluation of additional background knowledge (Artikis et al, 2010). This knowledge captures semantic metadata descriptions (the domain of interest), and the context related to critical actions and decisions. This metadata is evaluated for complex events in order to detect relevant background information or to propose certain intelligent recommendations in real time.

To provide this functionality there is proposed a model of intermediary service provider (Ivaschenko et al, 2014) – a software platform with Internet portal able to match service requests (orders or applications) and opportunities and generate profitable options of integrated services.

On the basis of the analysis of the current trends of automation of logistics parties' interaction in integrated information space powered by intelligent multi-agent technologies there was identified a following challenge. Most of software solutions provide operative dispatching and allocation of orders in real time or automate scheduling based on the current resources availability. Optimization software tools provide long term scheduling for a concrete and limited set of resources. 5PL platform allows situational allocating of new coming orders to currently available resources with very limited planning horizon. In order to combine these two approaches there should be proposed a 6PL solution based on the flexibility of interaction with autonomous shippers provided by 5PL and getting new opportunities of contracts formation and execution which allows long term scheduling.

2.2 INTELLIGENT INTERMEDIARIES CONCEPT

2.2.1 Management by conditions as a new paradigm

The process of distributed actors' coordination can be treated as a problem of centralized logistics management. In case of various actors (people, facilities and supplies) involvement this problem becomes complicated and requires original and specific scientific solutions based on the implementation of optimization technologies and algorithms (Leung, 2004). High use of information and communication technologies in logistics management breaks the peace and makes these efforts ineffective. Integrated information space forces actors to interact in virtual reality and coordinate planning, implementing and controlling procedures under the pressure of incoming events. This new possibility of negotiation in real time makes any coordinated plan unfeasible. Complicated scheduling and optimization algorithms require many time and efforts, and logistics procedures being adapted according to every incoming event become uncontrolled.

Nevertheless, complete rejection of optimization strategies is not a solution as well. Management based primarily on self-organization is possible in highly motivated multi-actor communities, and multi-agent software can provide decision-making support in such systems by simulating the real negotiating processes and detecting the bottlenecks. However, such a solution of decision-making support cannot give any predictable and explicable result, which makes it difficult to put it into practice. Therefore, from one side the actors should have freedom of autonomous interaction with no direct instructions. From the other side the negotiation procedure should be open and comprehensible in order to make it possible for an operator to explain the results and manage the decision making process. This contradiction becomes specific for multiple logistics parties with high autonomy of actors.

To overcome these issues there should be proposed a meaningfully flexible concept for actors' negotiating management based on motivation and coordination of their behaviour. This approach is based on the idea of forming the informational operating environment for the actors, provided that each actor gets own individual representation of the current scene. Each actor together with a corresponding agent has its own view that can be different from the views of other actors and the real situation. Generating the views that in general correspond to the current situation but contain information items (or descriptors) that are filtered and prioritized considering the compromise between the actor's local objectives and the system strategic goal makes it possible to avoid direct instructions and make the management procedures flexible and adaptive.

Let us introduce this concept as "Management by conditions" (Ivaschenko et al, 2015) and illustrate it by Fig. 2.2.

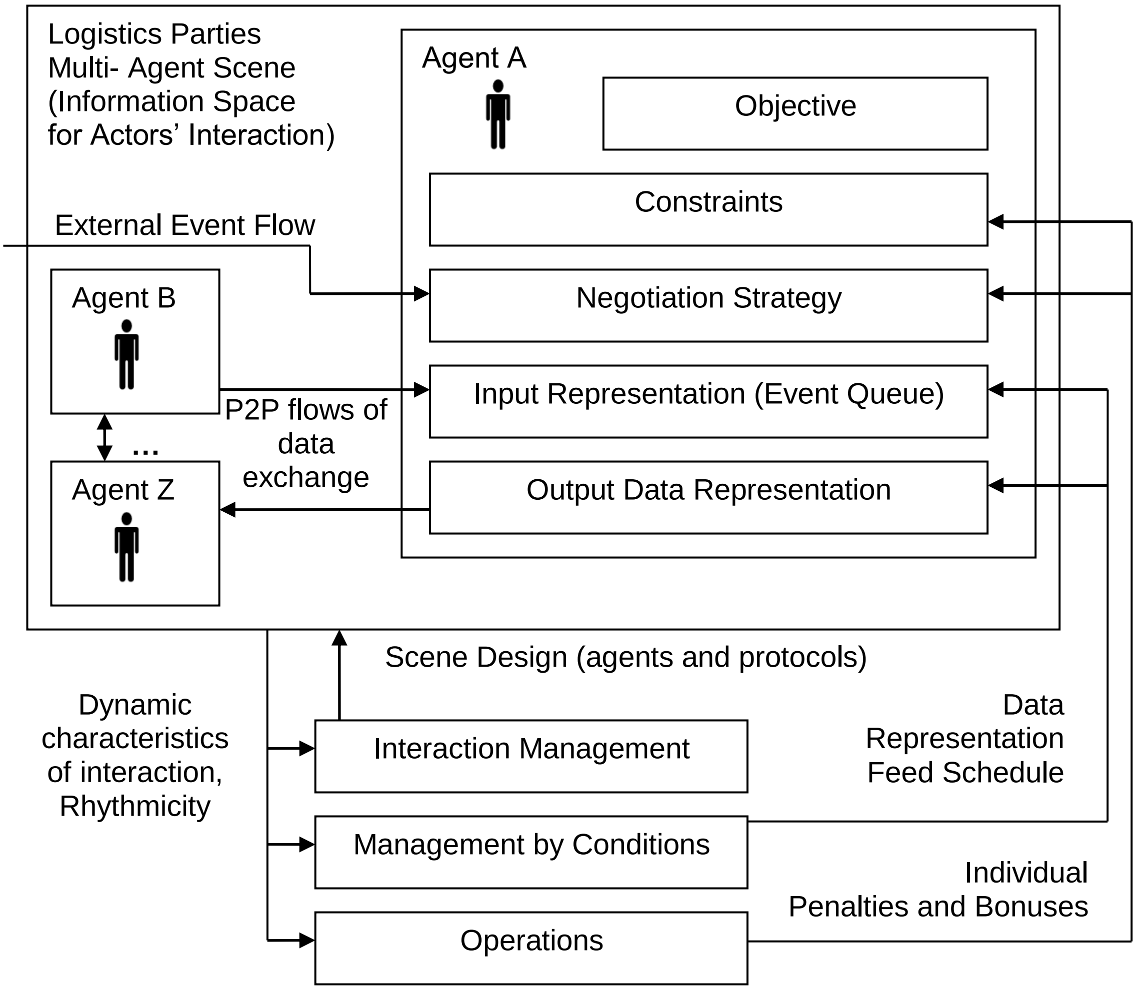

Fig. 2.2 Management by conditions in multi-agent scene

At conceptual level, the paradigm is based on forming the certain conditions for each actor that facilitates decision making in real time. Making any decision in the process of negotiating with others the actor is driven by own objectives and constrains, and the current understanding of the scene. Under any circumstances, the actor has no ability to capture and analyse the whole scene, especially when acting in real time, and needs to derive a concentrated view that contains the description of the most beneficial options. The system can help the actor by introducing filtering and priorities individual for each actor. Main idea is to generate the views in a coordinated way considering cross correlation between the actors strategies and generalized system goal.

To provide the approach at logical level there should be introduced time management algorithms based on statistical analysis of event flows. Events that happen in the system can characterize interaction with external environment (external events) or can be related to the messages that are sent between the actors and agents (data exchange events). Both have irregular time intervals and can be described by non-equidistant time series. Each agent as well as the operator (represented by the Centre or the World agent) can analyse these time series, discover the strategies of negotiators and build its own strategy in the form of a schedule of limited data exchange. This approach intends a procedure of interaction, in which the agents do not exchange all the information that they have, but distribute it to portions, given at different time to different contractors.

To implement the approach at physical level there should be introduced a special software platform that can help actors decompose, split, share and distribute tasks between each other by carrying out a series of auctions with bidding iterations determined with the help of generated conditions.

Management by conditions provides a balance between autonomy and controllability of actors from their manager or partner point of view (within our concept any manager becomes a partner as soon as the possibility to give direct instructions is lost). At the same time, this paradigm allows to review and rearrange the logic of logistics parties' mutual interaction. Having two different views for supplier and buyer an actor becomes a mediator of broker, getting additional benefits from his intermediary position and role and giving new opportunities for his partners at the same time. Benefits include a possibility to balance the commitments and effectively utilize outsourcing. Opportunities for partners resolve in a possibility to offer related services provided by a single actor on his own responsibility. In the process or execution, this accountable actor can involve any subcontractor that will not be noticed by the customer. This approach can be used as a basis for either management strategies, or intelligent software for decision-making support described below.

2.2.2 Intelligent Intermediary Service Provider

To generate effective combinations of related services from different logistics providers in supply chain there is introduced an Intelligent Intermediary Service Provider (IISP) concept that is based on management by conditions concept. Intelligent intermediary represents a new concept for multiple logistics parties. Targeting effective interaction between services providers and consumers it meets the challenge to find a balance of service cost accessible for all parties. To make this possible IISP should analyse possible opportunities and provide a list of options enforcing the autonomous actors to make own decisions.

In addition to the basic functionality of IISP (looking for the most beneficial options of integrated services based on matching the actors' requirements and available options in real time) there should be implemented a feature of forecasting. As soon as IISP is functioning in real time new orders and service opportunities form a continuous event flow. While looking for the best services combination for a certain customer's request the system should understand whether there is a chance to find a considerably better option due to a new service opportunity appearing or there is no need to waste time.

The same decisions are made by customers. Usually after an order is submitted the customer is willing to wait for a certain period of time, even if a satisfactory option is found. After a certain period of waiting time the customer is ready to agree with the existing option, and it becomes important for him to understand if there is any chance to find a better opportunity in the near future.

So there is a strong request for IISP forecasting solution. In this paper we introduce an updated model of IISP, which was probated in practice with a description of decision making support based on a combination of network-based optimization and multi-agent technology implementation. On the basis of the analysis of IISP implementation in practice the solution was extended by intelligent forecasting feature based on Big Data analysis using interval cross correlation functions. This functionality allows considering a combination of human and time factors in the process of decision making support.

Let us introduce the multi-agent world, where customers issue a sequence of requests for related services combined into an integrated order demand, each submitted at the moment of time. The types of services are marked as s_j, where $j = 1..N_s$ – is a consecutive number of service.

For each logistics service, there can appear several options from different providers. Services can be provided one by one, or in a batch as a group of related services.

Each request for a related service can be described by a Boolean variable:

$$r_{i,j,l} = r_{i,j,l}(d_i, s_j, t_l) \in \{0, 1\}, \tag{2.1}$$

where $t_l, l = 1..N_r$ is s_j order submission time.

The fact of each service delivery is defined by:

$$v_{i,j,l,k} = v_{i,j,l,k}(r_{i,j,l}, g_k, c_{i,j,l,k}, \Delta t_{i,j,l,k}) \in \{0, 1\}, \tag{2.2}$$

where g_k represents the real provider of a service, $k = 1..N_g . c_{i,j,l,k}$ – costs of the service, $\Delta t_{i,j,l,k}$ – duration of the service being delivered.

In this model, we assume that multiple providers can fulfil one service, which is significant for a business with high competitiveness. The number of options $v_{i,j,l,k}$ generated for each demand is limited by the current service provider capabilities and their core competence.

The options $v_{i,j,l,k}$ are related to each other in resources: the same providers g_k can be used for different services allocation). For two service options $v_{i,j_1,l,k}, v_{i,j_2,l,k}, j_1 \neq j_2$ there are also defined the following relations:

- sequence $\phi(v_{i,j_1,l,k}, v_{i,j_2,l,k})$, one service requires for its start one or several preceding services to be completed, and
- combination $\psi(v_{i,j_1,l,k}, v_{i,j_2,l,k})$, the services are implemented simultaneously.

In such a way there is generated a network of services (see Fig. 2.3), combined by a network of options $v_{i,j,k}$ with transitions of sequence and relation to one demand or resource.

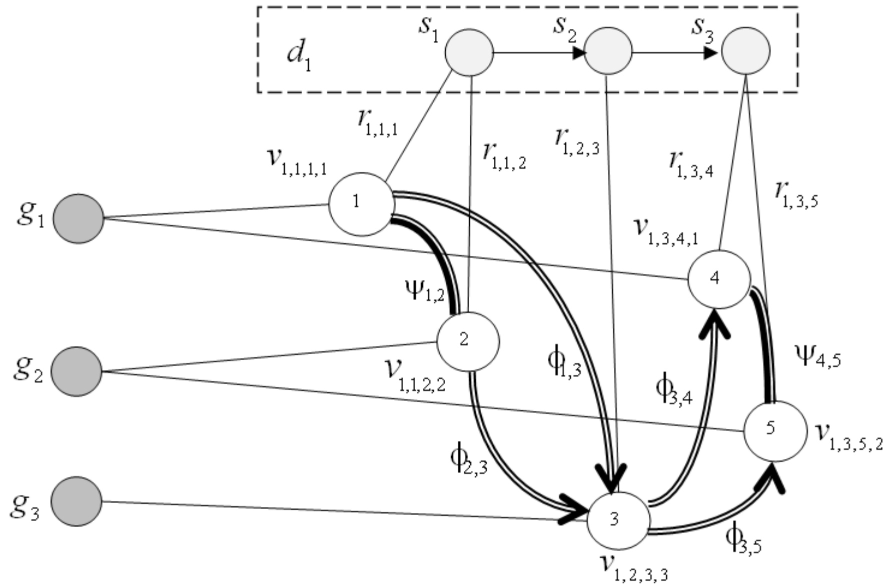

Fig. 2.3 Intermediary Service Provider network of services

The proposed model allows formalizing the following challenges of ISP. Firstly, it is necessary to minimize the services costs, which make the platform attractive for customers:

$$C(d_i) = \sum_{j=1}^{N_s} \sum_{l=1}^{N_e} \sum_{k=1}^{N_g} v_{i,j,l,k} \cdot c_{i,j,l,k} \rightarrow \min \ . \tag{2.3}$$

Next, the operational efficiency and performance of services should be high:

$$T(d_i) = \sum_{j=1}^{N_s} \sum_{l=1}^{N_e} \sum_{k=1}^{N_g} v_{i,j,l,k} \cdot \left(t_{i,l_{min}}^{fin} - t_{i,l_{min}} \right) \rightarrow \min \ , \tag{2.4}$$

where $t_{i,l_{\min}}^{fin}$ is d_i delivery time.

Finally, the individual earnings of each real service provider should also be high, which comes to a certain contradiction with goal (3):

$$\forall g_k : \sum_{i=1}^{N_d} \sum_{j=1}^{N_s} \sum_{l=1}^{N_e} v_{i,j,l,k} \cdot c_{i,j,l,k} \rightarrow \max \ \square \tag{2.5}$$

The solution of the introduced problem is specified as a set of non-zero values of Boolean variables

$$\mu(d_i) = \left\{ v_{i,j,l,k} \left(r_{i,j,l}, g_k, c_{i,j,l,k}, \Delta t_{i,j,l,k} \right) = 1 \right\} \tag{2.6}$$

that represent a service route with the cost $C(d_i)$.

There can be several service routes for one order demand, so the basic problem of ISP is to find and dynamically manage a number of service routes for incoming order demands considering the challenges (3 – 5).

Optimization logic is extended by multi-agent functionality (see Fig. 2.4). Agents are introduced to represent the customers and service providers in the integrated information space and can be triggered both for simulation of customers activity and for representing the real customers in the process of searching for the integrated services.

The architecture of multi-agent scene is quite simple: there are introduced three types of agents for Customers, Service providers and Services. Customers and Service providers can interact according to their objectives and constraints and establish the links of cooperation according to which the Services are transmitted.

The strategies of agents correspond to the goals (3 – 5). The Customer agent tries to reduce the time and costs of the integrated service, and the Service Provider agent tries to increase its utilization delivering as many services as possible. The process of search can be presented as a sequence of local contracts between the customers and service providers. It is proposed to make this process free, flexible and be based on the principles of self-organization.

The strength of this solution is in its ability to adapt to various changes in real time. Still the proposed optimization logic based on network search can be better in some cases as it allows the system to determine effectively the best option. Thus it is proposed to implement both solutions of decision making support and use network based optimization to look for the best combination of services and multi-agent approach for reacting to incoming events in real time.

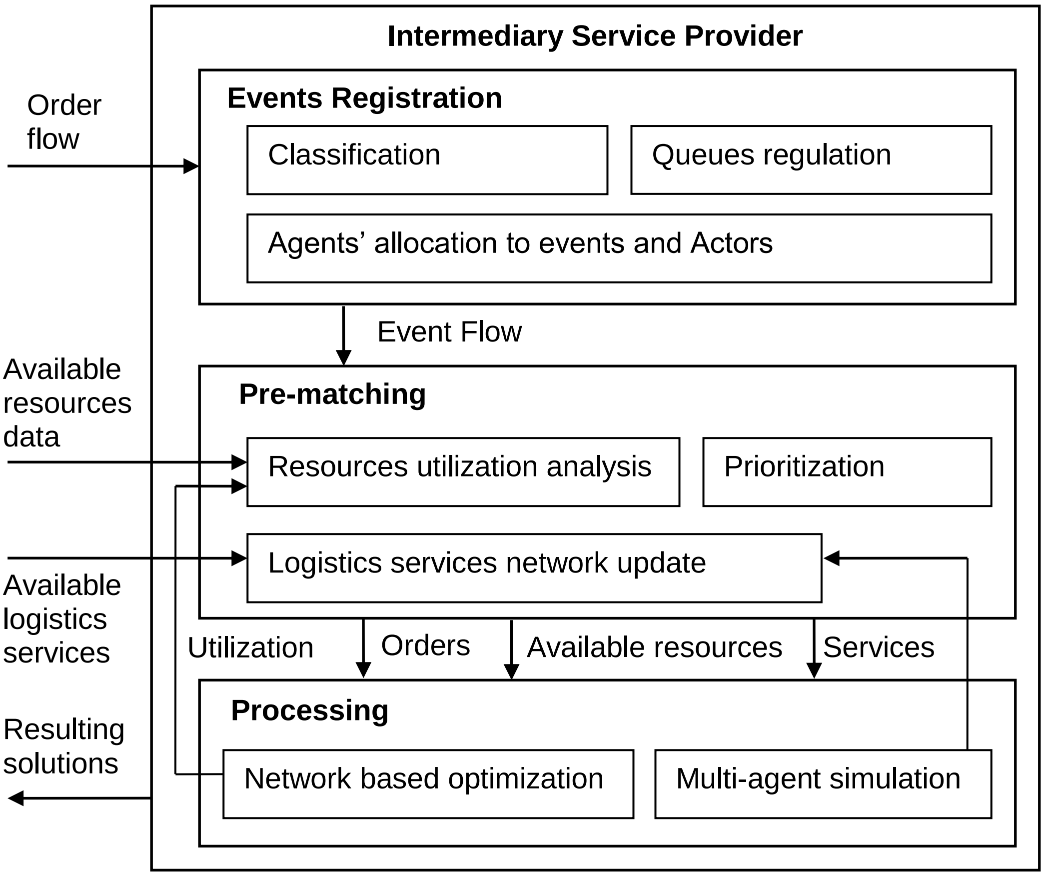

Fig. 2.4 IISP concept

Implementation of management by conditions is IISP, which gives effective opportunities for an improved decision making support. Primarily the following logic is introduced, which is supplementary to the general negotiating strategies:

- The agents of logistics parties - service providers look for the possibility of cooperation based on statistics of generalized customers' requests. The services that are usually requested together are declared as related services, and the providers start proposing them in a batch.
- The agents of customers use the strategy close to ant colony algorithm. While navigating the services network and looking for the most preferable options the customer agents mark transitions indicating the popularity of services. This helps the newcomers to find the most widespread option of the related services delivery.

Two strategies of networking to join the efforts of both customers and service providers force implementation of swarm intelligence that simulate the evolution processes typical for living organisms. Orders forecasting can be provided based on statistical analysis of the events captured by IISP during the corresponding period in the past. Analysis of the real data has been resulted in a conclusion that customers' activity is wave shaped with little jitter. E.g. in case one service was popular during the certain period of time it will probably be required next year during the same period of time, which can be slightly shifted in time.

2.2.3 Multiple Logistics Parties Intermediary Model

Let us consider a generalized business model where orders (or jobs) w_i are proceeded to actors u_j. Any actor can be assigned to perform any order, incurring some cost that may vary depending on the exact assignment. It is required to perform all the orders by assigning exactly one order to each actor in such a way that the total cost of the assignment is minimized. The centre is introduced as a solid dispatching agent that offers the orders to actors and ensures the effectiveness of the whole system.

The objective of the order agent is to be proceeded by any actor available on time (particular the KPIs can be formulated as "early average absorption"). The actor's objective is to receive the most corresponding orders with the highest relevance.

Let us set the following order lifecycle events, represented by Boolean variables:

$e*(w_i, t*_i) \in \{0, 1\}$ – appearance of w_i, $t*_i$ is the time of its appearance;

$e(w_i, u_j, t_{i,j}) \in \{0, 1\}$ – offer of w_i to u_j at time $t_{i,j}$;

$e'(w_i, u_j, t'_{i,j}) \in \{0, 1\}$ – assignment of w_i to u_j at time $t'_{i,j}$;

$e''(w_i, t''_i) \in \{0, 1\}$ – escape of w_i at time t''_i in case of order rejection.

These events describe the history of interaction in the integrated information space and form a study subject for various technologies of Big Data analysis.

The cost of order w_i execution by actor u_j is $c_{i,j}$.

It is determined by the actor and proposed to the centre. Let us assume that one actor cannot execute several orders at a time.

The allocation problem for this model can be represented as

$$\begin{aligned}&\sum_{i=1}^{N_w}\sum_{j=1}^{N_u} e'\left(w_i,u_j,t'_{i,j}\right)\cdot c_{i,j} \to \min,\\ &\sum_{j=1}^{N_u} e'\left(w_i,u_j,t'_{i,j}\right)=1, \quad i=1..N_w,\end{aligned} \qquad (2.7)$$

$$\sum_{i=1}^{N_w}\sum_{j=1}^{N_u} e*\left(w_i,t*_i\right)\cdot e'\left(w_i,u_j,t'_{i,j}\right)\cdot\left(t'_{i,j}-t*_i\right)\to \min \; , \qquad (2.8)$$

where N_w is the total number of orders and N_u is the total number of actors.
For the order flow $e*\left(w_i,t*_i\right)$ there should be developed a strategy (schedule of offers) $e\left(w_i,u_j,t_{i,j}\right)$ for a set of u_j that will reach (1) and (2).
From the other side, each actor considering the order flow $e\left(w_i,u_j,t_{i,j}\right)$ should decide on the strategy $e'\left(w_i,u_j,t_{i,j}\right)$ that comes out at

$$\forall u_j : \sum_{i=1}^{N_w}\sum_{k=1}^{N_u} e\left(w_i,u_j,t_{i,j}\right)\cdot e'\left(w_i,u_j,t'_{i,j}\right)\cdot\left(1-e'\left(w_i,u_k,t'_{i,k}\right)\right)\cdot c_{i,j}\to \max \; . \qquad (2.9)$$

In case the actor starts execution as soon as the order is allocated the following limitation is valid:

$$\begin{aligned}&\forall u_j : \sum_{i=1}^{N_w}\sum_{l=1}^{N_w} e'\left(w_i,u_j,t'_{i,j}\right)\cdot e'\left(w_l,u_j,t'_{l,j}\right)\cdot\\ &\left(1-\theta\left(t'_{l,j}-t'_{i,j}\right)\cdot\theta\left(t'_{i,j}+\Delta t_{i,j}-t'_{l,j}\right)\right)=0 \; ,\end{aligned} \qquad (2.10)$$

where $\theta(x)$ – Heavyside step function [12]: $\theta(x)=\begin{cases}0, x<0\\ 1, x\geq 0\end{cases}$.

The statement (1 – 3) is introduced as a problem of “proactive allocation”. Its direct solution is not possible as soon as the number and availability time frames of resources and orders changes with time. To prove it there can be specified the following logic. Firstly, the statement (3), being summarized by u_j, results in a contradiction with (1). Secondly, to solve (1) one needs to fix the number of events considered, but at any moment of time $t*$ there is no information about the events $e*\left(w_i,t*_i\right): t*_i > t*$, and there cannot be proposed any substantial approach on how to pick-out the orders w_i accepted by the platform for scheduling in real time. The solution of (1 – 3) problem is formalized as a schedule of allocation events $S(t*)=\left\{e'\left(w_i,u_j,t'_{i,j}\right), t'_{i,j} > t*\right\}$ that is generated at the moment of time moment of time $t*$ as a response to incoming order flow. The size of this set is an indicator of 6PL quality. In order to increase it the system should motivate the actors to give more determinacy and confidence in $e*\left(w_i,t*_i\right)$. To solve this problem there can be proposed a rule of rhythmical assignment: there is developed a schedule of assignment events that form time frames for contract agreements.

So the following challenges can be specified for a 6PL provider:

- attract customers and executors in order to increase the number of options for each order allocation;
- enforce interaction conditions to support competition and cooperation between the users of 6PL platform, which is beneficial for them;
- capture and reuse permanent allocations in a form of contract agreements that formalize stable and dynamic relations between the contractors;
- develop long term schedules based on rhythmical assignment.

2.3 IISP IMPLEMENTATION FOR 5PL AND 6PL

2.3.1. Solution Vision

Functioning of 5PL provider is totally based on IT infrastructure and contains a number of interrelated business processes for supply chain members, which proves the advantages of IISP application in this area. By analogy with 5PL provider there is proposed to implement a new concept for 6 Party Logistics (6PL) based on IISP concept. On the level of 6PL there are formed the conditions of logistics supply chain members interaction in integrated information space. These conditions are being expressed in the form of contract agreements that reflect the cases of permanent cooperation between the actors. In contrast to 5PL provider that does not change the conditions of interaction and makes no limitation of actors' decision making, 6PL provider can develop new contract agreements that determine long-term cooperation or competition between the actors. There is provided a list of components of software that implements a concept of 6PL provider. 6PL provider software platform can be introduced as part of logistics supply chain resources management systems, manufacturing scheduling systems, Web portals, enterprise resources planning systems, business processes simulation and modelling and decision making support.

Fig. 2.5 illustrates the suggested solution. 5PL provider, being based on the software platform for realizing the interaction of the participants of logistics supply chain in the integrated information space, forms the variants of executing orders and offers them to actors. 5PL provider realizes information management. The offers are formed on the basis of analysing the current situation, thus, the operative management of actors' interaction is provided.

In contrast to the 5PL provider logic that does not change the conditions of interaction and does not limit decision making by the actors, 6PL provider can form new contract relations that define the long-term cooperation and competition among the actors. 6PL provider is also based on the software that realizes system management of interaction based on the analysis of interaction statistics. Time series analysis methods were used as the basic algorithms of statistical analysis.

On the level of 6PL there are formed the conditions of logistics supply chain members interaction in integrated information space that are being expressed in the form of contract agreements that reflect the cases of permanent cooperation between the actors. 6PL provider software platform can be introduced as a part of logistics supply chain resources management systems, manufacturing scheduling systems, Web portals, enterprise resources planning systems, business processes simulation and modelling and decision making support.

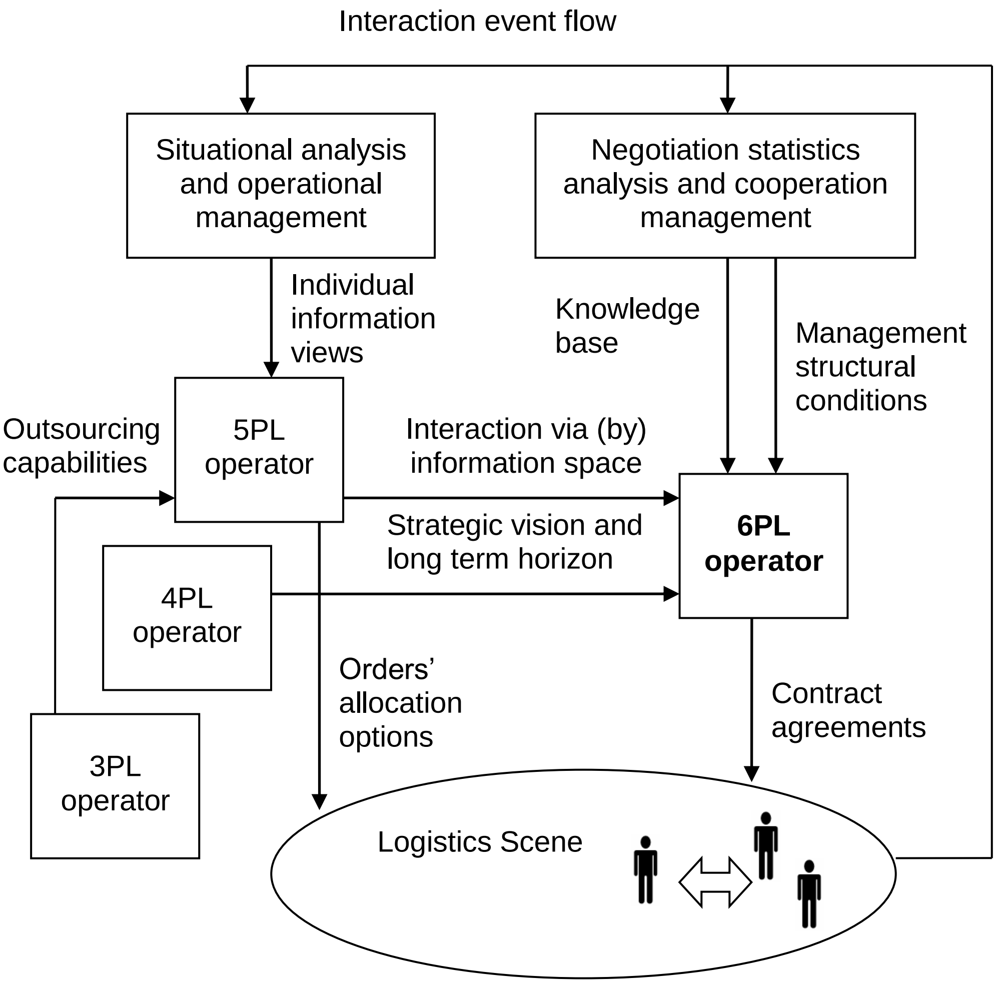

Fig. 2.5 5PL and 6PL providers operating based on IISP

6PL intermediary provider, being based on the software platform for realizing the interaction of the participants of logistics supply chain in the integrated information space, forms the options of executing orders and offers them to actors. In contrast to the 5PL provider logic that does not change the conditions of interaction and does not limit decision making by the actors, 6PL provider can generate new contract relations that define long-term cooperation and competition between the actors.

For example, let us consider the case of transportation logistics management based on 6PL services. Transportation logistics is one of the most important domains in industry that involves multiple logistics parties to optimize the transported cargo weight and volume and minimize costs. Cargo is usually being transported through a variety of transportation means and the number of allocation options is usually too high to be analysed using standard optimization techniques.

In transportation logistics there are usually specified two groups of agents representing demands and supplies and negotiating in order to find trade-offs. For example, there can be introduced the driver agents that strive to maximize utilization and the order agents that try to allocate at lower costs. For each group of agents there can be proposed a separate business process, which includes a number of states connected by the relations of precedence. The order can be input into the system, stay for a while in events queue, become scheduled to a certain resource, proceed to execution state after it starts and finalize being done or rejected in case of exception. Each driver iteratively repeats the states of being free or busy with order with some intermediate states of pick-ups, drops and idle moves. The generalized scheduling problem involves determination of a consistent combination of these states across the planning horizon in the near future.

Special aspects of IISP service make it necessary to consider these business processes from a different point of view. In case of drivers' flexibility to take a certain order or reject it there can be evaluated no consistent planning horizon – the time interval of resources availability and the list of orders to be done. The centre offers the orders to appropriate resources with no guaranty that they will be accepted for execution. That is why it should evaluate and analyse the probability of orders acceptance and allocation.

In transportation logistics much is determined by the network of geographical locations and roads. According to the pick-up point of a new order, the probability of its allocation is dependent upon the density of executors in the near area. Consequently, the higher is the number of resources free from loading and waiting for new orders at a certain location, the higher is the probability of orders being allocated at this point.

Still we should consider two constraints:

- actors waiting too long would escape (as soon as the platform is open for entry and exit);
- drivers would congregate at locations with the highest density of orders (this is valid for taxi business: e.g. taxi drivers are attracted to airports and tourist sights).

Both factors influence the service level and lower the force of attraction of 5PL and 6PL providers. To overcome this challenges the dispatching centre should attract the actors' interest and aggregate drivers at proper areas.

The way to solve this problem is to specify such an event flow of assignments that will reduce the variability of assignments in reaction to the irregular event flow of incoming orders with minimum waiting time. This is similar to providing line balancing in production project management. The schedule of assignments sets up the moments, before which the centre needs to determine the options and send the offers to the actors according to the priority of waiting time. Representation of the current transportation network for each actor can vary as soon as the centre provides limited information about the orders and the current situation.

2.3.2 Implementation Example

The described approach has a big potential for commercial use in modern scheduling software, intelligent systems for decision making support, simulating software, situational centres and other IT solutions being available on the Internet for logistics companies. First results can be illustrated by multi-agent software developed for transportation logistics scheduling and allocation management.

The example is given at Fig. 2.6. The order 5 (that came later than others) is reduced from the view of Actor 1. Besides the set of orders 2, 3, and 4 are hidden from Actor 2. As a result both actors are interested in order 1. It should be mentioned that the hidden data will appear for the actors with time, so in any case they retain an option to wait till the situation changes.

In the Fig. 2.6 Actors 1 and 2 get independent description of the current scene in the form of an overlay network. This network is generated by the system by transformation of the actual situation citation based on multi-agent allocation at 5PL level considering priorities formed at 6PL level on the basis of long term contract agreements.

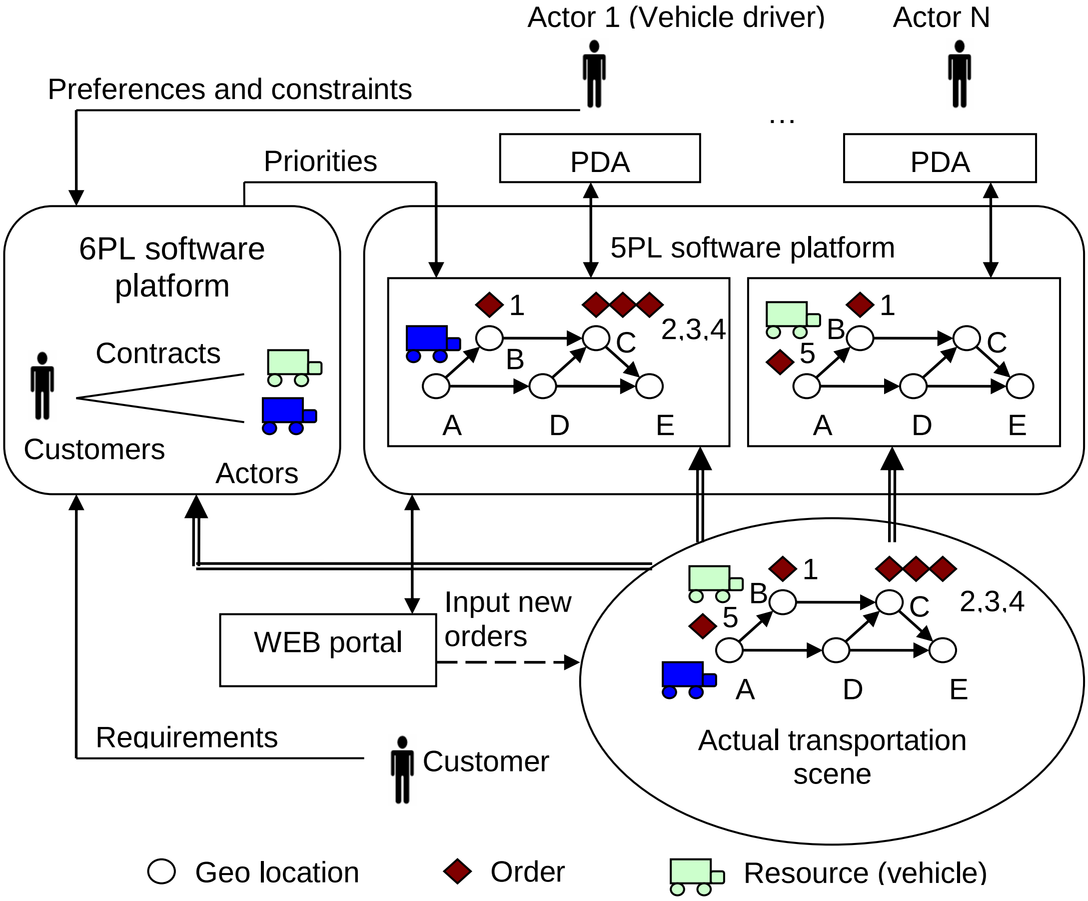

Fig. 2.6 5PL and 6PL providers implementation example

Implementation of the introduced solution allows solving the stated problem by giving the orders and actors an opportunity to look for each other. The system helps them to find the best combination of services, but the final decisions are made by the users themselves. Such an approach provides self-organization and therefore corresponds to the ideas of subject-oriented management.

According to the current situation characterized by a number of orders and actors available, the actors will choose the following types of interaction peculiar to self-organized communities:

- competition, e.g. a contest between the actors to get the order from the preferable provider earlier;
- cooperation, e.g. collaboration between the actors to increase the number of contract agreements.

To meet this requirements 6PL operator should encourage either competition or cooperation between the actors according to the current situation. Competition can be organized in the form of auctions. Auction is a public sale of a lot representing an order according to the rules predefined by the platform. The exact form of an auction can be different and depends on the features of exact logistics industry.

Practical use the described ideas can be also illustrated by Maxoptra Web based solution, developed by Magenta Technology Inc. (see Fig. 2.7) that functions on a Software as a Service (SaaS) basis and is available from any PC with Internet access.

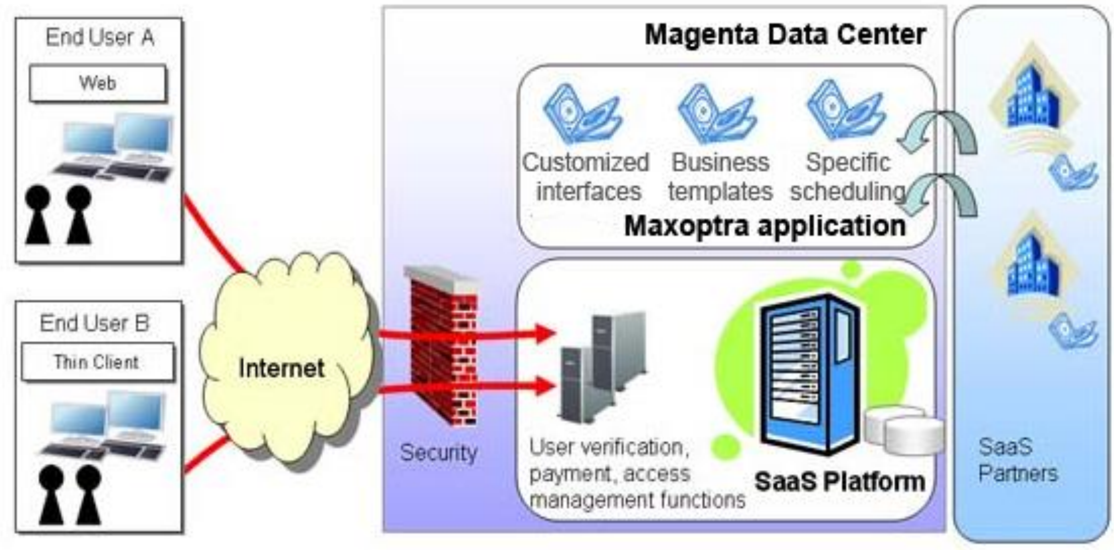

Fig. 2.7 Maxoptra logical architecture

Maxoptra functionality includes:

- order entry: manual order file upload and integration with an existing order management solution;
- manual or automatic jobs scheduling;
- orders allocation to vehicles and optimal vehicle route creation;
- dynamic and batch scheduling support;
- adjustable scheduling objectives: cost reduction, mileage reduction, optimized own resource utilization, etc.;
- manual plan adjustment by means of a ‘drag and drop’ mechanism;
- vehicle capacity planning;
- visualization of: delivery routes on the map, real time mileage and cost KPIs;
- workflow management, printed manifests and management reports;
- planned vs. actual analysis of: vehicle locations, delivery times, followed routes;
- proof of delivery signature captured and password protected administration.

Available resources (including drivers and vehicles) and customer data are captured in a knowledge base (ontology). It is very important to capture statistics and link it to the knowledge about orders and resources (e.g. certain VIP clients prefer to take specific drivers, some drivers prefer certain locations or are not allowed to visit specific locations, etc.) This can be used in order to introduce special client management and pricing schemes and enrich the agents’ decision making logic.

One of the features is that the drivers are included into the scheduling process not only as providers of actual data, but also as decision makers. When several orders can be scheduled to one driver these can be sent to his handheld device. So that the driver can make a choice between several orders or consolidate them if it is possible. As soon as the same proposals can be sent to different drivers the system can initiate a competitive process of orders assignment (auctioning). In addition to this, the data flow generated for each driver forms a virtual overlay network for him. The number and sequence of orders sent to drivers can be used for manipulation. In such conditions drivers are free to make their own decisions to some extent, but, nevertheless, stay under the dispatcher’s control.

As the result the Maxoptra solution provides:

- advanced booking facilities for customers to enable a quick, streamlined booking process including return bookings;
- automatic real-time dynamic scheduling of orders to ensure effective and cost efficient transportation operations through the following: notification of optimum booking preferences at the time of booking; real time tracking of vehicles' location; fleet optimization based on a variety of criteria to minimize empty mileage and maximize vehicle capacity utilization, reduce operational costs, and meet agreed customer service levels;
- a secure yet easy way to access and manage data through the web, available for vehicle suppliers (to access vehicle details and data on resource availability).

2.4 CONCLUSION

The new concept of management by conditions and its implementation in Intelligent Intermediary Service Provider is based on new and challenging principles of logistics management using data flows to provide flexible and adaptive behaviour of autonomous actors. This solution is potentially promising for logistics parties' interaction organization and management. Its practical use can be illustrated by 5PL and 6PL providers implemented using multi-agent technologies. However the presented approach is not limited to transportation logistics and can be advantageous to solve various problems of next generation logistics.

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Chapter 3

Business Process Management in Logistics in Czech Companies

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Abstract

This chapter has two dominant orientations. First of them is using the principles of Business Process Management in the processes of Czech industrial companies, especially in logistics processes of this companies. Solving the issue of process management in this chapter was created from the original results of the quantitative research evaluating aspects of process management in context of company strategies in Czech enterprises which was carried out in 2006 with regard to the extension of its further utilization. Followed by the interest of the professionals in practice the research continued and was re-implemented in 2012, with the interviews completed in 2013. My main goal was to assess how the use of process management components has changed, as well as the aspects of process management, i.e. comprehensive views and statements on the issues of the management of business processes, namely goals, factors, components, support and benefits of the process management in the Czech Republic especially in the context of logistics. Second orientation of my chapter is to the Logistics in the context of Industrial engineering.

Keywords: Business Process Management, Logistics, Czech Companies, Quantitative Research, Pillars of Business Process Management

3.1 TRADITIONAL – FUNCTION MANAGEMENT

Traditional – functional management model is based on a hierarchical decomposition of the organizational structure. Its final result is the division of the enterprise on individual departments and sections up to the individual functional sites. This means that each department has largely separated agenda, power and responsibility. Concept of functional management mainly solves the question of division of labour in the enterprise and also worker's specialization and their competences.

The function itself is a sub-activity without any additional context (Mašín & Vytlačil, 2000). In other words, these are task-oriented or skill-oriented groups through which our activities are organized, e.g. production, finance, sales and distribution (Hodgson, 1995).

Function or even functional management (from now on both terms will be used in this context as synonyms) is typically presented by organizational scheme. This scheme expresses hierarchical links between staff and organizational units. Common complaints of functional management are mostly defined by unclear boundaries of powers and responsibilities among the various departments, especially in the situation where the real process runs through multiple departments.

The functional approach often leads to the ambiguous assignment of competences with regard to responsibility for the outcome of the process as a whole, because it does not perceive the process as a whole. The process as a whole often runs across all functional organizational structure. Where the process runs over the various departments of the company, this situation may cause problems in the transfer of results between individual activities. The purpose of the process approach (Šimonová, 2009) is to uncover the processes that are often covered by "non-functional" functional organizational structure, to clean them from activities that do not add value for the customer and bring them into focus.

3.1.1 Business Process Management - Definition

Business Process Management (BPM) is becoming a hot topic for the scientific community solving a variety of research in the field of BPM as well as for the business sector constantly dealing with problems resulting from dynamic changes in the market. A process approach, which is the basis of BPM, is often referred to as a philosophy that is the cornerstone of the work organization in the company and the foundation of all business operations and activities (Šmída, 2007). The process approach allows organizations to eliminate the biggest disadvantages of a traditional functional approach that cannot be considered as an approach appropriately flexible for changes in the corporate environment, variety of procedures, or excessive substitution of workers.

Process management by Šmída (2007) represents: “systems, procedures, methods and tools of permanent ensuring of maximal performance and continuous improvement of business and inter – business processes that are based on a clearly defined strategy of the organization. Its goal is than to meet determined strategic goals.” This author understands the term process approach as the basis for the organization of work, namely as a basis of all business activities in the company. It indicates a process approach as an approach that responds to changes in a corporate environment and simultaneously flexibly responds to customer’s requirements.

Process management can be defined as a methodology for evaluation, analysis and improvement of key business processes based on the needs and desires of customers (Tuček & Zámečník, 2007). In any case, BPM is a step forward in terms of dynamics typical for today’s business world. The process is based not only on “what” but also on “how” (Basl et al., 2002). In many discussions there arises a question whether management is an art or a science. On this topic, it is possible for BPM to state that it is the art and science about how we do things and how we can do things even better (Lehmann, 2012).

Afterwards process management as a managerial approach leads to:

- integration of fragmented activities into value-chained processes;
- reduction of unnecessary activities, duplications, approvals, waiting, etc.;
- unambiguous focus on the customer process;
- harmonization of processes and strategies of the company;
- collaboration across individual departments of institution (companies, plants, workshops or individual workplace) due to process teams.

For better understanding of what allows a process approach, Závadský emphasizes these following factors (Šatanová et al., 2014):

- focus on objectives and outputs of the process regardless of the boundaries in the form of crossing of various departments created according to the functions of the company;
- define internal market suppliers and customers (in many companies based on service-oriented architecture, the basis is internal service contracts between process owners);
- identify critical areas of value creation for customers faster than in the case of hierarchical functional structures;
- optimize the cost structure to the calculation unit;
- faster achievement of innovations of business processes by sequence of activities and their properties (attributes);
- identify the relationship between the strategic goals of the enterprise, business processes and performance of sources allocated to the given activities.

The strategy is directly connected to the other definitions, this time defined by authors Jeston & Nelis (2008) who characterize process management as the achievement of strategic goals of organization through improvement, management and control of key business processes.

Řezáč (2009) explains that process approach focuses on the identification of the causes of bad results of processes both inside and outside of the company with the emphasis on change. The aim of this change is to eliminate processes with no added value or to increase the process efficiency that adds value to the customer. In terms of process approach, it is not primary essential to reduce costs or number of employees, but mainly to increase added value to the customer. Many other authors agree with this statement, too (Carda & Kunstová, 2001). They claim that process approach is based on the assertion that the cause of poor economic results resides in inefficient ongoing processes in the company.

In the collective monograph, Závadský (Šatanová et al., 2014) defines process management *„as the systematic identification, visualization, measurement, evaluation and continuous improvement of business processes using the methods and principles that are based on process approach”.*

The objective of business process management can be defined (Lewellyn & Armistead, 2000) as the development and optimization running of the organization to ensure effective, efficient and economical reaction to customer requirements. A process-driven company is focused on the outcome of its activities, or the added value for the customer who paid for them. Such company is more flexible and able to respond more quickly to market changes and customer preferences.

BPM principles are applicable in the other areas, e.g., in.:

- the quaternary sector (Tučková, 2012);
- some energy efficiency models for the mini-load AS/RS, for the support of the design process of warehouses (Lerher et al., 2010; Lerher et al., 2013);
- logistics processes (Trebuňa et al., 2013);
- services such as health care systems (Tučková et al., 2012);
- management controlling system of companies (Zámečník, 2014).

Regarding the process measurement performance, some authors, such as Rajnoha & Chromjaková (2009) or Popesko (2010) recommend implementation of Activity-Based-Costing (ABC) method in the enterprise. In the context of cost for the business processes, some of companies notices the causes of the cost remanence but it is not them able to predict. Managers should not forget that in a situation where company will be able to assign costs to a specific activity, and in practice it often happens that the analysis of the activity ceases to be necessary, because it is given little attention, and the company loses the opportunity to rigorously control costs (Novák & Popesko, 2014).

Additionally, implementation of calculation based on processes and activities causes also non-quantified effects such as:

- transparency and rationalisation of performed activities and processes,
- more responsible proceeding of enterprise work,
- identification of enterprise's competitive advantages or disadvantages,
- information support for strategic management and goal oriented management,
- assignment of overhead costs to performance on case-by-case basis,
- support of price policy and production-sales program optimization (Rajnoha & Chromjaková, 2009; Popesko & Novák, 2011).

First of all, in this chapter we would like to evaluate the reasons which lead enterprises to exploit elements of process management in their working practices. The aim of Process Management is to develop and to optimise the daily running of an enterprise in a way which defines these work-related procedures (i.e., processes) as a unified flow or cascade of activities throughout the enterprise, where for each and every process its inputs are clearly defined as are the outputs or results, and where the associated responsibilities and personal responsibilities are assigned for each and every process or activity, while establishing a system for the measurement of the performance of these processes and tracking and evaluating each and every process (Vyskočil, 2010).

These activities must be realised (i.e., implemented) such that:

- the quality of production will be maintained through given measurement parameters;
- all available resources shall be optimally exploited;
- all of the performance indices of the enterprise have been improved continuously throughout in line with previously agreed and known and measurable criteria (Vukovič & Sikošek, 2005).

The market forces of today's business processes development have begun to place an important emphasis on business process quality. Evidently, the quality of a business process model highly influences the deployed business process. This motivated several researchers to propose metrics to evaluate the quality of business process model.

In fact, the concept of quality metrics was initially introduced to examine software quality. According to (Cardoso et al., 2006) a quality metric is a quantitative scale and a method that can be used to determine the value taken by a characteristic of a software product. Exploiting the maturity of software quality metrics, several researchers adapted several metrics from the field of software engineering for business process models (Gruhn & Laue, 2007); (Khlif et al., 2010).

This however means that there is a need to describe just what distinguishes or characterises a process, which is a so-called "management process". This means that such a process has:

- a defined, ranked set of steps to be taken and appropriate responsibilities allocated;
- a set of measurable parameters derived from customer demands or requirements, or internal standards – "owners" of the process/es;
- a permanent process team who meet regularly with the aim of seeking improvements to the process/es;
- an annual plan which contains the requisite outputs/outcomes/results for each and every key process, as well as appropriate budgets and demands on resources;
- a mechanism for the regular and interim controls of the process/es performance;
- procedures and resources (i.e. the process team) for the resolution of problems associated with the process/es (Vukovič & Sikošek, 2005).

3.1.2 Short History of Business Process Management

We should begin with the principles. Managers are often confronted, even in renowned magazines, with several similar terms and concepts which may be confusing or at least their correct content and principles may be misinterpreted on the basis of inaccurate information. What do the terms Business Process Management (BPM) and Business Process Reengineering (BPR) mean? What is their application in practice? In this subheading we would like to acquaint you briefly but precisely with these terms and their content.

From the point-of-view of management and Business Process Management development, authors such as King, Fingar, Smith etc. have offered various conceptions in order to comprehend the connections and differences between them. King, for instance, has distinguished between four development waves BPM (Smith & Fingar, 2003).

He has mentioned the following in his publications:

- The first wave of BPM – was concentrated on constant improving of the processes and coincides in many ways with the philosophy of TQM (Total Quality Management), a philosophy which leads to an increase in productivity, a simultaneous increase in quality and increased customer satisfaction while decreasing losses caused by poor quality production. TQM is thus a systematic and consistent application of several methods within the company organization clearly concentrated on quality and customer satisfaction.
- The second wave of BPM - consisted of a focus on Business Process Reengineering, or in short Reengineering. This is regarded as the second wave involving the trend of management leading towards essential, radical and fundamental changes in the organization of applied work procedures or technologies. The achievement of not merely incremental but has a radical rise in organization productivity as the expected result.
- The third wave of BPM – the authors Smith & Fingar (2003) refer to activities leading to the creation of a process focused organization. This involves the application of main component procedures or process management consisting of the following:

- key process determination including the appointing of process possessors and customers;
- within the process description, their mapping and process map formation (a company process model) for recording process system management;
- the application of process maps (models) for cost intensity evaluation and increases in their efficiency;
- continual process improvement and measuring of efficiency;
- quality in the enterprise is mainly understood as the demand for quality standards which lead off the process model;
- information technologies considered as the process support in the enterprise;
- while the process model creates the basis of the process management, the strategy management is comprehended as the peak of the “pyramid” of process management;
- competence management is comprehended as the system enabling fulfilment of roles in individual processes (both management and key processes) by those people who have appropriate knowledge and abilities for them (Woolliscroft et al., 2013).

3.2 OBJECTIVES AND HYPOTHESIS FORMULATION

But in this chapter I cannot describe whole research areas. That is the reason why, I focus only on the utilization level of business process management and its individual components in Czech companies with focus on objectives that managers wish to achieve by BPM implementation and factors that are combined with a process-oriented company. Seven goals of this research were define in accordance with the research in 2006 so that it would be possible to realize the comparison in time in different application areas of process management as following:

- C 0. To propose a methodology for processing and evaluation of quantitative survey that is applicable to analysis of the process management usage in the companies.
- C 1. On the selected basic set, examine to which extent Czech companies use process management.
- C 2. Clarify the objectives and procedures that are important for Czech companies when using process management components.
- C 3. Specify the view on the usage of process management components in Czech companies by comparing of the levels of components usage and principles of corporate process management in various sectors along with the size and with the focus mainly on manufacturing companies.
- C 4. Evaluate which process segmentation is preferred by the company (i.e. for example segmentation according to ISO 900X, BSC, Porter or others) and to highlight the process areas in which the rated companies hides their imperfections.
- C 5. Determine to what extent respondents use software for supporting of process management.
- C 6. Evaluate concrete benefits and barriers that are present in the companies while using process management. Compare each sector, i.e. variously sized enterprises (see C 2).
- C 7. Analyse changes in individual process management areas (support of human capital, factors, components etc.) between the years 2006 and 2013.

Thanks to the goal no. 3 it was possible to specify the influence on logistic processes in production companies, too.

3.3 METHODOLOGY OF DATA COLLECTION AND SUBSEQUENT EVALUATION

We conducted extensive research aimed at the utilization level of business process management in Czech manufacturing companies in 2006 and in 2012/2013. The research was focused on several aspects of business process management. In this research, aspects of BPM are understood with the meaning of manager’s views and opinions on management of business processes (Business Process Management). The research specialized in the area of goals, factors, components, support, benefits of and barriers to process management. The authors explored the extent to which Czech manufacturing companies use business process management. We focused on the logistics processes too. The utilization level of BPM in Czech companies was determined by self-assessment of managers and according to the actual utilization of BPM components. The research has also clarified the goals and procedures that are important for Czech companies in the use of BPM components and found the extent to which the addressed companies use a software support of process management. Last but not least, the research also focused on identifying the benefits that the company achieved by BPM implementation and also on identifying barriers which the Czech companies faced in the BPM implementation. The results of the research, particularly the first part intent on the objectives and factors of BPM support, are the subject of this article. Part of the chapter consists also in comparison of the results of previous research conducted in 2006 (Suhendra & Oswari, 2011) and the current research. The comparison of these findings allows identifying trends of business process management in Czech companies for the past 6 years.

The quantitative research was conducted through a questionnaire survey (Annex A). The sample included manufacturing companies that have more than 5 employees and their turnover was higher than 0 in 2012/13. A limit (5) on the minimum number of employees was determined based on the experience of previous survey implementation, which showed that small businesses do not use business process management or any of its components. A sample of size of 300 firms was chosen at random. Return of questionnaires was 144 (Table 3.1), it is 48%. To minimize the risk of acquiring an insufficient number of completed questionnaires, at first, the authors addressed key employees of selected companies by phone and then the questionnaire was sent. When processing questionnaire results, all 144 companies were included (Table 3.1).

Table 3.1 Distribution of respondents by number of employees. Source: own research based on Grasseová et al. (2008)

Characteristics of a company		Number of evaluated companies	
	Number of employees	Absolute frequency	Relative frequency
Micro companies	1 – 19	36	25%
Small companies	20 – 49	20	13.89%
Medium-sized companies	50 – 250	43	29.86%
Large companies	250 and more	45	31.25%
TOTAL		144	100%

The aim of this research was to explore attitudes, opinions and judgments of managers of Czech companies to individual aspects of business process management. A scaling method based on the principle of quantifying qualitative data was used in this research. The reason for this usage is that manager's responses involve subjective statements, which must be subsequently converted using a verbally, numerically or graphically expressed scale. Specifically the Likert scale method was used. Likert scales are used to indicate the degree (level) of agreement or disagreement with the specified statements, on which it is subsequently possible to deduce the attitudes and opinions of respondents (Stříž et al., 2006). Respondents expressed their agreement or disagreement with the given statements using a 5-point scale, where 1 expresses absolute disagreement and, conversely, 5 represents absolute agreement with the relevant statement. These values were subsequently converted to values 0-100% or 0-1, where 0 represents absolute disagreement of respondents and 1 stands for absolute agreement. The calculated values of confidence intervals are quantified directly in charts.

In order to organize and arrange the findings obtained using a questionnaire survey and prepare data for statistical evaluation, Excel software was used. The actual statistical evaluation was carried out using JMP 10.

Within this research (in 2013) we chose a more comprehensive evaluation of reliability and validity of the entire survey. The descriptive statistics was an appropriate beginning for our survey interpretation. As a part of the description, relative representation in the responses was detected and the basic characteristics of location and variability were identified. Median was chosen as an ordinal mean value ($\tilde{x}$) and discrete ordinal variance (*dorvar*) was used as the characteristic of variability. Calculation of both variables was implemented according to Řezanková et al. (© 2014).

At ordinal variable, median category (*Me*) belongs to measures of position. It is the category for which the cumulative frequency (*P*) is 0.5 or higher, while for the previous category the cumulative frequency was less than 0.5. This means that $P_{Me-1} < 0.5$ and $P_{Me} \geq 0.5$. Furthermore, the median $\tilde{x}$ can be calculated, more specifically, according to the formula:

$$\tilde{x} = Me - 0.5 + \frac{0.5 - P_{Me-1}}{P_{Me}} \qquad (3.1)$$

For variability rate of the basic set, we may use (Řezanková et al., © 2014) so called *dorvar* ordinal scattering (discrete ordinal variance), determined by the formula:

$$dorvar = 2\sum_{i=1}^{K} P_i(1 - P_i) \qquad (3.2)$$

This rate expresses the exact difference of all pairs. While rewriting the interval from 0 to 1, we will get normalized *norm. dorvar* ordinal scattering for which the following formula is applied:

$$norm.dorvar = 2 \cdot \frac{dorvar}{(K-1)}; norm.dorvar\ \hat{I} < 0; 1 > \qquad (3.3)$$

Moreover, we calculated another typical characteristics, a mode (modus), as the most frequent value. Such calculated characteristic can be further commented and taken as a "classical" mean value, more specifically, as the median and the variability, i.e. scattering.

Median determines the location of the centre of all answers whereas this ordinal version of median does not simply come from an ordered set of values but it calculates centre based on the ratio/significance for each category (according to formula specified in the link above). Values "Dorvar" are defined as the differences between all pairs (again across evaluative representation for each category) and it may be taken as a scattering, too. Higher value of dorvar means more diverse representation of answers and lower value represents the same opinion only with minor deviations from the centre.

Cluster analysis

Cluster analysis will be used for evaluation of selected answers in its typical graphical image – dendrogram. This method is at the borderline between descriptive and multidimensional inductive statistics (Klímek, 2008).

3.4 RESEARCH RESULTS

3.4.1 Who supports the use of techniques and tools of Business Process Management?

One of the objectives of this research was (within the question 3 in questionnaire) to investigate who supports the usage of techniques and tools of process management from the point of view of human factors – this is interconnected with the question what implementation processes do businesses chose while implementing process management. Subsequently this is related to the fact that either they want to save more and implement changes only after training or with "seemingly more expensive" but often more effective support of consultants.

The following question was aimed at finding out how companies implement various tools and techniques of process management. The purpose was to determine the extent to which businesses use during the BPM implementation and BPM components their own employees, BPM training courses and consulting companies. In the case of using consulting companies, managers were asked about the area for which the consulting company services were used. Managers, who had answered in the first question that process management is an unknown term to them, did not respond to this question, i.e., the question was answered by only 75% of respondents. Respondents had an option of multiple choice answers. The results therefore cannot infer the exact number of businesses using the various interest groups.

Summary results of this question in 2006 are displayed in the following figure (Fig. 3.1) and table (Table 3.2), from which it is clear that companies implementing BPM tools and techniques use mainly the experience of own employees and knowledge gained in BPM training courses (almost 85% of all responses). Only 15% of responses concerned the possibility of using services of consulting companies. Only 8 of the 22 managers who confirmed the use of external companies specified in greater detail the specialization of the consultancy used. Most often it was a consultancy focused on improving production processes, specifically, e.g.:

- problem-solving methodology;
- QMS;
- Poka-Yoke;
- logistics;
- improvement of production processes;
- SMED.

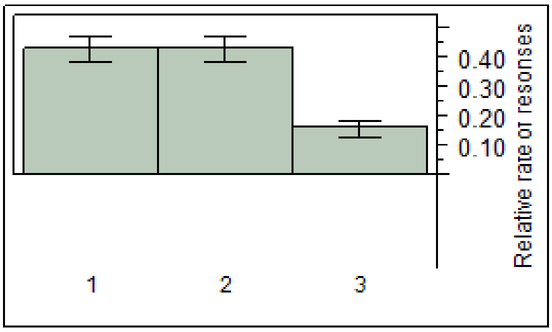


Fig. 3.1 Interest group (year 2006). Source: own research

Table 3.2 Legend to the previous graph with quantified confidence intervals (year 2006). Source: own research

Code	Interest group	Number	Proportion of answers	Lower interval	Upper interval
3A	Own employees only	61	42.36%	0.34592	0.505272
3B	BPM training courses	61	42.36%	0.34592	0.505272
3C	Consulting company	22	15.28%	0.103109	0.220491

Confidence intervals (for reliability estimation of 1 - α = 0.95), multiple answers.

The effect of company size on this question appears to be significant. However, it should be noted that the question was not answered by managers for which the BPM is an unknown term, i.e., managers of mostly micro and small enterprises. Since the use of consulting services can be very expensive, it is not surprising that these services are used almost exclusively by medium-sized and large enterprises. Even more surprising is the fact that micro enterprises make greater use of external consultants in comparison with BPM training courses.

Table 3.3 The effect of company size on the use of interest groups. Source: own research

Code	Interest group	Micro	Small	Medium-sized	Large	Total
3A	Own employees only	16.39%	14.75%	37.70%	31.15%	1
3B	BPM training courses	4.92%	11.48%	26.23%	57.38%	1
3C	Consulting company	9.09%	0.00%	45.45%	45.45%	1

In comparison with the results of the previous research, there has not been any significant change.

In 2013, a strong dependence was shown between two factors, namely between who supports the use of techniques and tools of process management and the sizes of enterprises (with respect to the value of p-value = 0.005 and value of GKgamma over 0.6 which suggests a relatively strong dependence – both of these are listed in Annex B). Contingent Table 3.3 in Annex C additionally illustrates that the categories of small businesses almost entirely rely on the experiences of own employees. On the other hand, large majority of huge companies rely on the services of consultants (consultancy companies operating in the company). In the case of industry itself, no dependence was proven.

In the category of large companies, the services of external consultants in 2013, similarly as in 2006, included the following areas:

- implementation of the requirements of ISO 9001 or ISO 14001, i.e. consultation in retaining the quality management system (Quality Management System – QMS), EFQM;
- continuous professional training relevant to the selected process areas (e.g. focusing on process teams or problem-solving methodology);
- however companies often focuses their interest primarily on process improvement from key and management groups, e.g. finance, manufacturing, sales, logistics, organizational structure and its optimization in relation to process oriented;
- similarly as in 2006, respondents mentioned external consultancy focused on quality management system;
- moreover there appeared also consulting based on economic, accounting, legal, and software basis, selected methods of industrial engineering (SMED, poka-yoke), furthermore consulting of design, development, production and sales, robotics, health and safety conditions, fire safety etc.

3.4.2 The main reasons for implementing BPM

Evaluation of question no. 6 contributes to better clarification of an opinion on how process management is perceived by managers. Simultaneously it illustrates the previous questions on what aims are monitored by managers by using process management. Generally, process management is perceived as a strategic change which affects the processes. As the most significant reasons for this change, in 2006 managers specified the most significant reasons for this change:

- high inefficiency of the process identified (at the level of 0.64);
- reorganization of the company requiring a different flow of the process (at the level of 0.60).

After the implementation of changes (processes) through process management, the managers considered these reasons as being moderately significant:

- lack of competitiveness of the company;
- change in IT support process;
- the need to provide a new product or service.

Fig. 3.1 also shows that acquisition factor or merge in the enterprise (asserted during the growth of the company or during acquisition of new companies, i.e. by merging with other company) proved as a little significant (at the level of 0.40). Other elements were reported by managers only marginally.

And how does this understanding changed after circa 7 years?

As it is evident from Table 3.4, three same reasons have been revealed in the top four list and these were with **the highest** importance:

- identification of high inefficiency of the process;
- reorganization of the company requiring a different process development;
- lack of competitiveness.

The first place according to importance went to a change of IT support process. It has the highest value of median factor and the lowest for dispersion: $\tilde{x} = 3.854$. As being seen, dispersion is still relatively high (*dorvar* = 1.204) and modus $\hat{x} = 4$ refers to the high importance of IT change for managers.

Table 3.4 The concept of process management (in 2013) – descriptive statistics. Source: own research

Answers option	X6.1 Inefficient business processes	X6.2 Reorganization of the company	X6.3 Insufficient competitiveness	X6.4 Change in IT support process	X6.5 Providing new service or product	X6.6 Acquisition or merge
Median	3.500	3.500	3.521	3.853	2.947	2.500
OR	1.290	1.380	1.411	1.271	1.204	1.396
NOR	0.645	0.690	0.706	0.635	0.602	0.698
Modus	4	4	4	4	3	1

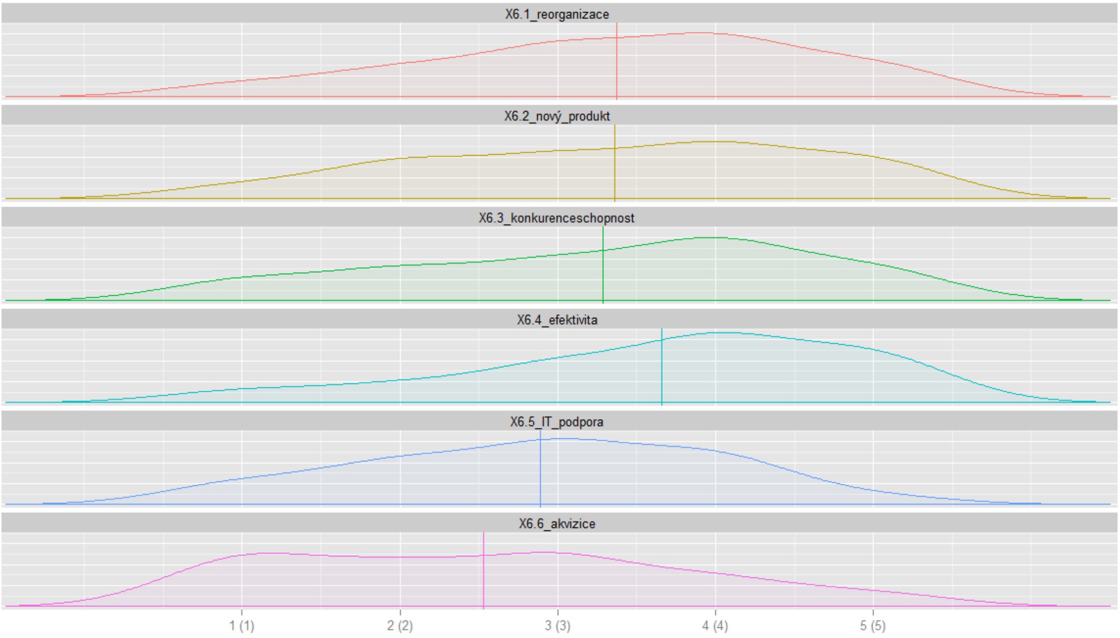


Fig. 3.2 The concept of process management (in 2013) – graphical representation. Source: own research

Due to the median and modus values given in Table 3.4 and due **to the density of responses** emerging **from graphical representation** (Fig. 3.2)**, it can be stated** that the process with high inefficiency is of a **slightly lower importance**. Acquisition or merge in the company (asserted during the growth of the company or during acquisition of new companies, i.e. by merging with other company) has emerged **as irrelevant, similarly as in year 2006**.

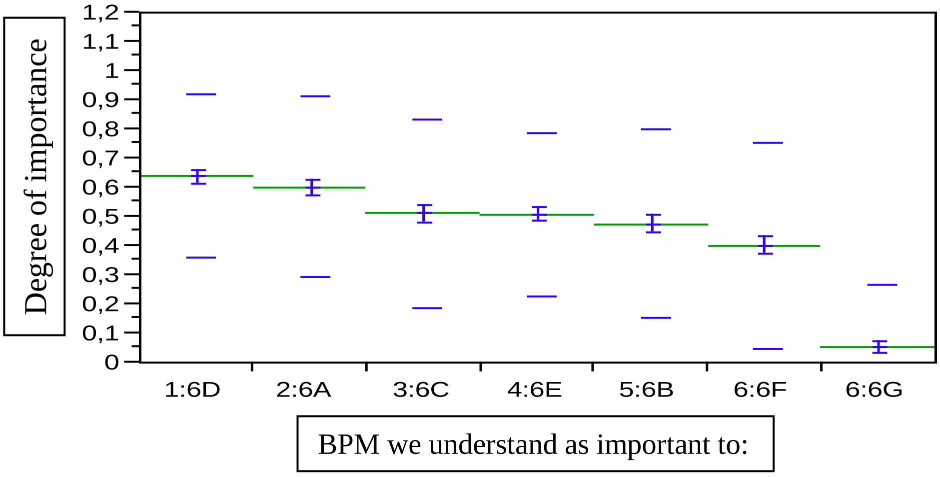


Fig. 3.3 Process management approach (year 2006). Source: own research

Table 3.5 Reliability intervals (for estimation reliability 1 – α = 0.95). Source: Tuček & Zámečník (2007)

Process management is perceived as important by managers due to these reasons:	Average	Standard deviation	Lower interval	Upper interval
1:6D – Inefficient business processes	0.638258	0.280258	0.59000	0.68651
2:6A – Reorganization of the company	0.602273	0.308831	0.54910	0.65545
3:6C – Lack of competitiveness	0.511364	0.322300	0.45587	0.56686
4:6E – Change in IT support process	0.507576	0.277907	0.45972	0.55543
5:6B – Providing a new product or service	0.475379	0.325242	0.41938	0.53138
6:6F – Acquisition or merge	0.401515	0.351873	0.34093	0.46210
6:6G – Other reasons	0.054924	0.214713	0.01795	0.09189

In the case of reorganization of the company that required different process behaviour, the following factors have been demonstrated:

The size of the company and its effect can be interpreted by a statistical hypothesis. It is possible to confirm the alternative hypothesis H1, i.e.: “The size of the company according to the number of its employees (and turnover) is significantly associated with the fact that managers understand and evaluate the impacts of business processes due to reorganization of the company.”

This is the evaluation regarding the second largest sector of process management, i.e. essential components. Its usage in the company feasibly meets the real process management principles. Process engineers sometimes name its summarization as "Ten commandments". Its application means real and actual usage of the process approach in practice.

The questionnaire (Annex A) also included so called control questions which should confirm some claims of the managers. Examples of these may be found in the second block (Area II) of the questionnaire, i.e. the seventh and eighth questions related mainly to the active usage of the components in process management. These components should be used when managers answered on the first question that their company fully or partially uses process management. In other words the real usage of process management components in our companies is presented in the following paragraphs. Managers reported their opinion on the given topic also in another questions and their opinions were often methodically correct. However, for practical usage only answers on two questions are relevant. These components were formulated as "Ten Commandments" and were included into the most important components that are essential for practical usage of process management in the company. Specifically, these are the components that were defined on the basis of qualitative and quantitative surveys in 2006 (Tuček & Zámečník, 2007).

If we compare the development of the first survey in 2006, it is clear from Fig. 3.3 that the highest importance is attached to the following principles:

- management of authorities that is seen as a system enabling to assign; a role in individual processes (key and managerial) by such employees who have adequate knowledge and skills (at the level of 0.74);
- information technology in the company that leads to support of processes (at the level of 0.72).

In 2006, in the category of small businesses the lower importance was shown in the usage of information technologies for process support (Fig. 3.4; at the level of 0.65), while in investigating large businesses in 2006, it was the principle with the largest weight.

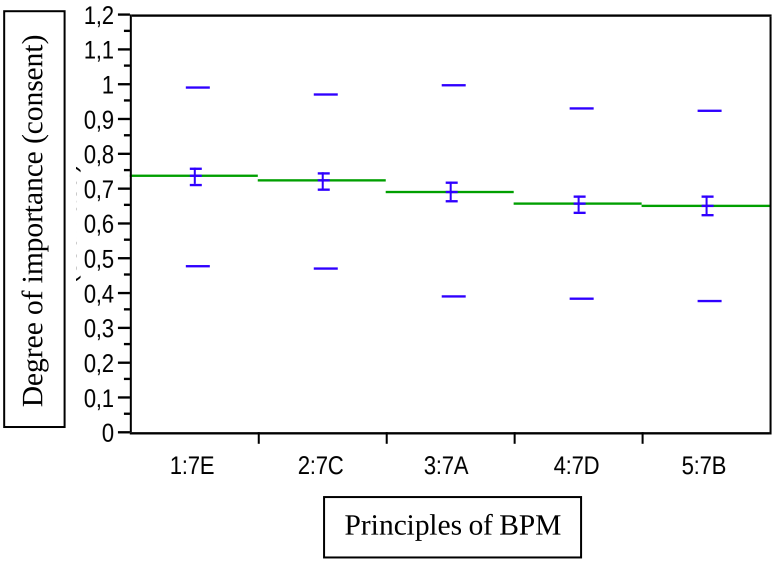


Fig. 3.4 Significance of process management principles (in 2006). Source: Tuček & Zámečník (2007)

Table 3.6 Reliability intervals (for estimation reliability 1 – α = 0.95). Source: own research

The importance of the process management principle from the perspective of managers	Average	Standard deviation	Lower interval	Upper interval
1:7E – assigning a role in processes to appropriate employees	0.736742	0.257176	0.69246	0.78102
2:7C – IT supporting processes	0.723485	0.251442	0.68019	0.76678
3:7A – quality is perceived as a requirements of standards	0.695076	0.304725	0.64261	0.74754
4:7D – strategic management is seen as the top of process management pyramid	0.659091	0.271539	0.61234	0.70585
5:7B – standards are based on process model	0.653409	0.272197	0.60654	0.70028

And the situation in 2013?

According to the values shown (Table 3.7 and Fig. 3.5), i.e. median $\tilde{x}$ = 4.052, dispersion: *dorvar* = 0.993 and modus $\hat{x}$ = 4, it is possible to conclude that the management of competences is understood as a system enabling to occupy roles in different processes (key and managerial) by such employees that have adequate knowledge and skills. Therefore management of competences **is perceived by managers as the most important principle**; although the scattering of responses is relatively high.

Unfortunately it appeared that the quality is taken rather as the requirement of quality standards. Specifically it means that the trend of more formal description of the current situation in the company is prevailing along with the new concepts. Processes understood and managed according to this trend bring larger benefits to managers neither in the present nor in the future.

Based on the values listed in Table 3.7 and Fig. 3.5 and depending on the extent of how these principles are used, the following principles emerge:

- quality standards that come directly from the process model;
- strategic management which should be seen as the peak of a process management “pyramid”.

The importance of information technologies in the company has shifted to the last imaginary place in terms of importance in 2013 compared to 2006. However, scattering response (dorvar) is relatively high in all of these results.

Table 3.7 Meaning of process management principles – descriptive statistics. Source: own research

Answers option	X7.1 Quality is taken as a requirement of standards	X7.2 Standards come directly from the process model	X7.3 IT supported processes	X7.4 Strategic management is seen as the peak of a process management pyramid	X7.5 Filling a role in the process by appropriate employees
Median	3.862	3.830	3.370	3.693	4.052
OR	1.406	1.186	1.154	1.017	0.993

NOR	0.703	0.593	0.577	0.508	0.496
Modus	4	4	3	4	4

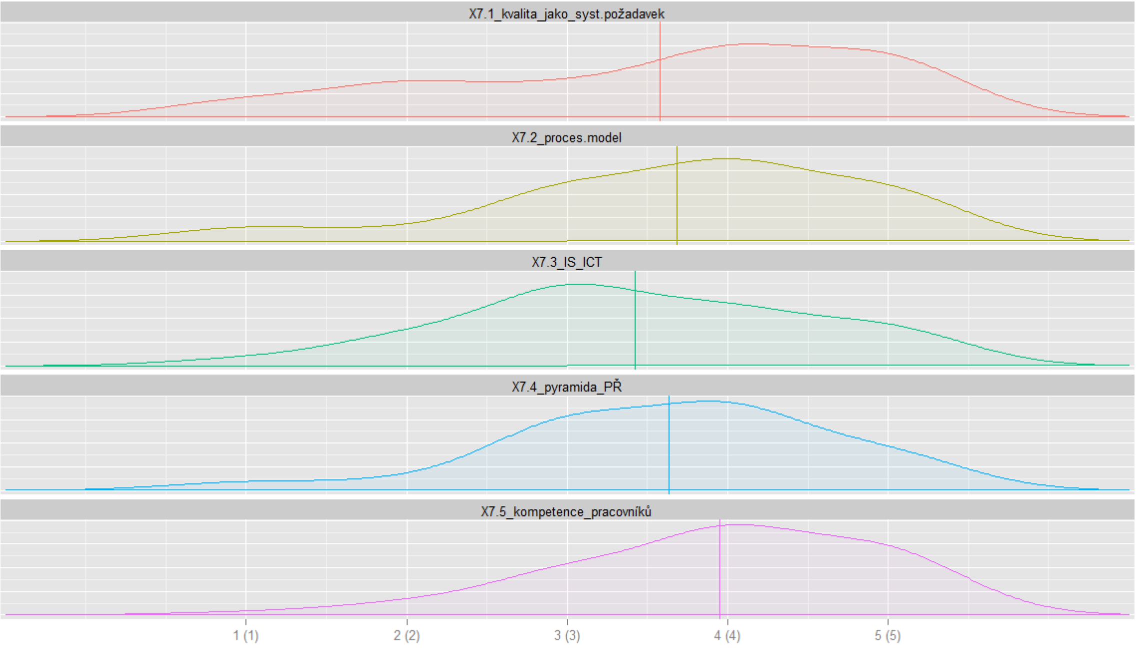


Fig. 3.5 Meaning of process management principles – graphical representation. Source: own research

Controversial principle of understanding and quality management by respondents (including also quality managers) is rated as following:

- the impact of company's size according to the number of employees has not been confirmed;
- the influence of the company's size according to turnover can be interpreted by confirmation of alternative hypothesis H1, i.e.:

„The size of the company according to turnover is significantly linked with the fact that the quality is understood and used primarily as a requirement of quality standards."

Based on the chi-square test, it can be stated that variables are in dependent relationship, at the significance level of 5%. Therefore the strength of interdependence can be confirmed by p-value = 0.0035. Given the GKgamma value -0.176 with confidence intervals (-0.356; 0.005), a dependency is interpreted as weak. The influence of the industry to the level of understanding and usage of competences is also very weak, see GKgamma value -0.083 with confidence intervals (-0.356; 0.005). Its dependence based on the value going over zero is taken as very weak.

Principles of process management require both understanding and quality management to come out of process model. Influences evaluated on the basis of size can be evaluated by confirming the alternative hypothesis H1:

„The size of the company according to the number of employees (and turnover) has a significant correlation with the fact that quality is understood and used mainly as a requirement coming out of process model."

3.4.3 Evaluation of process segmentation typology

The issue of definition and segmentation of processes was comprehensively analysed in detail in the previous sections. The analysis showed that managers have more options of which concrete process segmentation to choose. This area of **questioning was incorporated into our research since it shows:**

- How do managers proceed with process segmentation?
- Which problems are the most frequent?
- How many groups of process do companies usually have?
- What type of processes are they and what specific attributes they have?
- Whether performance in these processes is monitored?

In the questionnaire, respondents were asked to identify the type of process segmentation they use. Fig. 3.6 shows that the highest number of companies, approximately 60%, use the separation of process groups into managerial (top), main (key) and supportive. This is clearly supported also by ISO 9001 standards. This requirement of regulation of segmentation can be further found in practical form in the very first table in this collective monograph. Just a little over one fifth of the respondents (21.3%) use Porter's value chain model (primary and supportive processes). Approximately one-tenth of respondents (11.35%) use value chain approach based on Balanced Scorecard principles (innovative, operational and after- sales processes). 6.38% of respondents use Earl division, not so often occurring. Even in terms of practicality and ease of use, the most used method of process segmentation (managerial, main and supportive) comes directly from the requirements of ISO 9001.

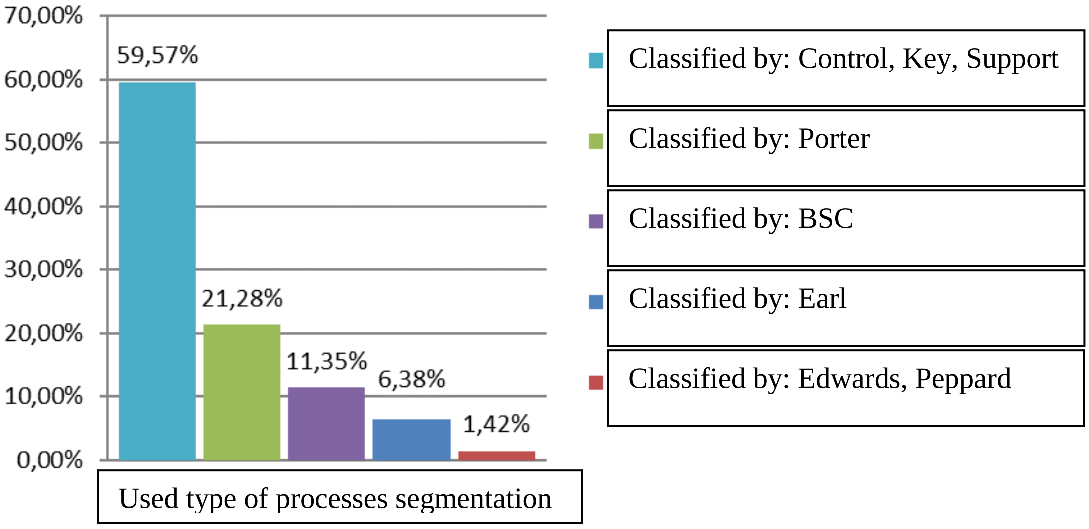


Fig. 3.6 Usage of different ways of process segmentation in companies (in 2013). Source: own research

The positive aspects of clear process segmentation reside mainly in improving of their performance. However, in practice, this process classification may cause that some previously highly appreciated specialists will play the role of those who are not in the spotlight anymore.

The influence of size of the company can be seen in Annex B (l.12). Based on this, it is possible to confirm the alternative hypothesis H1, i.e.:

„The size of the company according to the number of employees (and turnover) has a significant association with the type of process segmentation used in the company (on the highest level of groups of processes).” Based on the results from chi-square test, it can be concluded that variables are in dependant relationship. At the significance level of 5%, we may confirm the strength of interdependence by p-value = 0.006. GKgamma value 0.172 with confidence intervals (-0.036; 0.38) described very weak dependence. Moreover p-value = 0.0075 represents the value for the size of the company according to turnover. GKgamma value 0.187 again represents a weak dependence. The influence of the industry to the level of process management usage has not been proven (Annex B).

With regard to small businesses (according to the number of employees), Porter’s value chain model is the most commonly used classification. This classification includes innovative, operating and after-sales processes along with the managing, key and supportive processes. Even in medium-sized and large companies (according to the number of employees) their managers divide processes into these three groups (managing, key and supportive). Moreover, medium-sized companies use also value chain approach based on Balanced Scorecard (innovative, operating and after-sales processes).

Table 3.8 Classification of groups of processes in companies presented as: managing, key and supportive in 2006 and in 2013. Source: own research

Managing processes	Relative frequency %	Key processes	Relative frequency %	Supportive processes	Relative frequency %
Management of the company	29.31	Production (management and planning of production process and its changes)	59.19	Human Resource Management	27.01
Strategic management (and planning of resources)	17.81	Purchase, SCM, selection of subcontractors	47.13	Economic management, finance, controlling, accounting	24.71
Human Resource Management	7.47	Sales (in the Czech Republic or abroad), customer satisfaction and its evaluation	42.53	Maintenance and repair of equipment	21.26
Audits (internal, others)	6.32	Design and development of the product, (innovation), research	14.94	IT support, ICT	17.24
Quality management processes	5.17	Logistics (Distribution)	13.79	Care for environment	13.79
Marketing	4.60	Providing services (e.g. the service of the product, after-sales services, etc.)	12.64	Health and safety at work	13.22
Operational management (and planning)	4.59	Quality management processes, product testing	9.77	Documentation management (or contract formation or statistical data processing)	11.49
Receiving of orders and planning of production	3.45	Technical preparation of production, technological processes	8.62	Purchase, SCM, selection of subcontractors	9.77

Investment and documentation management	2.87	Marketing	7.47	Technical preparation of production, technological processes	6.90
Finance, controlling	2.30	Documentation management (or contract formation or statistical data processing)	5.84	Quality management	6.89
Continuous improvement	2.30	Warehouse management	5.17	Logistics (distribution)	7.47
Environmental management system	2.30	Contractual management, communication with customer, CRM, processing of orders	5.17	Providing services (e.g. the service of the product, after-sales services, etc.)	7.47
Control and management of discrepancies	1.15	Human Resources Management	5.17	Management of discrepancies	7.47
IT	1.72	Audits (internal, others)	4.6	Metrology	5.74
		Energetics	4.02	Marketing	5.74
		Contract and project management	3.45	Trust	4.59
		Finance, controlling	3.45	Monitoring (recording), measurement, managing and measurement devices	3.45
		Planning	3.45	Design and development of the product, (innovation),	2.87
		Development and analysis of processes	2.87	Warehouse management	2.87
		Trade	1.15	Customer's care, customer's satisfaction	2.30
		IT	0.57	Audits (internal, others)	2.30
				Sales	1.72
		Transportation	0.57	Contract and project management	1.15
Monitoring and measurement of processes	0.57			Processes of competitiveness	1.15
				Administrative processes	1.15
				Complaints and their resolving	1.15
				Continuous improvement	0.57
				Energetics	0.57
				Workflow	0.57

Table 3.8 depicts types of processes that managers stated as being managing, key and supportive. This evaluation is expressed as relative percentage to all 90 companies. In 2006 managers of these companies stated that they implement this process classification to 84 companies. These 84 companies identified this segmentation in survey in 2013. This evaluation is applied in percentage regarding all 90 evaluated companies in Table 3.3. It was those managers who stated that they use this process classification. In 2013, it was stated only by 84 managers of companies. Therefore it is the summary evaluation for all 174 respondents.

It should be noted that **each of these companies does not always define all three processes, i.e. managing, key and supportive.**

However, results in Table 3.8 cannot be generalized to the entire primary set. Our ambition is identical with the case of reproduction of answers to question 10 and 11 regarding software for process management support. Therefore the ambition is only to add opinions and options for the segmentation of processes (and groups of processes).

Therefore, in Table 3.8 collective sorting out of groups of processes is referred to as: managing, key and supportive, both in 2006 and in 2013. Based on the information that was already known about process segmentation (managing, key and supportive), it is obvious that this segmentation is largely individual. This means that a universal method of process segmentation does not exist. Moreover such aim would be irrational due to the way of process division.

Table 3.8 depicts the mainstream practice in the segmentation of groups of processes in the Czech companies according to ISO 9001. From the results (of 140 companies), it is evident that the same group of processes may occur both in managing, key and also supportive processes. For example, the processes of the human resources management or recruitment in typically manufacturing companies are perceived as supportive processes which should detect the functioning of the main process, i.e. production. In contrast, this same process in typical HR agency is classified as the main (key) process since it generates revenues to the agency. More similar examples can be found in Table 3.3. Results are managed in descending order according to the relative frequency of their occurrence in those 174 companies. Interestingly, the method of process allocation of these three primary groups (managing, key and supportive) has changed very little since 2006, with comparison to 2013. Possible slight change was made in some positions of the given groups (managing, key and supportive). Therefore the following values of relative frequencies are introduced in relation to these 174 respondents.

Porter’s value chain model and BSC model

Porter’s value chain model is another process model that is used in the study of competitive advantage in companies. Specifically, it is a model of process structure which depicts value chain and is often used in the study of the competitive advantages of the company as well as in implementation of SWOT analysis. Porter divides business processes into two groups, **namely primary and supportive.**

1. Primary – core business processes. These are operational processes which result in production of outputs required by the customer (input logistics, production, output logistics, sales and services).

2. Supportive - enable the existence of primary processes (e.g. top human resources management, marketing, research and development and provided activities). Model demonstrates a lack of manager’s attention to primary processes (production and logistics). This leads to lower ability to respond to customer’s need. Another shortage resides in the lack of innovation processes that are required by the customer. (Porter, 1993)

Another approach dealing with process segmentation is a process model – **the value chain model from the creators of BSC** (Balanced Scorecard). Kaplan and Norton (2005) recommends to managers to define the complete value-chain. This starts with innovation process revealing the current and future customer needs and developing the new ways used for solving these needs. Further it continues with operating process, i.e. by the delivery of existing products and services to existing customers. Finally it ends with after sales service, i.e. supply of services after the sale which adds to purchased products and services additional value.

Y model of professor Scheer

Interestingly, the segmentation of processes according to Professor A.W. Scheer is not used in practice as a method for process segmentation. However, it is particularly suitable for process identification in manufacturing companies since it emphasizes the connection of logistics (within production) with selling of the products. It also depicts the continuity of operational and long-term management (Hejduk, 2006; Scheer et al., 2002). Both chains, i.e. trade and logistics, have a character of knowledge processes in its upper part. Though they can be referred to as so called existential processes. At the bottom, they are so called data processes. The size of the opening of existential triangle defines the openness of the company to opportunities. In other words, it defines the ability to capture future potential of both the market and also its own innovative ability with regard to usage of hidden assets. Simultaneously completing of triangle by information and knowledge defines future prosperity of the company. (Tuček & Zámečník, 2007)

As stated by (Vráblík et al., 2003) the evaluation of all models will lead us to the conclusion that process classification, that these models suggest, is not applicable and suitable for small and medium companies. Literally, it divides professional shaped structures from managerial activities, mostly those with competence character. Thus it does not allow determination of one basic process management component, namely competence management. Therefore these authors describe the process structure for segment of small and medium companies that would be based on value chain of internal business processes. (Vráblík et al., 2003)

3.5 LOGISTIC FUNCTIONS, TECHNOLOGIES AND METHODS

Based on the practice of surveyed industrial companies, it is possible to conclude that processes occurring in logistic chains means transformation of orders. This transfer leads from concrete products to supply. Packaging, creation of manipulative and transport units, loading, transportation, unloading, storage, picking, assembly, consolidation, control, making out documents, invoicing, and so on – these steps are described as logistic functions.

They are usually structured into four levels:

- Strategic, decision-making about resources, rules and procedures.
- Decision about the way of identified needs and their satisfaction.
- Administrative identified with information processes. Publication of directives or orders can be taken as a first incentive.
- Operative, i.e. realization of material side of logistic chain.

Logistic technology is described as a sequence of actions, operations, processes and sub-processes that lead to minimization of costs on logistic chains while achieving the required performance.

- Just in Time (JIT), KANBAN, Quick Response, satisfaction of the need for a certain material delivered in exact time, i.e. in the exact agreed terms and according to the need of the customer.
- Centralization of storage associated with the concentration of their networks and using all advantages of mechanization and automation.
- Usage of progressive types of transport means and transportation systems.
- Information technology supporting the informational exchange without any documents along with code labelling, automatic identification and computer optimization of transport processes.

Logistic methods. In terms of methodology, logistics has no own methodology since it is a marginal discipline that uses other various disciplines such as transportation technology, process automation or informatics. Theoretical foundations of logistics are namely system theory, cybernetics, stochastics (queuing, reliability and inventory), mathematical programming or theory about decision-making. Therefore logical approach uses various methods of mathematical - logistical simulation along with other simulation models. Except for these methods, it also uses various simpler methods that are taken from other scientific and technical disciplines.

- Methods for monitoring of the material flow (procedure, connection, time consumption and distance).
- Methods of analysis and planning of technical resources and employees (time required for operations, time and three-dimensional screening, normative of determination of technical resources and employees or calculation of storage capacity).
- Methods of three-dimensional distribution of technical resources, facilities and warehouses.
- Methods of operational research in order to solve special transport problems, for activity harmonization, queuing, replenishing stock or recovery.
- Methods of value analysis and value engineering in order to detect obvious and hidden inefficiencies and evaluation of functions (determining of function’s importance, the degree of function’s fulfilment, function costs and measurement of critical functions.
- Methods of calculating costs.
- Statistical methods used for information processing.
- Methods of multi-criteria evaluation of more alternatives.

It uses a comprehensive and integrated (systemic) approach to the analysis of material flow. These are horizontally and vertically integrated into material chains (schema) that are possible to earmark, examine and model from different perspectives.

System approach

- Macro-logistic, social transport system (transport means, transport network, tariff policy, transport regulations, standards by ISO);
- Micro-logistic, flow of material, energy, information in time and space inside of the company – logistic spiral of production;
    - shopping logistic subsystem, the production process (warehouses, manipulation, transport and IS);
    - internal logistic subsystem, the production process itself (warehouses, manipulation, transport and IS);
    - sales logistic subsystem, the post - production process.

3.5.1 Functions of logistic systems

- Disposal;
- transport;
- transhipment;
- storage;
- collecting and distributional;
- packing;
- manipulation;
- informative;
- managing and control;
- rationalized and innovative;
- special functions (transport service directly to customers, insurance, dispatching, credit and payment functions).

External relations of material flow

- Natural conditions;
- authorities and organizations cooperating in ensuring of circulation processes;
- supplier vs. customer companies at the output and input of material flow;
- economic conditions, tariff, price, salary and financial policy;
- economically-legal system and regulations;
- social conditions;

Internal structure of logistic processes

Division into components and subsets:

B.1 Material perspective:

Input components:

- passive (material, products, goods…);
- active (labour force, flow and control centres, transport and manipulative means).

Transformation components – the way in which movement takes place (transport technology)

Output components – operating outputs while implementation of material flow (transport, manipulation with material, service).

- segmentation according to distribution channels, direct and indirect flows;
- segmentation according to sector structure - supply, storage, transport, trade and internal flow;
- hierarchical segmentation.

Microstructure:	1. stage: workplace
	2. stage: stores, plants, shops
	3. stage: factories, manufacturing, transport, store and trade
Mesostructure:	4. stage: companies with more plants
	5. stage: organization of higher order
Macrostructure:	6. stage: government authorities

Segmentation according to material and transport links on: homogenous groups, material and transportation chains.

B.2 Functional perspective

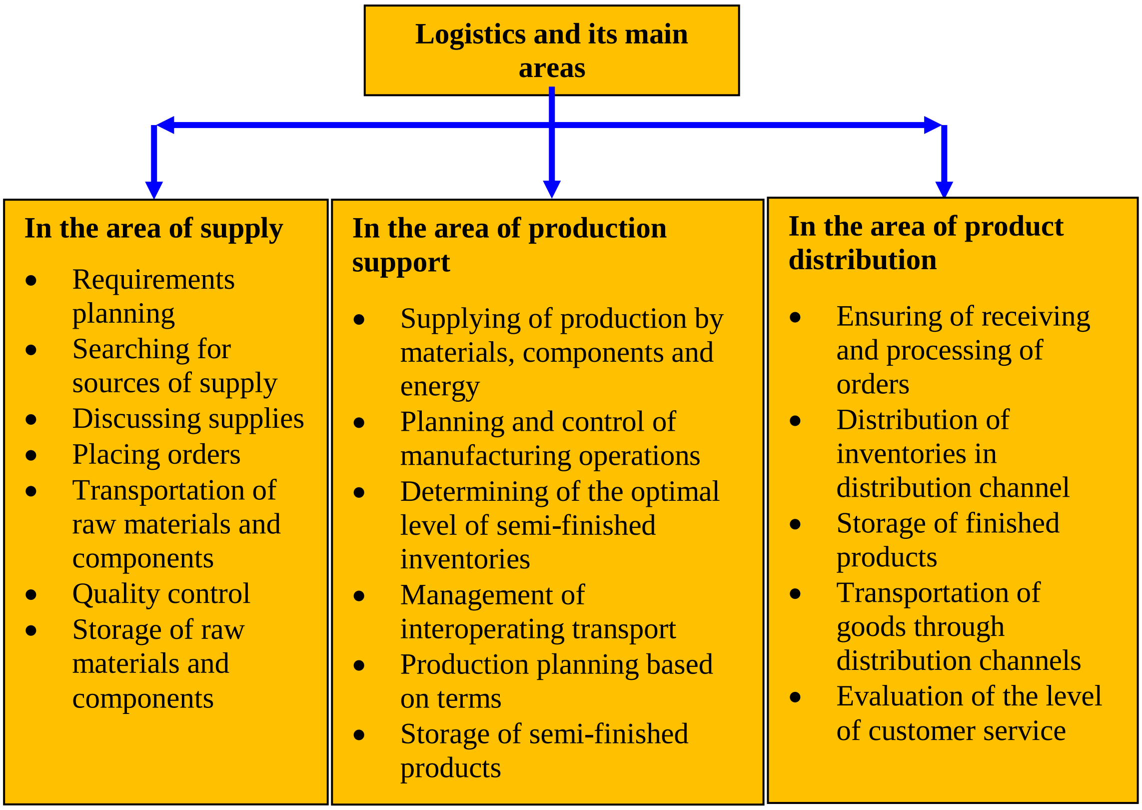
Logistic and materially energetic and service subsystems are divided into functions, processes, sub-processes, basic units and operations.

- Transport;
- stock management;
- inventory management;
- material manipulation;
- packaging management;
- customer service;
- communication, telematics and data processing.

Subsystems of logistic management and the main logistic activities

- Information subsystem (collection, transfer, storage, linking, transformation and presentation of information dealing with the progress of supply and costs of material flow).
- Organizational subsystem (centralization and decentralization of activities).
- Decision-making subsystem (planning, project, regulative, motivational, control and rational processes, economic decision-making).

The main logistics activities in the Czech companies are expressed in the Fig. 3.7 and Fig. 3.9.



Logistics and its main areas

In the area of supply

- Requirements planning
- Searching for sources of supply
- Discussing supplies
- Placing orders
- Transportation of raw materials and components
- Quality control
- Storage of raw materials and components

In the area of production support

- Supplying of production by materials, components and energy
- Planning and control of manufacturing operations
- Determining of the optimal level of semi-finished inventories
- Management of interoperating transport
- Production planning based on terms
- Storage of semi-finished products

In the area of product distribution

- Ensuring of receiving and processing of orders
- Distribution of inventories in distribution channel
- Storage of finished products
- Transportation of goods through distribution channels
- Evaluation of the level of customer service

Fig. 3.7 Division of logistic processes. Source: Bobák (1999)

In the developed market, businesses are getting into magical triangle since their overall success in the market depends on the success of quality improvement, cost reduction and increase of flexibility. These three factors represent vertexes of a triangle. Moreover they are linked with the level of technology, with the level of business organization and level of employees. The importance of previously mentioned factors is in recent years shifted from quality through cost reduction to flexibility.

3.5.2 Processes in logistics

High flexibility may be achieved by good technical equipment and by perfect management of production and circulatory processes (pre-production and post-production processes in which material plays a significant role, specifically raw material, auxiliary material, components, products in progress and finished products for sale – goods).

A company, which decides to get a competitive advantage, must remove everything that burdens it:

- reduce inventory;
- cooperate with customers;
- cooperate with suppliers;
- eliminate wastage in production;
- reduce current time of production and product manufacturing;
- reduce delivery deadlines;
- ensure quality of supply system;

- in terms of packaging technology;
- the speed of response to order;
- supply reliability in time and given extent.

Business logistics solves the problematics of how to implement the given path. It offers a way of thinking in which holistic approach as a time interrelated process leads to new organization of production. Its new way resides in economic optimization, better usage of technical and economic potential (in terms of costs) and leads to better adaptation to the market (in terms of higher revenues from each realized product).

It works as operationally economic cross-cutting function and it runs across these economic areas:

- Logistics has to combine logically and economically factual, three-dimensional and time differentiation along with the consumption in important areas within the plants and also between them. The process of work interconnection responds to each process of labour division.
- Logistic processes are taken as transfer processes used for bridging of time and space concept. Concretely, these processes are represented as transportation, loading and storage processes.
- Logistic management is the area of business management that is responsible for planning, management and control of physical logistic processes at both strategic and operational level.
- The purpose of logistic optimization resides in reduction of islets, analysing of overall economic progress of material and goods movement.
- As a consequence of logistic improvement and its performance there exists better level of services and respond to customers, reduction of fixed means of storage and transportation costs due to supply chain (Fig. 3.8). Integrated logistic includes complete material flow along with data flow which is needed for planning and managing the flow of materials.

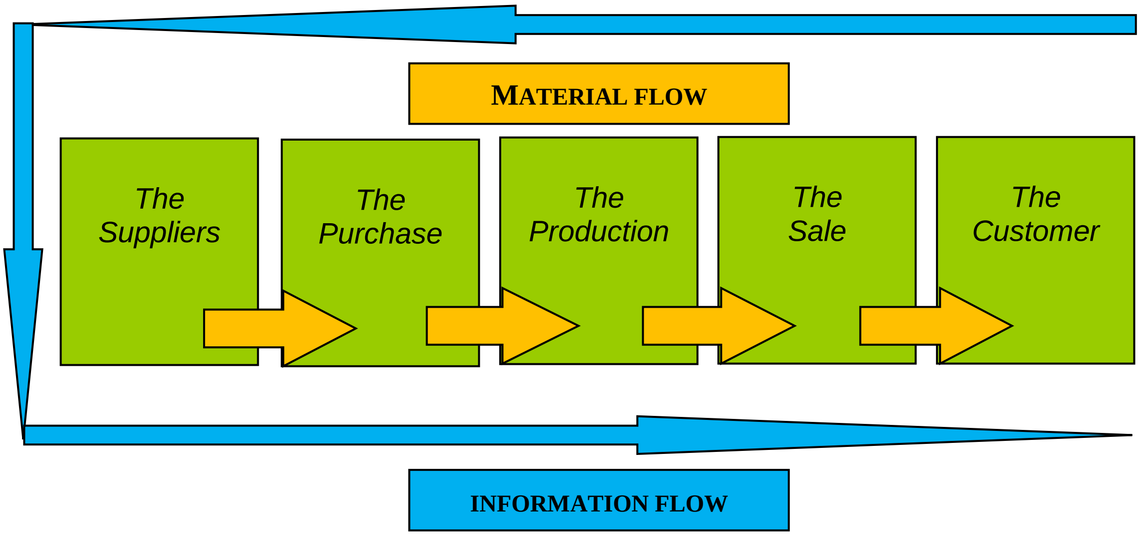


Fig. 3.8 Schematic representation of logistics pull chain. Source: Bobák (1999)

The goal of each logistic activity is to optimize logistic performance along with their components and logistic services and costs.

Logistic performances, activities

Area of product distribution in close cooperation with marketing

- income assurance and fulfilment of customer orders;
- monitoring of deadlines of order fulfilment;
- management and distribution of inventory;
- packaging, storage, completion and shipping of finished products;
- assurance of product transportation through distribution channels;
- business operations;
- choice of appropriate distribution channels.

Area of production support

- planning of production program;
- setting of the production and consumption and preparing materials for supplying;
- ensure smooth production by supplying of material and energy;
- operational management and support of manufacturing processes;
- determine optimal inventory level with respect to semi-finished products;
- internal management and interoperating transport;
- storage of inventory of products in progress;
- decision-making about their own production and purchase of semi-finished products.

Area of purchase of raw materials, components and package

- formulation of supply plan;
- searching for the source of supply;
- tender organization;
- deciding about suppliers;
- discussing supplies;
- placing orders;
- transport, storage of raw materials;
- confirmation of supply;
- continuous monitoring of suppliers.

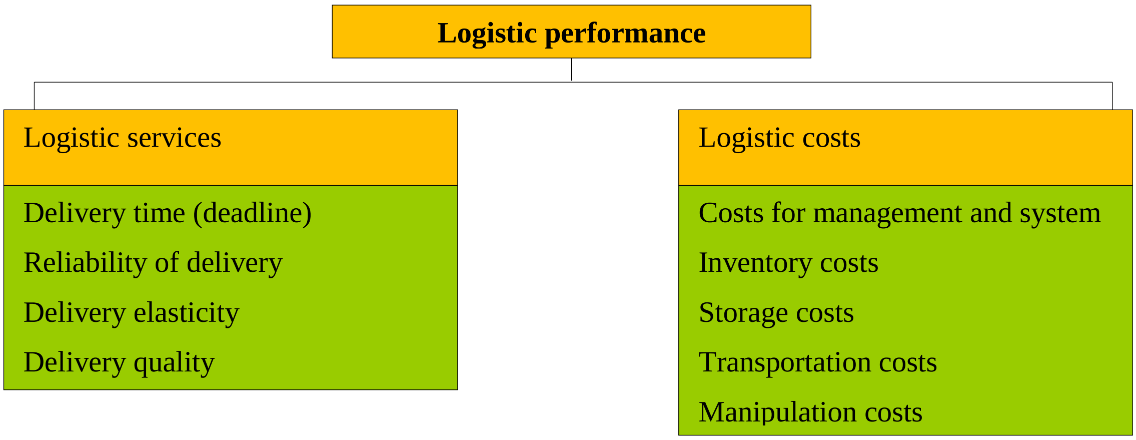


Fig. 3.9 Components of logistic performance. Source: Bobák (1999)

Turnover: Market research of some companies at a group of customers shows that logistics and services oriented on customer are of a great importance mainly for purchase decision-making. It is the main influencing factor for some products and markets, for others it might follow the product quality but it stands before price. Delivery on a specified time is more important than the term itself.

Costs: The businesses may gather information about direct costs within manipulation, storage and transportation costs, interests from warehouse stock or costs spent on planning which together represents approximately 11% of net sales and 22% of added value. Another hidden overhead costs are tied to production and purchase management, changes in assembly lines or to complexity of production facilities. Costs spent on raw material may vary due to delivery dates and discounts when changing methods and models of orders.

Complexity of management: Stagnant and declining markets along with excessive economic performance evoke a wide range of trends affecting management of material:

- greater variety of products in order to remain on the market increase the demand for components and raw materials;
- life cycle of products and components is shorter, managers search for more frequent modification and the speed of technological innovation is increasing;
- a considerable share of export is still increasing;
- searching for cheaper supplier forces managers to purchase things abroad.

In management of logistic functions and in the organization, this invokes introduction of more advanced systems and computer support.

The inflow of material is indispensable for society as is the blood circulation necessary for human body. Logistic management is a management technique for blood circulation through which material gets to the right place at the right time. It is important mainly for the following reasons:

- aspect of trade policy, ensure profit and reduce costs;
- organizational point of view, integrated systematic approach respecting the relationships between different functions including management of material flow;

- projection of hierarchical goals of the company into functions related to material flow.

Economic system must be implemented into environmental framework. Manufacturers must completely close the material flow (Fig. 3.10). This will result in source savings and re-usage of raw material as it is observed in nature. The company, that will adopt this strategy, should, with regard to the environment, handle with the following:

- the usage of environmentally friendly production processes (production, transport and packaging technologies);
- production of ecological products that will not increase environmental pollution during their usage and subsequent disposal.

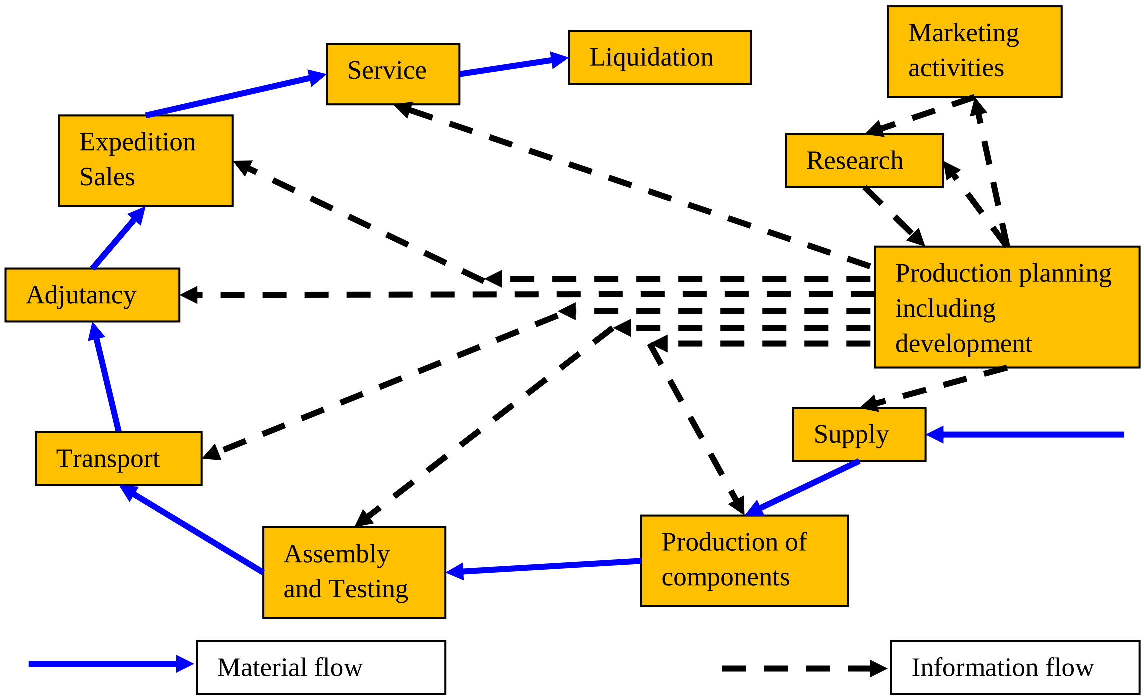


Fig. 3.10 Logistic life cycle of a product. Source: Jurová (1998)

The main principles, that should be used, include:

- efficient use of materials;
- no usage of materials harmful to environment and to humans;
- minimize emission;
- minimize energy consumption;
- re-use of materials in all forms;
- reduce waste and create opportunities for its simple processing and subsequent disposal.

Diagnosable questions relating to the appropriateness of logistic implementation in the company:

- Do you have any problems with long term performance of orders?
- Do you provide uncompetitive level of service to the customers?

- Do you have to still solve conflicts in management of material flow in your company?
- Do you have high costs related to business activity? Do you have high level of inventory in your company?

If the answer to any of these questions is yes, use logistic in your company!

The principal characteristic of all processes in the business unit is the manufacturer's competitiveness, factors of its growth and its system of indicators used for its assessment.

1. The concept of competitiveness belongs to conceptual system of economic competition between companies in a market environment.
2. According to majority of sources, the competitiveness is understood as the ability to obtain "a competitive advantage" in turbulent environment through low costs or differentiation (Porter, 1993).
3. Competitive advantage comes out of the value (Košturiak & Gregor, 1993), which is created by a producer, in his value-chain (Porter, 1993) and use it to its long-term growth and wealth.
4. In order to achieve this advantage, the world's best practices and approaches in terms of processes, company and methods must be applied along with people in marketing, development, manufacture and service (Vytlačil & Mašín, 1999).
5. From the previously mentioned assumptions, we may speculate about the determination of factors influencing the competitiveness of the manufacturer. (Matuszek, 1998).
6. Similar possibilities for the group of factors regarding competitiveness of the company can be found in the method SPACE (Strategic Position and Action Evaluation) (Leština et al. 1998).
7. Transformation place of the reality is a display (model) of an object, reality and a filter through which a human observes objects and analyses their behaviour, performance and the ability to react to a stimulus of the surroundings. The object is further interconnected with the surrounding by materially energetic and information links.

Those, who formulate goals in the company, are well informed in their activities through information. The control process is perceived as a decision-making process transforming information into action. In business system, following classes of information are needed for effective decision-making:

- information for goals determination in the business system;
- information for setting goals corresponding to activities of the business system;
- information expressing partial coordinated activities that should lead into fulfilling of target idea;
- control information expressing the results of activities;
- in the management process that is sequentially connected with regulatory circuit, these main problematic areas occurs;
- problem of setting of goals at various management levels associated with the application of management techniques by using target quantity;
- problem of management by using desired output quantities or by results;
- problem of providing relevant feedback information for different levels of control.

3.5.3 Logistics in practice

Logistics in practice means a tool of business management used to improve planning and operational management within traditional organization structure of the company, initially in the distribution sector. It was a follow-up to marketing and it worked as an implementer of its defined flow of goods through intermediated components directly to the customer. An obstacle appeared in the form of respecting traditionally defined boundaries of the business units. Logistics contributed to the position of cross-cutting activities covering the core business functions of supply, production and distribution. As such, it has become the function of corporate security along with financing and human resources management. Later on, especially in large companies logistics started to be separated into an independent corporate body, e.g. within matrix organizational structure. Recently, it is well known that the potential of logistics can be fully applied only if it cooperates with marketing and other business areas from the very beginning of the business strategy formulation. Logistics is no longer taken as marketing logistics, being responsible for material flow between the company and its customers. This perception is replaced by integration of logistics (logistic experts) into teams bringing together specialists from other areas. These specialists cooperate together on innovation processes, formulate strategy of the company and seek the optimal tools for its realization.

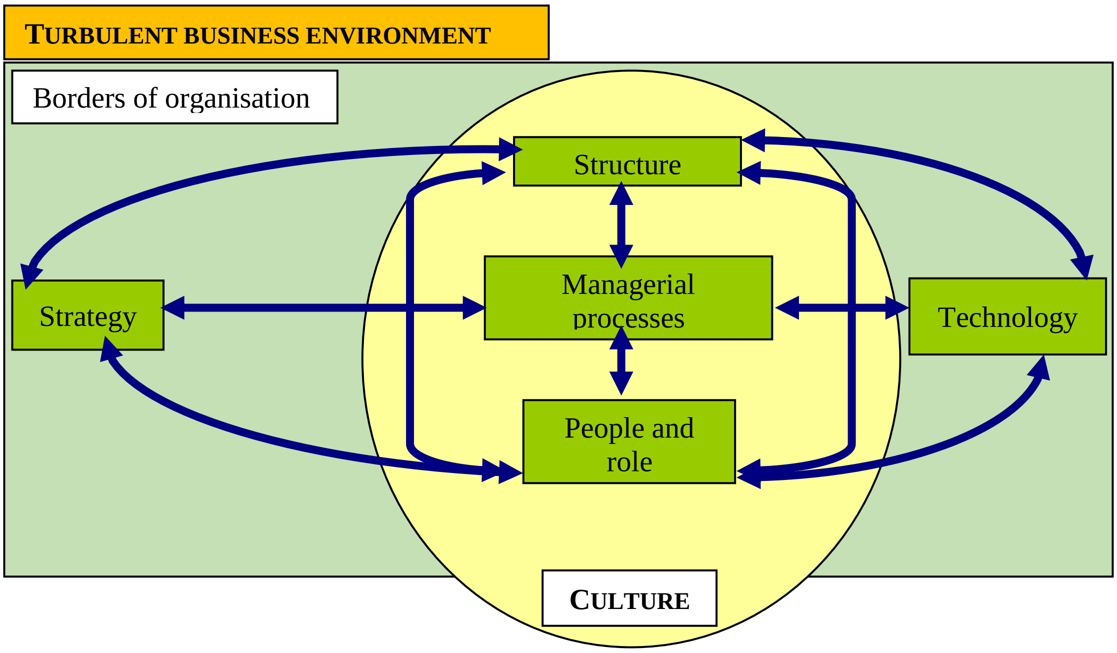


Fig. 3.11 Components of the company and their relationships. Source: Bobák, 1999

When specifying the terms, we use the following assumptions:

- the connection between control (CS) and information systems (IS) with ongoing material processes in the business unit along with its human resource management and information security;
- the connection of IS with ongoing economic processes in the business unit (accounting, financing);

- the connection of IS with ongoing processes of the top strategic management (strategic planning, marketing, social development, investment and technological development);
- marketing support for the integrated management system in the company, being focused on the customer;
- determination of internal structure information by IS character concentrating on material processes and on the way of management. Data basis must capture specific data describing material flow.

These basic assumptions are schematically demonstrated in the model of relationships (Fig. 3.11), while respecting the classification of market and business environment (Porter, 1993). IS position, as a part of managerial information system of business unit with marketing-oriented system, is described in the model of information pyramid in detail (Fig. 3.12). Therefore marketing information system (MaIS) is seen as a part of internal and external information of the company for senior management – Executive information system (EIS) and for decision support focused primarily on the customer and on the market.

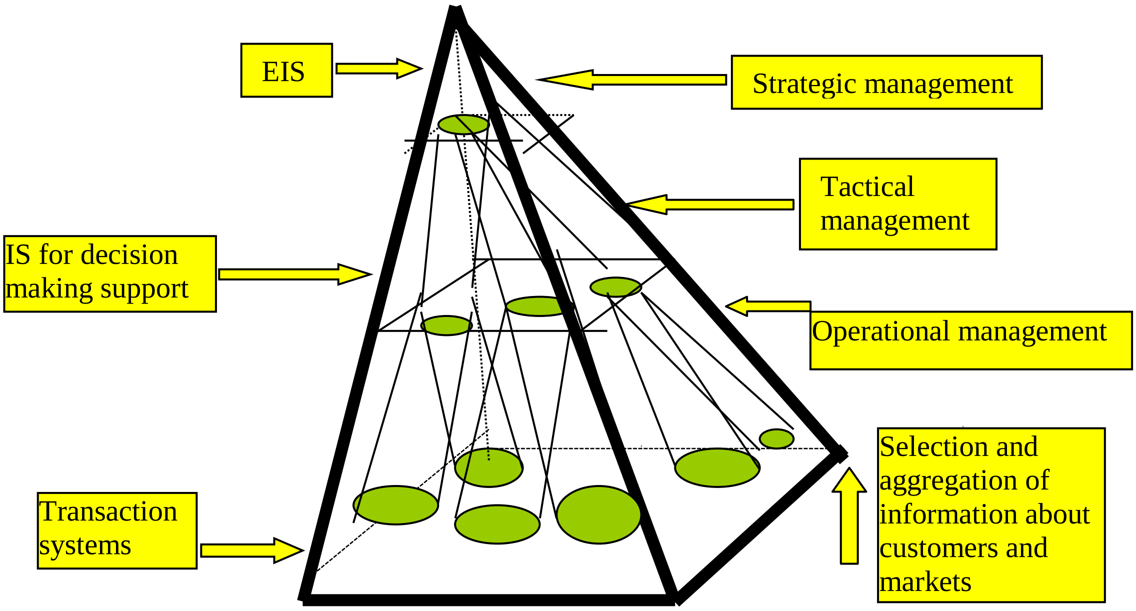


Fig. 3.12 Information pyramid of the business unit. Source: Bobák (1999)

Influence of post - transformational growth of the Czech economy on business processes in business units of consumer's goods and its production.

Characteristics of basic changes in the transformation of economic mechanisms affect functioning of business processes in business units in relation to internal business environment, aims of business behaviour, internal structure and ongoing processes. This characteristic is based on the concept described in Table 3.9. (Košturiak & Gregor, 1993), (Porter, 1993)

According to Košturiak & Gregor (1993), the changes in past and present orientation of business means were used for generating profit and these are depicted in the following Table 3.9.

Table 3.9 The company Yesterday and Today. Source: Košturiak & Gregor (1993)

"Yesterday" company	**"Today" company**
Main goal: profit	**Main goal: profit**
Dominant is:	Dominant is:
High machine utilization Higher stocks Relatively long running period Relatively high costs and prices Production overload Centralization Complicated management Local optimization	High flexibility Reduction of stocks Porter running period Reduction of production costs Just in Time Decentralization Management simplification Optimization of the whole

3.5.4 Priority of goals in the implementation of process management

The purpose of this question was to identify objectives that managers pursue by process management implementation. In other words, the results of this question show the emphasis which managers attach to secondary objectives that are closely linked to process management implementation. A question pursuing the priority of goals in process management implementation is designed to clarify the opinion of managers of the existence of the synergetic effect regarding the use of process management implementation as an overall strategic change as part of the certification according to ISO 900X, as part of the implementation of a new information system or only as part of the partial improvement of processes. The question examines the current attitude of managers to the issue as well as the expected change in attitudes in the future.

The graph (Fig. 3.13) and table (Table 3.10) below show the summary results of this question. As can be seen from these outcomes, the opinions of managers on this issue in all sub-questions are not clear enough. Currently, managers of Czech companies see the greatest significance (0.66) of using the process management implementation in certification according to ISO 900X. It is followed by, with almost the same degree of importance (0.65), process management implementation as an overall strategic change (i.e., as the need to respond to fundamental changes in the business environment, the need for a change in the corporate organizational architecture, e.g., the transition to horizontal organizational structure, the emergence of autonomous teams within a company, changes in the way of motivation, etc.). Managers expressed only weak consent (0.56) to the statement on the use of BPM as a tool in the implementation of a new IS. The biggest ambiguity in decisions (0.52) was evident in connection with the use of process management for minor changes to improve the selected group of processes.

As already mentioned, the issue also examines a possible shift in priorities of objectives in process management implementation in the future. These results are also displayed in Fig. 3.13 and Table 3.10. In the future, managers will focus more on both the BPM implementation as an overall strategic change (shift from 0.65 to 0.69) and the use of BPM for minor changes to improve selected processes (shift from 0.51 to 0.57) and, last but not least, the use of BPM in the implementation of a new IS (shift from 0.56 to 0.61).

Only the use of BPM for the requirements of certification according to ISO 900X in the future was expressed less clearly by the addressed managers than at present.

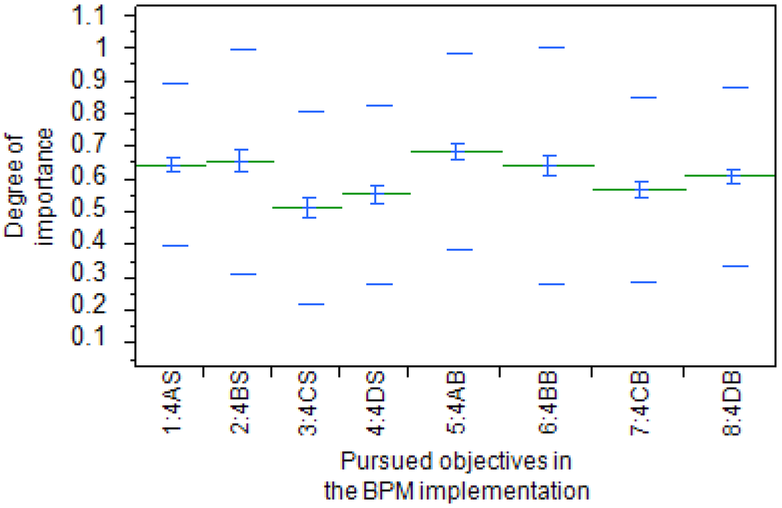


Fig. 3.13 Priority of objectives in the BPM implementation. Source: own research

Table 3.10 Legend to the previous graph with quantified confidence intervals. Source: own research

Code	Pursued objectives in the BPM implementation	Average	Standard deviation	Lower interval	Upper interval
1:4AS	BPM as an overall strategic change (present)	0.649533	0.247296	0.60213	0.69693
2:4BS	Certification according to ISO 900X (present)	0.661215	0.342115	0.59564	0.72679
3:4CS	Partial improvement of processes (present)	0.518692	0.29078	0.46296	0.57442
4:4DS	IS implementation (present)	0.558411	0.271655	0.50634	0.61048
5:4AB	BPM as an overall strategic change (future)	0.689236	0.297493	0.64023	0.73824
6:4BB	Certification according to ISO 900X (future)	0.645833	0.359073	0.58669	0.70498
7:4CB	Partial improvement of processes (future)	0.572917	0.283391	0.52624	0.6196
8:4DB	IS implementation (future)	0.614583	0.270772	0.56998	0.65919

Confidence intervals (for reliability estimation of 1 - α = 0.95), multiple answers

The following table (Table 3.11) illustrates the effect of company size on a priority of secondary objectives that managers of Czech companies pursue by process management implementation. The results imply that company size does not have a significant impact on the priority of secondary objectives in the BPM implementation. As in previous research, even the current research shows large ambiguity mainly on the part of managers of micro as well as small enterprises. The greatest importance for small enterprises consists in the BPM implementation for certification according to ISO 900X. The process management implementation as an overall strategic change is attached the greatest importance by managers of large companies, who also expect an increase in the importance of this objective in the future. From the results it can be concluded that the larger the company the more managers of Czech companies perceive the BPM implementation as an overall strategic change (Tuček et al., 2009).

Table 3.11 The effect of company size on the priority of objectives in the BPM implementation. Source: own research

Code	Pursued objectives in the BPM implementation	Micro	Small	Medium-sized	Large	Total
1:4AS	BPM as an overall strategic change (present)	0.535714	0.566667	0.604167	0.755952	0.649533
2:4BS	Certification according to ISO 900X (present)	0.428571	0.733333	0.694444	0.684524	0.661215
3:4CS	Partial improvement of processes (present)	0.517857	0.533333	0.576389	0.464286	0.518692
4:4DS	IS implementation (present)	0.5	0.7	0.534722	0.547619	0.558411
1:4AB	BPM as an overall strategic change (future)	0.520833	0.5875	0.715116	0.844444	0.689236
2:4BB	Certification according to ISO 900X (future)	0.493056	0.7	0.744186	0.65	0.645833
3:4CB	Partial improvement of processes (future)	0.611111	0.5375	0.651163	0.483333	0.572917
4:4DB	IS implementation (future)	0.618056	0.7125	0.575581	0.605556	0.614583

Comparison of the results with the previous research

Upon the comparison of the two researches (Fig. 3.13, Table 3.10), (Tuček & Zámečník, 2007) we can claim a greater level of agreement with all the statements specified in the survey conducted in 2012. Questions about future views on priorities of objectives in implementing BPM were asked in a time horizon of 5 years. The time difference in the implementation of both the above researches was 6 years, i.e., the research results from 2006 regarding the future should correspond with the findings of the research focusing on the present situation.

The research shows that managers in the previous period assumed a greater growth in the importance in the future only in the case of the process management implementation as an overall strategic change (up to 0.73). The present results, however, showed an increase to 0.65 only. Therefore, there was a slight increase in the importance of this secondary objective than the last survey anticipated. For all other secondary objectives pursued by the process management implementation in 2006, managers expected only a slight increase in importance. The results of this year's survey, however, showed in almost all cases a much greater degree of agreement than was anticipated by the previous research. Specifically, it involves the following results: a shift from the level 0.54 to 0.66 (the process management implementation for the use of BPM for the requirements of certification according to ISO 900X), a shift from the level 0.43 to 0.51 (the use of BPM for partial changes to improve selected processes), and a shift from the level 0.52 to 0.55 (the use of BPM in the implementation of a new IS).

The previous research pointed out the following priorities of objectives in implementing BPM: BPM as an overall strategic change, certification according to ISO 900X, IS implementation, partial improvement of processes. According to responses of managers regarding the future, there were no changes in priorities of these objectives expected in this research. Nevertheless, the current research shows that some changes have occurred. At present, the priority of the objective associated with certification according to ISO 900X is the highest, followed by the BPM implementation as an overall strategic change. The lowest priority for managers is currently the use the BPM implementation for minor changes to improve the selected processes.

3.6 BPM APPROACH IN CZECH COMPANIES IN THE CONTEXT OF LOGISTIC

The survey carried out in Czech companies was a valuable source of information providing the authors with an opportunity to create and provide a comprehensive overview of the use of process management in the Czech Republic. In connection with the formulated hypotheses, the evaluation of individual questions that were the subject of this chapter allowed to establish the following conclusions in context of logistic:

1 The findings of the first question aimed at extending the concept of process management in the Czech Republic showed that almost 26% of respondents identified this term as unknown, and less than 3% of respondents were unable to answer this question. Due to the fact that 70% of respondents consider their company to be fully or partially process-driven, it can be stated that the concept of process management in the Czech Republic is well developed. This conclusion is confirmed by an interview with Professor Wilhelm Scheer (Scheer, et al., 2002); (Šupšák, 2006) who claims that the term process management is indeed wide-spread and in the Central Europe, including the Czech and Slovak Republics, and there is no need to clarify its importance very much. The creator of the ARIS methodology defines process management as a tool to gain a competitive advantage over other companies and a trend that is gradually spreading through banks, financial institutions, and engineering and energy companies to the entire market.

2 A comparison of the results of the current and the previous research (Tuček & Zámečník, 2007) shows a slight (by at least 2-3%) increase in the level of the use of all the essential components of process management, which can be considered as an ambiguous confirmation of H2. The most significant shift in the importance of individual components occurred for the respondents in case of continuous process improvement, which shifted on the scale of importance and significance from the third place (from 0.68) to the first place (0.78). Almost the same improvement is presented by process performance measurement; there was a shift from the level 0.59 to 0.67. These shifts can be evaluated very positively, because process performance measurement is the basis of and prerequisite for continuous process improvement that contributes to the fact that the established process management is dynamic and does not involve only redrawing of the existing processes into process maps.

3 The results of questions aimed at finding out the level of the use of each component of process management can lead to a conclusion that managers of Czech enterprises attach great importance to the use of the following components: continuous process improvement, definition of core processes, definition of customers and process owners and process performance measurement. BPM components related to the creation and use of process maps are not as important to Czech managers. The

difference in the degree of importance that managers attach to individual BPM components, which can be derived from different degrees of their use, means that managers of Czech companies do not apply all components during the BPM implementation simultaneously, but only some. This fact confirms the renewed hypothesis that managers do not understand the interconnectedness of individual BPM components. In relation to the first question focused on the full or partial use of BPM and based on the results of this question, conclusion can also be drawn that managers of Czech companies view the partial use of process management as the use of only certain selected BPM components rather than all BPM components at the same time but only in some fields of the company. These basic components, however, are closely interlinked and using only some of them can cause the benefits of process management to have little effect.

4 The investigated interconnection of individual BPM components lies in the fact that creating process maps leads also to defining core processes, their customers and owners. The subsequent use of process maps to assess, e.g., costs or time requirements of defined processes is associated with process performance measurement, because the actual process maps can be a source of information for performance measurement, which is the basis of and prerequisite for continuous process improvement as well.
Regarding of process measurement performance, some authors, such as Rajnoha & Chromjaková (2009) recommend e.g. implementation of Activity-Based-Costing (ABC) method in the enterprise.

Additionally, implementation of calculation based on processes and activities brings about also non-quantified effects such as:

- transparency and rationalisation of performed activities and processes;
- more responsible proceeding of enterprise work;
- identification of enterprise’s competitive advantages or disadvantages;
- information support for strategic management and goal oriented management;
- assignment of overhead costs to performance on case-by-case basis;
- support of price policy and production-sales program optimisation (Rajnoha & Chromjaková, 2009).

Interconnection of the mentioned BPM components is rooted in many definitions of process management. An example can be, e.g., a definition by Závadský (2005), who defines process management as a systematic identification of business processes (definition of core (main) processes and definition of customers and process owners), visualization (creation of process maps), measurement, evaluation, and continuous business process improvement (the use of process maps, performance measurement and continuous process improvement) using the methods and principles, which are based on the process approach. Other authors agree that (Llewellyn & Armistead, 2000); (Suhendra & Oswari, 2011); (Závadská et al, 2013) process management is the driving force for the profitability of the company and they characterize BPM as a discipline of modelling, automating, managing and optimizing business processes. Even in this definition, we can find the individual BPM components incorporated.

4 Upon the results listed in section 3.2, it can be clearly deduced that Czech companies are focused mainly on external customers, i.e., on core processes in the company only. Small internal customer orientation means that Czech managers do not attach

importance to the management of support processes that provide inputs and operation of key processes, which confirmed Hypothesis 4. This may in the case of implementation of process management cause incompleteness, which may lead to the insufficient use of all potential benefits of process management. Effective management of support processes should reveal the shortcomings of these processes and their improvement would lead to increased efficiency of core processes, which should have a positive effect on the final customer as well. The fact that supporting processes do not directly make profit and are not intended for external customers does not mean that they should not be given due attention. Even these processes must be, according to (Vyskočil, 2010), defined, evaluated and improved to ensure continuous improvement of the whole company. Nevertheless, they fall into the area of the corporate sector, thus management which can be outsourced or managed using the Facility Management.

5 The results specified in section 3 (of this chapter) clearly support the hypothesis that the use of consulting services in Czech manufacturing enterprises is not very widespread. In the BPM implementation, enterprises primarily rely on the knowledge of their own workers and information obtained by employees participating in BPM training courses. However, it can be noted that medium-sized and large businesses use the services of external consultants to a greater extent.

6 A question inquiring into manager’s focus on secondary objectives related to the implementation of process management (section 3.4) also examines the perception of process management as an overall strategic change. Ambiguity in the opinions of Czech managers cannot clearly confirm or disprove the last hypothesis. Currently, managers in the BPM implementation focus more on the requirements of certification according to ISO 900X. In the future, however, it is possible to expect from managers a shift moving towards the understanding of process management as an overall strategic change. On the other hand, it should be noted that the previous research had expected from the current one much higher levels of agreement with the perception of BPM as the overall strategic change than actually shown by the managers.

The issue of BPM vs. IT? It is possible to state, that organizational change using IT can begin with an analysis of existing organizational elements and an identification of ways to change the dependencies among them, especially between processes. Therefore, IT is one of the fundamental elements of Business Process Change (BPC) (Habjan & Popovic, 2008). Its role is significant throughout the entire duration of process change: before the process is designed (IT as an enabler), while the process is being designed (IT as a facilitator) and after the design is complete (IT as an implementer). Therefore, building a responsive IT infrastructure is the key factor for successful implementation of BPC. There is considerable anecdotal evidence that even small changes in the use of IT in an organization may require major restructuring of the organization to take full advantage of the efficiencies created by the technology. Conversely, there is also significant evidence that without major restructuring, the introduction of IT may not produce savings needed to justify the investment. Although the evidence for organizational restructuring to accompany technological change is strong, there is much less agreement on exactly what organizational changes are needed to take full advantage of the technology (Habjan & Popovic, 2008).

The utilization of process management in the Czech Republic, according to Weske (2007), can be also indicated as a hot topic today. Based on the conducted research, it is evident that the level of the use of BPM has been still, albeit slowly, growing. Managers begin to gradually understand the transition to process management as an overall strategic change. The complexity of individual components of process management is also starting to get into the minds of Czech managers of primarily medium-sized and large enterprises. As a negative result of the research carried out can be identified the fact that Czech managers put hardly any emphasis on the management of supporting processes and internal customer satisfaction.

3.7 BENEFITS INCORPORATED WITH LEAN PRODUCTION IN LOGISTICS

In spite of the zeal to embark on lean in the manufacturing sector. There are some challenges that come with it; some of these setbacks are discussed in the preceding chapter. In a research carried out by (Kilpatrick, 2003), it was evidenced that there were some challenges in the quest to implement lean business system. Some of these include,

Most companies fail to blend the improvement metrics to the financial statements. This stems from the notion that issues regarding money are not factored into the rate of improvement in the company, and hence makes it inevitable for efficient and effective lean application.

The building blocks of lean applications are calculated in a wrong direction. This result in an inability of production to go hand in hand with the mode of operation. This problem tempers the way and manner of utilizing lean application.

The tendency of embarking on low-impact project can ruin the efficiency of lean implementation. Of course if lean project proves futile, it goes a long way to affect the business system in, low return on investments, and the support of future projects also diminish.

Implementation of lean into companies takes a couple of years to succeed in larger and multinational companies. This long spun of years coupled with labour turn over results in the inability to fully embark on lean application within large full-fledge companies. For instance a manager starts the implementation and consequently leaves in the middle of the journey for someone else making it tedious for succession.

The attempt to embark on lean application changes the entire organizational culture of companies. The cause of this nature creates unhappiness in most of the companies, the rate of destabilization as a matter of lean application reduce production and hence increase cost.

Although, (Kilpatrick, 2003), argued that lean application has some challenges in its applications, he also enumerated some benefits associated with its implementation in three folds. These three metrics acquired by companies in pursuit of lean application are in the context of operational, administrative and strategic improvements.

Operational improvements: The basic tenets underlying operational set up of a manufacturing sector includes ,how progressive the sector is moving i.e. is manufacturing moving in the right direction?, proper space utilization, efficiency of logistics processes, increased in productivity, reduction in cycled time and among others.

With the efficient use of lean application in the operational sector, the likelihood of been successful in the aforementioned tenets of production.

Administrative Improvements: The tendency for administrative functions to improve as a result of lean implementation is common in the manufacturing sectors. Effective lean implementation results in the following advantages in the sector, processing errors are highly reduced ,paper work in the sector are giving a thought and hence reduced in the office, employees in the work place are apportioned well in their scheduled task. Documentation regarding the purpose of the manufacturing sector is critically looked at and hence processes geared towards customer satisfaction are streamlined.

Strategic Improvements: Management of every manufacturing sector adopts a strategic measure to succeed in business. With the idea of implementing lean in this sector, the higher the success attained. Lean in its wisdom sets the pace for profit maximization. The principles in applying lean make it prudent for improving the sector strategically.

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Chapter 4

Investments in logistics

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Abstract

Many of logistics activities are involved to execute other processes as supporting activities. According to the organization's culture supporting activities should be managed as a part of the supported processes or should be managed as a constituted parts of the independent logistic process.

On the other hand investment allows the maintenance of existing business operations, its increase or change in operations. In other words, organizations achieve their desired and expected business benefits mainly by selecting the right investments and by effectively managing them. Investment management begins in the conceptual stage of an investment and lasts until its implementation, and eventually it can be observed through the consequent business benefits that are relative to the values expected from the investment.

The importance of concretion business benefits with investments in logistics in an organization can be seen very large, especially because they are integrated into a network of other business investments with all specifics of logistics as a set of supporting activities within an organization.

Effective management cannot operate without effective control. Without both, effective management and control, there is a great possibility that investments will not bring benefits. Poorly controlled investments may even lead to losses. Based on the survey we found that in this area we do not use any necessary frameworks, standards or tools to manage investments in logistics effectively. Furthermore, it has become evident that we are faced with a lack of knowledge and awareness of their importance. The survey also shows that in the terms of investment in logistics there is much room for further development, innovation and change of existing practices.

Keywords: logistics, investment, performance analysis.

4.1 INTRODUCTION TO THE IVESTMENTS IN LOGISTICS

In most cases, the common denominator of business investments is that a great or even major part of a business investment is an investment in logistics, because in most cases, logistics is expressed as critical component of business. Therefore, the importance of concretized business benefits with investments in an organization can be seen as very large. What's even more important is the management of investments throughout its life cycle within the investment management in an organization – so investments in logistics should not be regarded as a single whole, but only as investments that are integrated into a network of other business investment (IT Governance Institute, 2006, 2007, 2008a, 2008b, 2008c). Any investment in logistics must have a clear business benefit, should contribute to business objectives and must be assessed through the prism of contributing to the business objectives. It must have its eligibility an expected correlation between inputs and utility.

Investment management begins in the conceptual stage of an investment and lasts until its implementation, and eventually is looked at through the consequent business benefits that are relative to the values expected from the investment. Effective management cannot operate without effective control. Without both, effective management and control there is a great possibility that investments will not bring benefits. Poorly controlled investments may even lead to losses. (Jereb, Cvahte, Rosi, 2012; Jereb, Cvahte, Rosi, 2012a; Jereb, Rosak-Szyrocka, 2014)

Both, practice and empirical research suggest that the investments that are managed within an effective supervisory framework achieve significantly better results than when implemented without supervisory approaches and frameworks. In this paper we describe the use of the Val IT framework, which provides approaches for successfully managing IT investments and will be administered to managing investments in logistics.

From this point on, the chapter is based on the hypothesis that both IT and logistics are similar to the extent that – depending on the position and relationship to other business processes within the organization and in particular with regard to perception by management – it is possible to appropriately use frameworks, primarily developed for IT, in logistics. Thus, we suggest using the same approaches to address the challenges associated with investments in logistics that have been successfully used for investments in IT. In this awareness is needed that in adapting solutions from one field to another, specifics of a certain field should be accounted for. Therefore it is not enough to simply replace phrases including IT with phrases that contain the word logistics. The approach in where investments in logistics use guidance from the related field of IT can be particularly meaningful because of the fact that there is currently no framework available on the field of investments in logistics, even though it is needed in practice.

As the field of IT has largely developed procedures for managing investments throughout their life cycle in a plethora of different organizations, in the field of logistics, the case is very much different. But, since quite some parallels can be seen between IT and logistics, our previous research was focused on developing a framework for managing investments in logistics by adapting guidelines from IT into the Val Log framework.

However, the development of the logistics framework is currently in the proposal stage, and ultimately we are hopeful the Val Log framework will be found useful. We can presume this according to the taken assumptions and experience, but it will be finally recognized as commonly useful only after it is thoroughly verified by practical use.

Val Log is a framework with complementary and mutually connected processes as well as with other guidelines on tactical level for managing investments in logistics, which are adapted for top leadership working on strategic level of the management pyramid. Processes and instructions are written in the language of leadership in a way that a leader can understand and use. At the same time it distinguishes the respective roles of members of the management of such investments.

The chapter is organized so that it begins with a section of status report on the investments in logistics. Section where Val Log as a framework of investments in logistics follows. Val Log is based on the common point and similarities between the fields of IT and logistics. Both sections end with their own short discussion.

4.2 STATUS REPORT ON THE INVESTMENTS IN LOGISTICS

This section shows the current state of investments and their management on the field of logistics. The research is based on a survey that was made using a questionnaire, answers to which revealed some important information that we need to assess the actual state of investments in logistics.

Currently, there is no equivalent research from this area, as this specific area is not well studied. At the same time we have not found any equivalent research into the state of the art of logistics investment management in the accessible literature. This work shows that it is possible and even necessary to raise investments in logistics to a higher level of management. Its idea is derived from previous research into logistics investments and their role in different aspects of business and its continuity. Research into the effects of investments in logistics as a means of increasing shareholder value can be found as early in 1999, when Walters (Walters, 1998) identified investment management in logistics companies as one of four essential elements of shareholder value planning. Similarly, Lambert and Burduroglu (Lambert, Burduroglu, 2000) identified the importance of value creation through investments in the logistics functional area, especially in the view of ensuring that a firm receives adequate rewards for their investments, innovations and performance in logistics (for this reason, of course the value derived from investments and innovations must be properly measured). Some authors, for example Wagner (Wagner, 2008), find that investments, especially those in infrastructure and capital goods, can help logistics companies generate innovative products or services and processes. Finally, the importance of investments in logistics as a building block of efficient logistics is well described by Christopher (Christopher, 2011), who sees a continuous program of improvement, innovation and investments into the logistics framework (consisting of quality, service, cost and time) as a prerequisite to gaining and maintaining logistics competitive advantage.

As a team of logistics researchers we are constantly interested about the position of logistics in organizations in our country and comparing that with other countries in Europe. This interest and comparison are important, because as educators of the next employment seekers we need to be extensively informed about the role of logistics as much as possible. Besides that, our main thought is that investments management in logistics could take logistics to a higher level, which is one of the major goals of our research (Jereb, Cvahte, Rosi, 2013).

Our survey was based on the method of interviewing with a questionnaire as the main tool of the research. In addition, an analytical approach was included with two most important procedures of analysis and synthesis. The objectives of this research were to present important information; explore the current state of investments in logistics in all of chosen companies in Slovenia and Croatia and to make a critical analysis, which helped us to present proposals improvement.

The survey for analyzing investment management in logistics covered 42 companies in 2 countries (Slovenia and Croatia), from many different industries, both large and small, and also public and private organizations. Our surveyors had to take a balanced and holistic approach with the questionnaire as well as with the process of surveying itself. The questionnaire that we used to interview selected organizations was modeled according to Global Status Report on the Governance of Enterprise IT (GEIT) in 2011 (ITGI 2011).

The questionnaire consists out of 40 questions on 15 pages, from more general to specific ones. As such, the questionnaire was divided into sections, in our case 3 of them. We were specifically interested in every company's placement (first 9 questions), understanding and knowledge of logistics (from 10th to 20th question), logistics management (with outsourcing, implementation of mechanisms and change of business), innovations and investment management in logistics (Val Log).

One of the presumptions of our research was that the position of logistics depends on characteristics of every organization. With the first group of questions in our questionnaire (every company's placement) we had information that we needed to acknowledge the position of logistics. We asked about the role and the working area of the respondent, the function in companies' administration, the sector, number of employees, number of employees with degrees in logistics, the income, the companies' structure and the business goals.

In the second part we focused on the meaning and knowledge of logistics within the company as well as on the organization of logistics, the model of logistics, the role of logistics, potential logistics manager, the impact of logistics on business, projects in logistics, logistics management etc. The data from this part will enable us to establish connections and legality that effect differently organized models of logistics and also investments in logistics.

The third part refers on implementation and management of logistics, outsourcing, implementation of mechanisms, business change, innovation in logistics, investments in logistics or the effectiveness of investment management (as set out in Val LOG – see (ITGI 2008c)).

4.2.1 Results

From 42 acquired questionnaires we mostly communicated with the leaders on the strategic level most directly related to logistics, this was the case in 61.7 % of organizations. Mostly, the direct respondents are responsible for logistics or they are a part of the companies' board. The companies are generally from the manufacturing sector (57.1 %), transport and retailing (19 %) and healthcare/pharmacy (7.1 %). 40.5 % of companies is listed among medium-sized enterprises, 35.7 % among large enterprises and 16.7 % among small businesses. Mostly they are privately owned (71.4 %), 21.4 % of them are in the public sector, and 7.4 % in mixed property. The two most important business objectives that companies selected are production efficiency/cost reduction (59.5 %) and service quality (66.7 %) (Uranjek, Cvahte, Rosi, Jereb, 1013).

Below, some specific results of the survey, which we find most interesting and crucial to our research, are presented with charts and explanations.

Maturity of logistics investments management

One of the most important information we can gain from organizations is their view of how logistics investments are being managed. Therefore, our goal was to determine if and how these investments are managed and whether some measurements and optimization is in place. Therefore, the question the respondents were asked was: “How would you evaluate the maturity of your business to manage investments in logistics?” The results are shown in Figure 4.1.

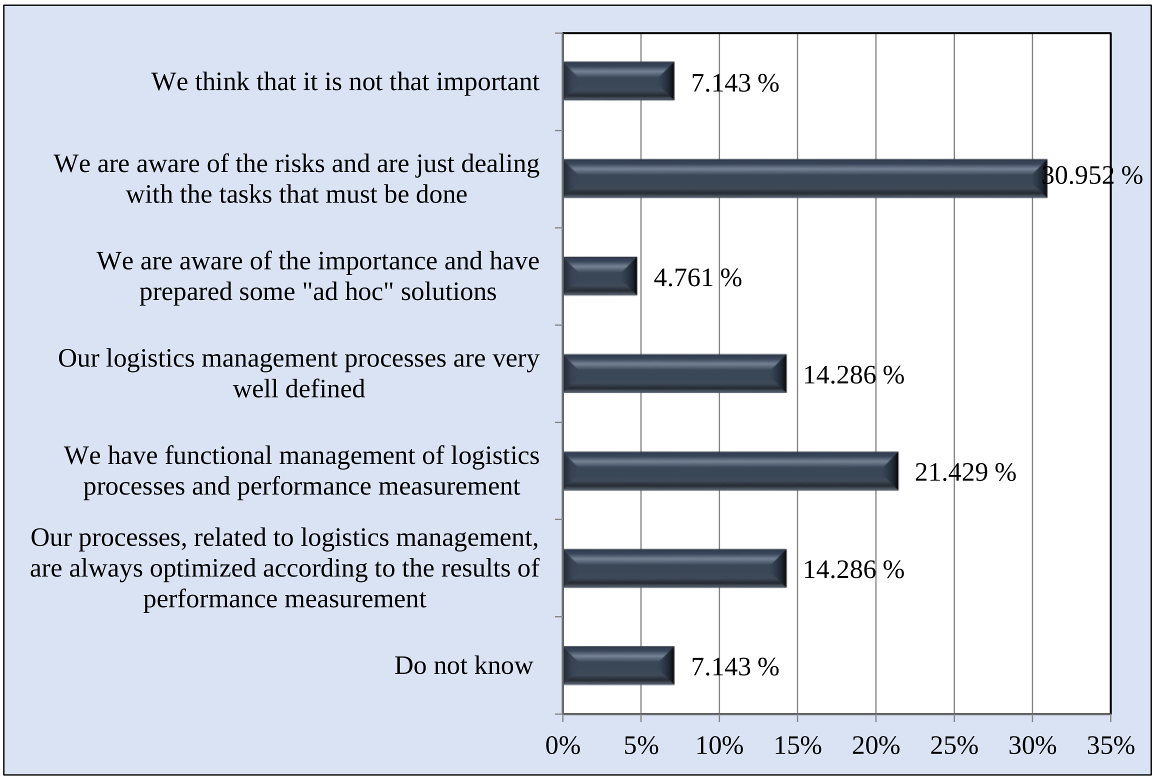


Figure 4.1 Evaluation of maturity of the organization to manage investments in logistics (Uranjek, Cvahte, Rosi, Jereb, 1013)

With this question, respondents were required to give only one answer. Almost one third of organizations claims to be aware of their risks and is dealing with the tasks that must be done to mitigate them. With 21.429 %, the answer that they have functional management of logistics processes and performance management takes the second place. It attracts attention that 7.143 % of respondents thought that the maturity of business approaches to investment management is not important. However, we can see that mostly, organizations are aware of the importance of managing logistics investments and do have at least some basic procedures in the field in place.

Innovations in logistics

In order to determine the scale and need for future investments, expected innovations in logistics are important, because innovations must be supported by planned and managed investments. Therefore, the respondents were asked: “Are you planning or will you plan to implement any initiative to promote innovation in logistics?”. The results are shown in Figure 4.2.

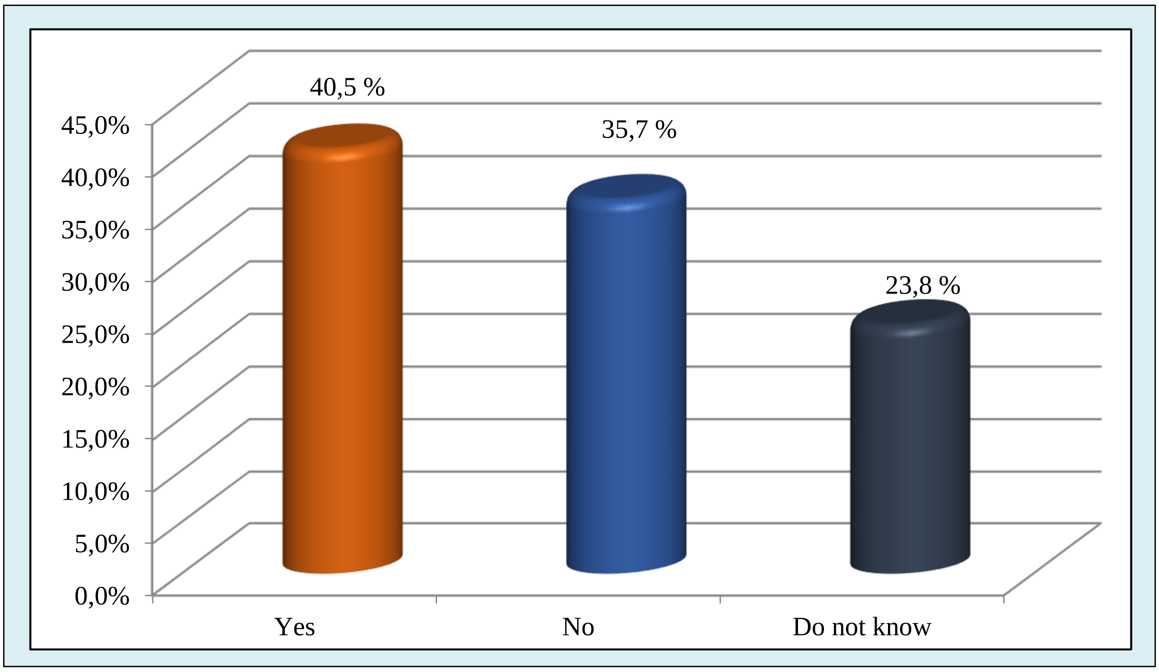


Figure 4.2 Plans to implement initiatives to promote logistics innovations (Uranjek, Cvahte, Rosi, Jereb, 1013)

In contrary to the expectations, 40.5 % of companies is planning (or will plan) to implement some initiatives to promote innovations in the field of logistics. Together with those who do not know whether they will plan innovations in logistics in the near future, these represent a major part of all organizations that will need to focus on managing logistics investments in the future. Therefore, we can assert that a large percentage of organizations will have the need for a structured approach towards this management aspect.

Promotion of innovations in logistics

As stated earlier, innovations in logistics must be supported by investments. In order to implement strategic innovations, some procedures and plans must be in place, therefore we inquired about those as well. The question, asked was: “Please specify the mechanisms that have been introduced or you are planning to introduce them in the next year for the promotion of innovation in logistics in your company.”. The results are shown in Figure 4.3.

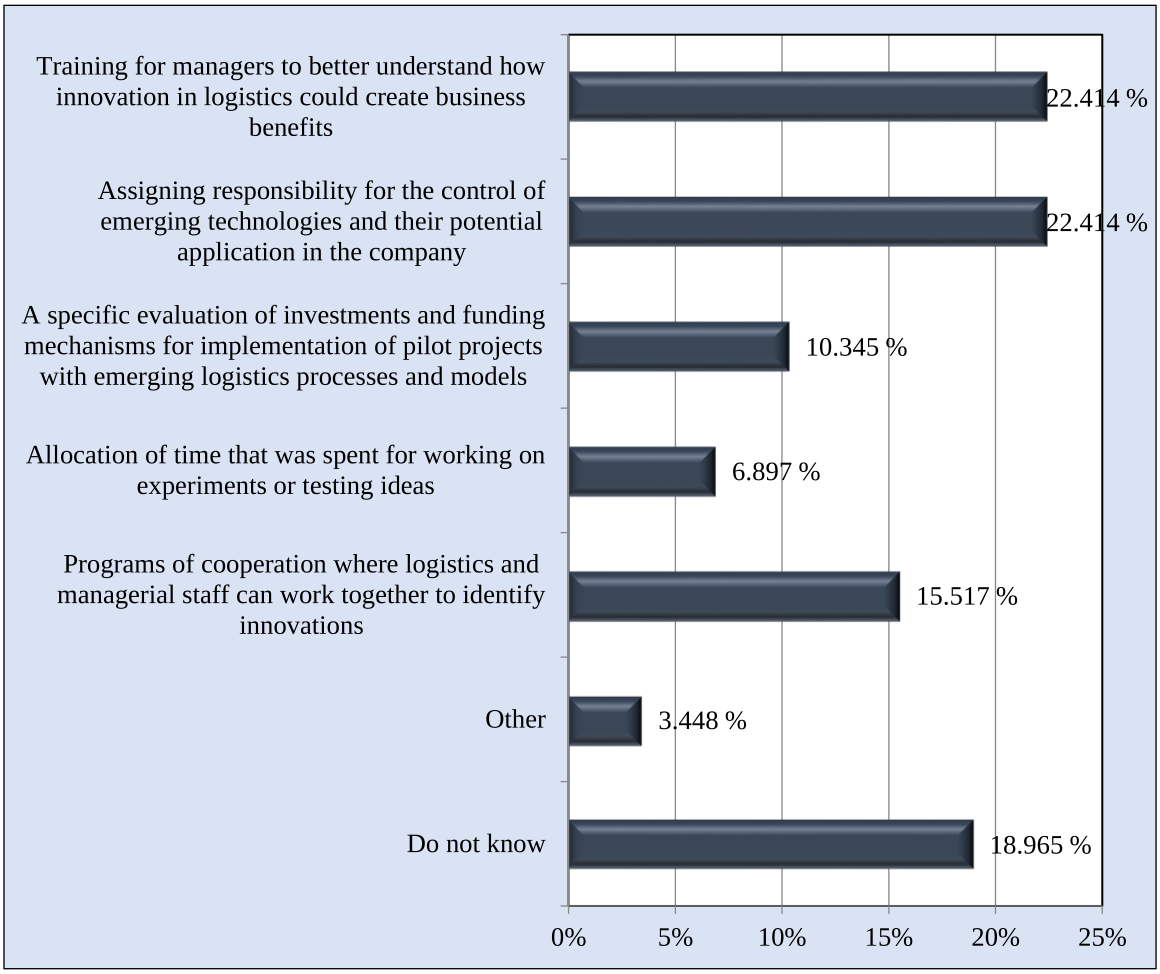


Figure 4.3 Introduction of mechanisms to promote logistics innovations (Uranjek, Cvahte, Rosi, Jereb, 1013)

This question did not require only one answer from the respondent. It seem like training for managers (for better understanding of innovation in logistics) and assigning responsibility for the control of emerging technologies are the main two mechanisms that have been (or plan to be) introduced for the promotion of innovations in logistics. Interestingly, more specific mechanisms, such as evaluations or testing, are not so commonly in place, and a concerning 19 % do not know how they plan their innovations.

Evaluation of investment performance

Assessing the usefulness and expected outcomes of every investment should be a priority in organizations striving to optimize their business operations and expenses. Therefore, some metrics or procedures for this evaluation need to be in place, and that was the subject of the next inquiry. The question, asked was: “Do you have an evaluation metric of performance of investments in logistics?” and the results are in Figure 4.4.

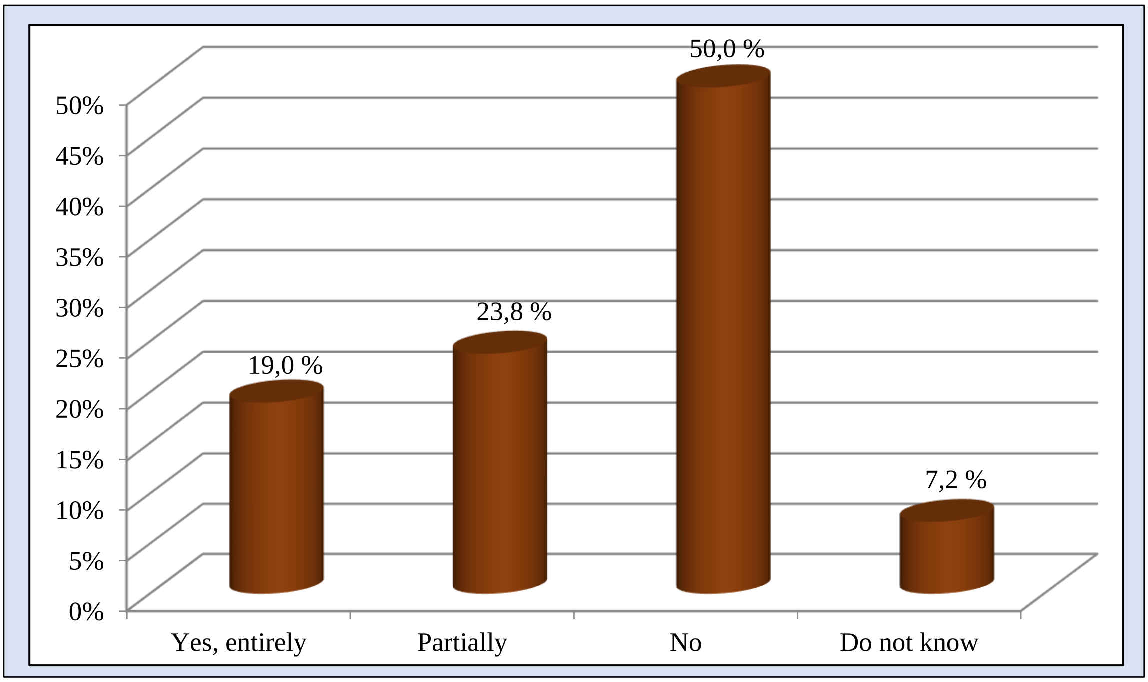


Figure 4.4 Existence of evaluation metrics for logistics investments (Uranjek, Cvahte, Rosi, Jereb, 1013)

Half of the organizations do not have any evaluation metric of performance of investments in logistics, in addition that 7.2 % of them do not know about this matter. Only 19 % claim to have metrics in place to evaluate investments in logistics, which shows a large deficit of awareness and control procedures.

Val Log

As previously mentioned, the field of IT has largely developed procedures for managing investments throughout their life cycle in a plethora of different organizations. On the field of logistics, the case is very much different, but since quite some parallels can be seen between IT and logistics, our previous research focused on developing a framework for managing investments in logistics by adapting guidelines from IT into the Val Log framework. The question to the respondents was: “Have you ever encountered the concept of investment management performance in logistics (e.g. Val Log)?” See Figure 4.5.

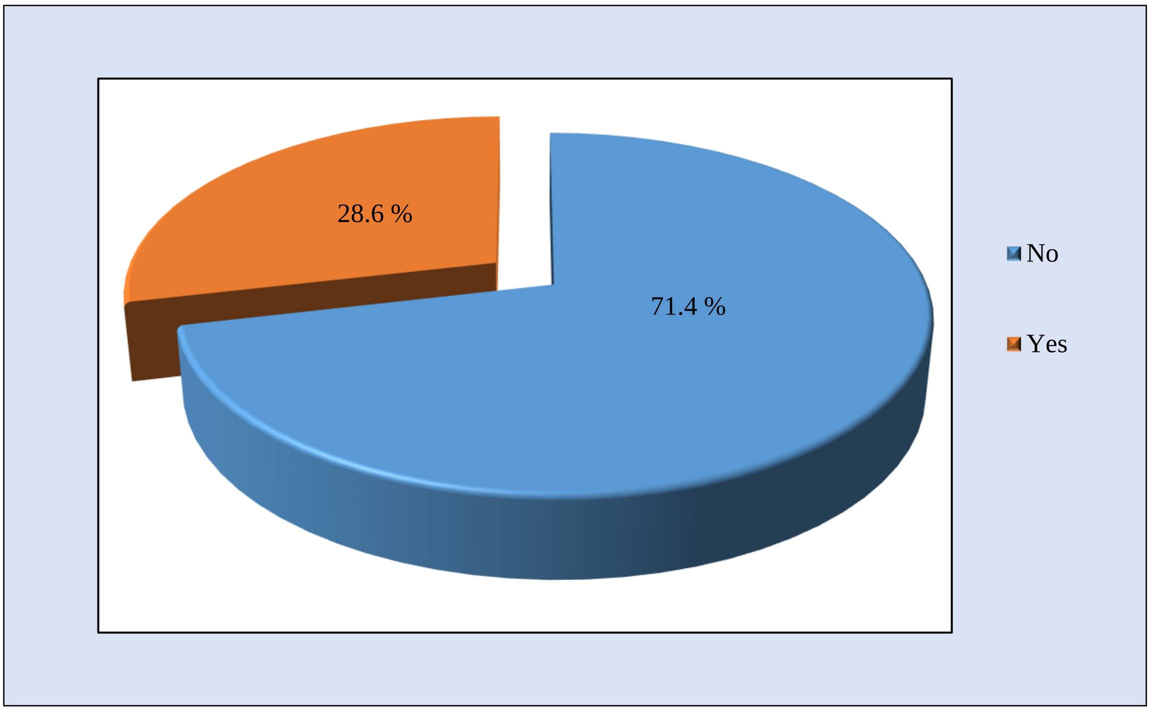


Figure 4.5 Encounter the concept of investment management performance in logistics (e.g. Val Log) (Uranjek, Cvahte, Rosi, Jereb, 1013)

Based on the results it seems Val Log is a distinct expression, 71.4 % of respondents are familiar with it. This can be interpreted as a sign that organizations are working or at least thinking towards better management of their logistics investments.

Planning level of logistics investments

In logistics (as in every other business aspect), three levels of planning can be identified – strategic, tactical and operational. In order to achieve maximum effectiveness of investments and to ensure they are in accordance with overall strategic goals of an organization, ideally they should be planned from the strategic level down. Therefore one of the main points of logistics investment research was to find out on what level organizations tend to begin logistics investment planning. The respondents were asked "At what level does your company start to think about investing in logistics?" The results are shown in Figure 4.6.

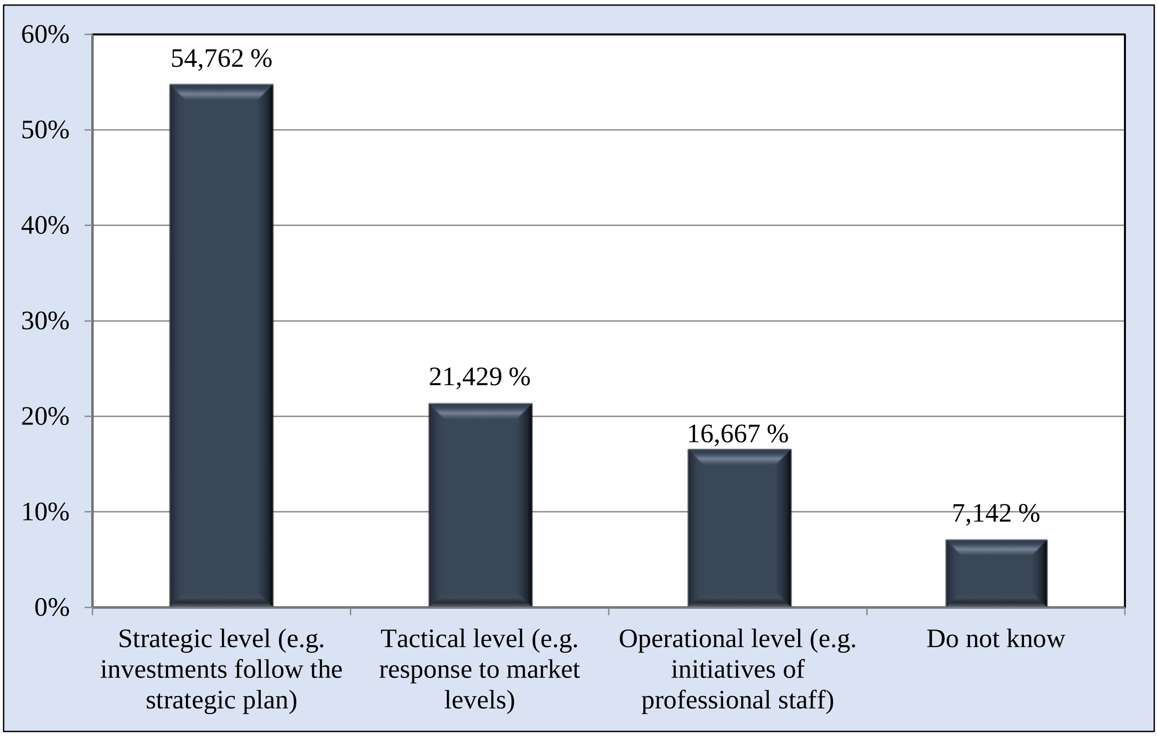


Figure 4.6 Level of planning logistics investments (Uranjek, Cvahte, Rosi, Jereb, 1013)

The strategic level is the one where plans and decisions about investment in logistics are mostly made. A significantly smaller percentage of organizations plan them at the tactical level, and only 16.7 % plan their logistics investments only on a day-to-day basis. This shows a step towards integration of logistics investments into an organization's strategy, but at the same time implies the need to put in place some recognized frameworks for their planning, implementation and evaluation.

Level of decision-making

Similarly to levels of logistics planning, the level of decision-making is also an indicator of the development of managing logistics investments. The higher the level of decision-making, the higher is the awareness of the importance of managing these investments. The question, asked was: “If your company decides to invest in logistics, who is managing or controlling these investments?” and the results are shown in Figure 4.7.

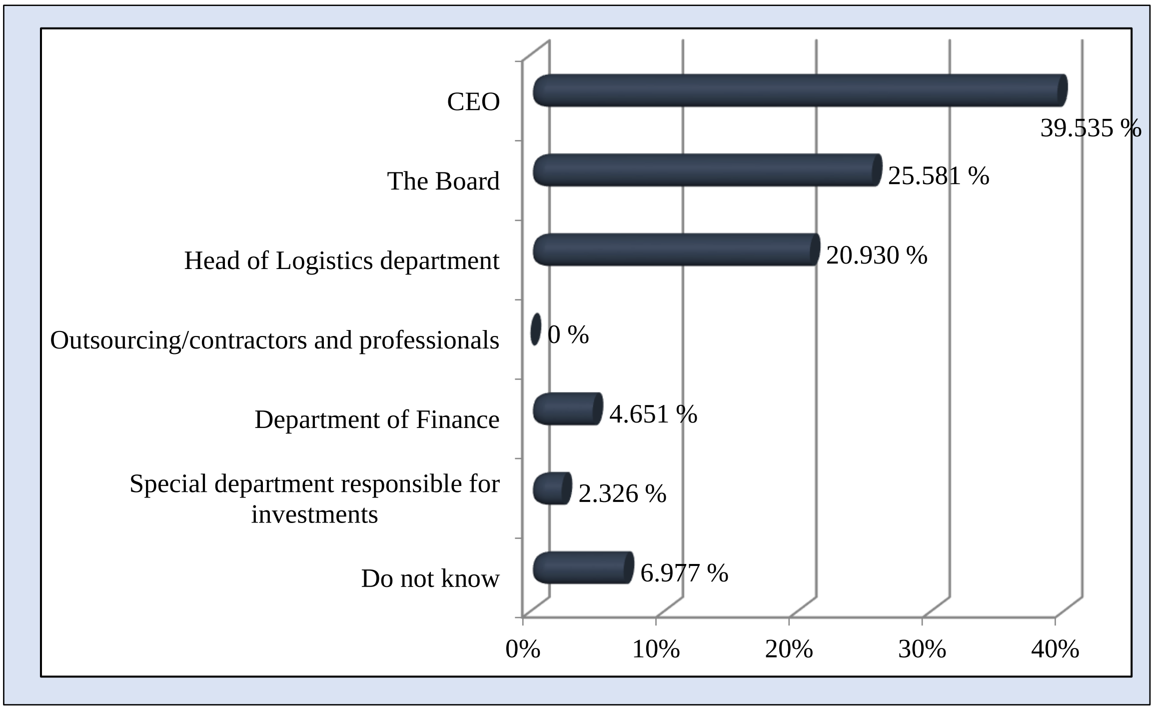


Figure 4.7 Responsibility for managing logistics investments (Uranjek, Cvahte, Rosi, Jereb, 1013)

In accordance with this, CEO and the Board are mostly the ones who manage or control investments in logistics; this is also in accordance with the fact that more than half of organizations plan their logistics investments at the strategic level. Even investments that are being managed by a special department or the head of logistics can be said to be managed at a sufficient level of decision-making.

Reasons for investing in logistics

In order to assess and plan an adequate framework for logistics investments management, the knowledge of why organizations decide to invest is most important. Therefore, one of the main questions of our survey was: “What do you think are the main reasons for investment in logistics?” The results are shown in Figure 4.8.

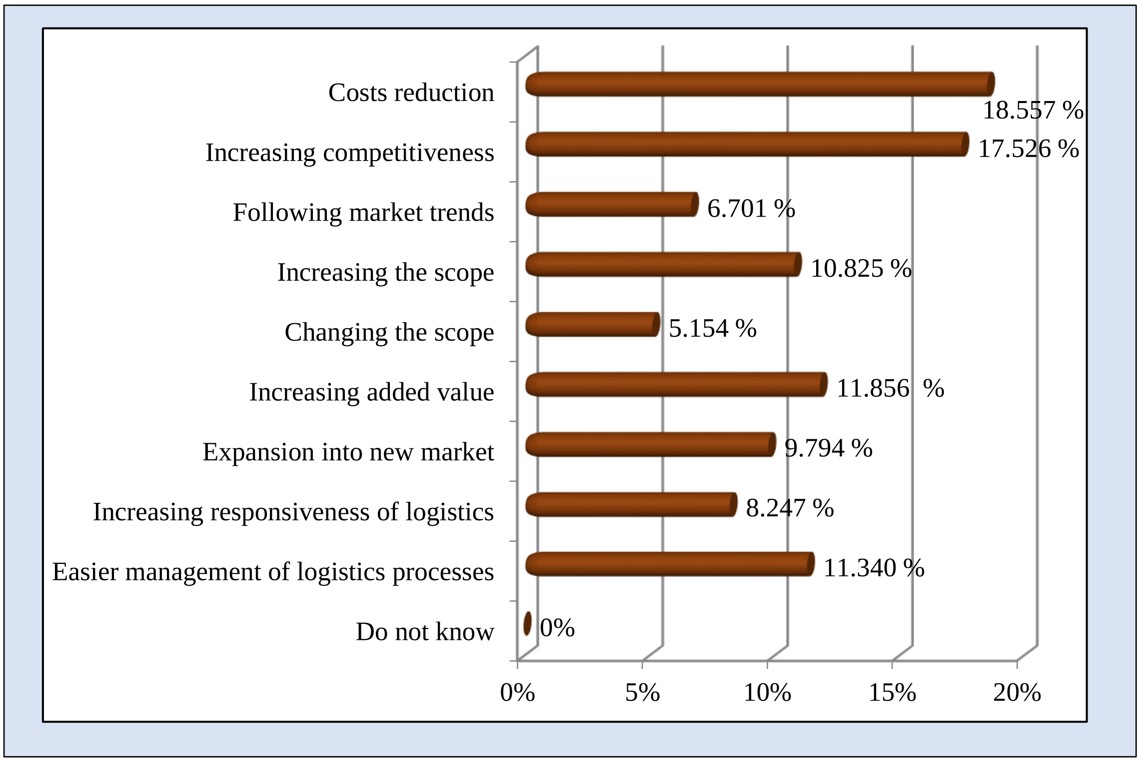


Figure 4.8 Incentives for logistics investments (Uranjek, Cvahte, Rosi, Jereb, 1013)

The most respondents replied that reducing costs and increasing competitiveness are the two main reasons for investing in logistics (these two reasons were expected given the global crisis situation). Added value, easier management of processes and increasing the scope of logistics were also mentioned as more important expected outcomes of investments.

Current use of logistics investment management tools

The main objective of this chapter focuses on the use (or lack of) of tools for managing logistics investments in organizations. Therefore, our basic inquiry consisted of determining whether some form of standardized tools are being used for these tasks. This was asked with the question: “Does your company use any tools for managing investments in logistics?“ The results are shown in Figure 4.9.

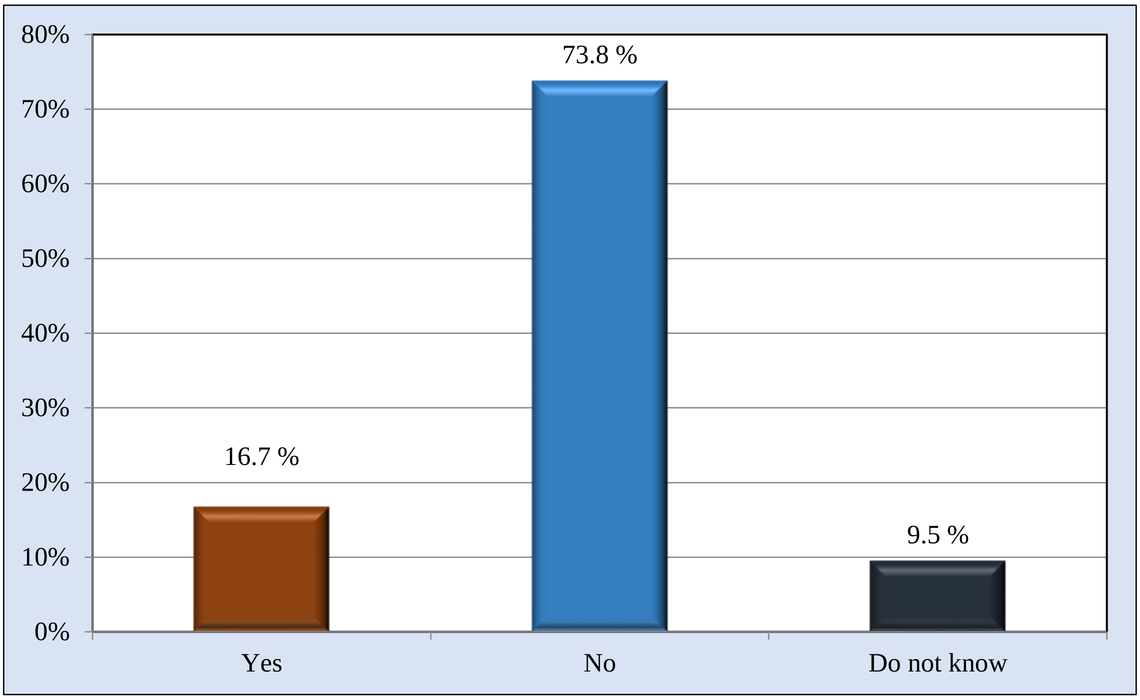


Figure 4.9 Use of tools for managing logistics investments (Uranjek, Cvahte, Rosi, Jereb, 1013)

The fact that this question was mostly answered negatively shows that companies are not familiar with the tools that can be used for managing investments in logistics (therefore a lack of knowledge in this field is obvious). Even though some previous questions pointed towards a better state of this field (for example the fact that logistics investments are managed on the strategic level), it can obviously be pointed out that most attempts are not backed up by the use of standard, all-encompassing tools or frameworks.

4.2.2 Discussion

The survey and its analysis revealed a significant degree of accord on the contribution of logistics to business success, the challenges and opportunities connected to logistics, the impact of the economic crisis and views on logistics outsourcing and social networking. The survey findings lend themselves to a variety of conclusions and issues to consider. There are still significant opportunities for many enterprises to transition logistics role to a more pro-active one. This can be done through the use of an appropriate organization structure encompassing roles for managing business relationships and standardized process to effectively bridge the business demand with the logistics supply. Innovations in logistics offer ample opportunities for logistics to play a more pro-active role. The right governance enablers can ensure the transparency of logistics supply and demand and facilitate decision-making about demand and its prioritization on pursuit of value delivery to the enterprise.

The final conclusion is that the position of logistics depends on organization's size, structure, the model and the role of logistics, the impact of logistics on business, logistics management etc. The survey also showed that the sector (public/private) of an organization does not particularly influence its position of logistics.

4.3 VAL LOG: A FRAMEWORK OF INVESTMENTS IN LOGISTICS

Under the concept of information technology (IT) we imagine a wide array of technologies and activities in organizations related to managing and processing information. As we encounter information almost everywhere in daily life and deal with them more and more every day, IT is embedded in almost all aspects of our lives. Here, logistics is no exception. Even more: one of the definitions of logistics reads: "... logistics includes the physical flow of material and information flow from the supplier ... " (Logistika, 2012). In this definition, the concept of information is presented as one of the subject on which logistics focuses. Both fields, information technology and logistics, are dealing with information.

But the information field is far from representing the only common intersection of the two fields. Both, logistics and IT sectors are necessary for the implementation of other business processes in organizations. As mainly infrastructural processes, they have much in common in relation to other business processes within the organization. They have similar challenges related to the required quality of service, to investments, risks, business ownership and their management. Their role is support, maintenance and development of business strategies and goals. In the individual business processes, investments, risks and other objectives we are dealing with IT or logistics processes, investments, and other risks, as well as with objectives that are own to each field, as is shown in Figure 4.10. In this, business processes usually define requirements for IT or logistics. Yet the difference is that with IT, in most cases a wider field is covered while it should also provide for smooth operation of logistics. So IT is a field which represents a part of logistics infrastructure. In lesser extent, vice versa can be applied, but generally speaking informatics is regarded as a foundation for logistics, especially since IT processes enable the implementation of logistics processes.

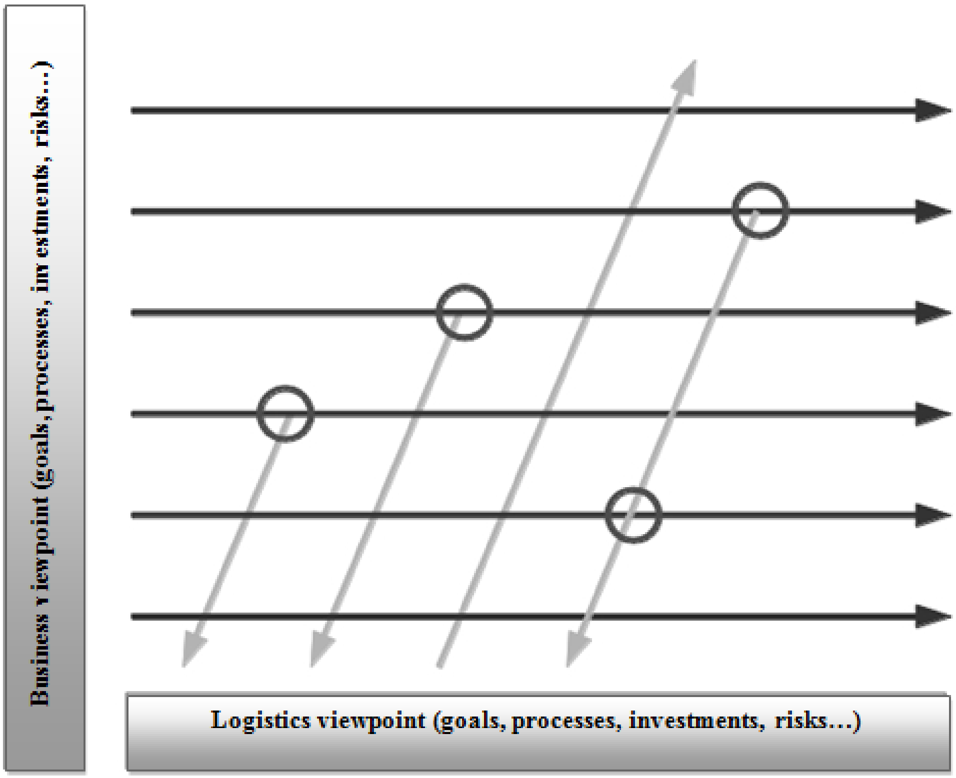


Figure 4.10 Cross points between business and IT/logistics fields (Source: adapted from ITGI,

2008c)

In IT, the following resources are available to implement IT processes; they can be "seen", invested into and ultimately protected (ITGI, 2007):

1. Information is the data, in all their forms; input,processed data and output by the information systems in whatever form is used by the business.
2. Applications are the automated user systems and manual procedures that process the information.
3. Infrastructure is the technology and facilities (i.e., hardware, operating systems, database management systems, networking, multimedia, and the environment that houses and supports them) that enable the processing of the applications.
4. People are the personnel required to plan, organize, acquire, implement, deliver, support, monitor and evaluate the information systems and services. They may be internal, outsourced or contracted as required.

Similarly, we also need to define the basic or primary resources which are specific to logistics and can be managed or invested into. Here we suggest the following logistical resources (Jereb, Cvahte, Rosi, 2011):

1. Flow of goods and services should be managed from the point of origin to the point of use in order to meet the requirements of customers.
2. Information is the data, in all their forms, input, processed and output by the information systems in whatever form is used by the business.
3. Logistics infrastructure and supra-structure as basic physical and organizational structures needed for the operation of logistics.
4. People are the personnel required to plan, organize, acquire, implement, deliver, support, monitor and evaluate the logistics systems and services. They may be internal, outsourced or contracted as required.

Definition of logistics resources is a prerequisite for the use of Val IT in logistics.

4.3.1 The importance of investments in logistics

The table 4.1 shows an amended introductory part of Val IT, adapted for use in logistics. The term "Val IT" was changed into "Val Log" wherever it refers to investments in logistics.

Table 4.1 A portion of the introductory part of Val IT, tailored to logistics (Source: adapted from ITGI, 2008c)

A prerequisite for determining the business benefits of investment in logistics is to achieve understanding with those, responsible for business investments (i.e. management), how logistics contributes to achieving business objectives. At all levels of management and all consequent levels of management of each investment it must be made clear how and to what extent the investment in logistics can contribute to accomplishing specific business goals.

What has been missing for many years has been ready access to a structured approach – a comprehensive, proven, practice-based structured governance framework—that can provide boards and executive management teams with practical guidance in making logistics investment decisions and using logistics to create enterprise value. With Val Log we produced a much needed framework for managing investments in logistics.

The views on logistics have changed over time, and until just recently, we evaluated the quality of logistics in light of factors that point to its success in supporting the implementation of business processes – nothing more and nothing less. Because today, along with updated means of performance evaluation, we look at logistics performance through the prism of investment in logistics, the focus is no longer just on the implementation of logistics solutions. Increasingly, we are aware that the goal is to implement some business changes, which allow for investments in logistics. Investment in logistics becomes an activity that is needed to achieve business results. Through performance evaluation of business investments, we are starting to assess the effectiveness of investment in logistics. This is the focus of interest (in the world of logistics) that is being further expanded to monitor the performance of investments in logistics. The new value gained by investing in logistics becomes a central concept in logistics. We wonder about the benefits that such investments can bring towards a new business value. In doing so, let us not forget that with investment in logistics we aim for both, maintenance as well as an increase or change in operations.

Because of evaluation of investments in logistics, we are starting to realize that also risks in logistics are substantially more complex and more important as we have been accustomed to seeing and taking in the past. On one hand, an evolution is present through which we recognize and acknowledge the impact of new elements in logistics operations; on the other hand, it is a fact that logistics represents a growingly large and important part of business and thereby the increase of impact of logistics on business operations is clear. A further consequence is reflected in the request for revision of management practices – including management practices in logistics. Practices that were current not long ago, are becoming not enough complex and inadequate. In the past, less attention was given to investments in logistics as is required by the present time. It looks as though the study of the performance of investments in logistics is becoming a crucial topic, which engages or will engage leaders in the logistics business. This applies to both public and private organizations.
In both, the only difference is that the performance evaluation of investment in logistics in the public sector proves to be more difficult, because here complexity and multilayered characteristics are more apparent, which contributes to increased complexity of evaluation.

We believe that the text in the table is essential for understanding the importance of investments in logistics. It refers to the relationship between 'business' investments and investments in 'logistics' and concludes that ultimately, they are still 'business' investments and as such are in the domain of management. It concludes by noting that investments are a complex matter, which requires new skills and changed attitude towards such investments. Although it was originally intended for investments in IT, the text is also current for logistics.

In Table 4.2 another portion of the adapted Val Log framework is included, which speaks about the role of leadership in business as well as about the relevance and need for guidelines for management of investments in logistics.

Table 4.2 A portion of Val IT, which speaks of the need for guidelines for the management of investments in logistic (Source: adapted from ITGI, 2008c)

Investments in business solutions that are supported by logistics or mainly by logistics can be repaid many times over, but only while ensuring the implementation of appropriate control and management activities and the full support and involvement of business management at all levels. Leadership in the past has not had a good overview of the investment in logistics. The practice of reporting and evaluation of investments in logistics has been deficient. Such a bad practice prevails even today, but with the evaluation of performance of investments in logistics practice itself is changing. Investments performance, which includes investments in logistics, is well understood by organization management, who also wish to have reports on their performance.

Due to a lack of knowledge about what IT investment and the problems which arise when evaluating the performance of IT investments are, the IT Governance Institute investigated options for improving the situation. They cooperated with experts from business and IT community. The result was the so-called Val IT initiative. The aim was to make this initiative lead organizations through providing various guidelines, which are associated with IT investments. Policies are prepared so that more optimal IT investments can be provided as a part of business solutions with known and acceptable risk. (ITGI, 2007) We use the analogy of the guidelines for investment in logistics (this sentence is an addition to the original text).

Val Log is a framework with complementary and mutually connected processes as well as with other guidelines for managing investments in logistics, which are adapted for top leadership of the management pyramid. Processes and instructions are written in the language of leadership in a way that a leader can understand and use. At the same time it distinguishes the respective roles of members of the management of such investments.

In Table 2, the claim that could be controversial in practice is: "leadership in the past have not had a good overview of the investment in logistics ". This is especially likely to be controversial for more specialized logistics organizations. But it is important to realize that logistics processes occur in every organization, not only in specialized logistics organizations, which together far surpass the number of specialized logistics organizations. From practice we can see that this in fact is true, although in this paper, we have no objective empirical evidence that this is the case. In future research, a thorough investigation of the situation and the position or the role of logistics in the hierarchy of different organizations will be needed.

In Table 4.3, a fragment of the work is given, which more accurately describes what can be expected from Val Log and what not.

Table 4.3 Detailed description of the Val Log mission and differences with SCOR (Source: adapted from ITGI, 2008c)

Val Log is useful when focusing on investments, where we ask ourselves:

1. Are we doing things right? Are the chosen investments right? These are strategic questions, among which the next questions are linked to investments:
    a) Do the chosen investment still contribute to the set business and logistics vision?
    b) Are we still consistent in our business principles?
    c) Are we contributing to the strategic goals of the organization?
    d) Are we ensuring an optimal and/or expected increase in business benefits, taking into account the acceptable input at the acceptable levels of risk?
2. What and how extensive are the real benefits of the investment? What and how extensive are the real benefits in comparison to the expected? This is a question of business benefits, where we ask ourselves:

a) Is it understandable to all to whom it should be, what we expect from the investment? Is it completely clear what we wish to gain with the investment?
b) Is it understandable to all to whom it should be, what should be done, what and how much will be invested in the realization of investments in logistics in order to obtain the intended benefits?
c) Is the metric of performance evaluation of investments in logistics relevant?
d) Is the process of achieving the business benefits implemented well?

On the other hand, SCOR (originally CobiT) focuses on the implementation of logistics processes, where we ask ourselves:

1. Are we working properly?
2. Are we performing logistic processes well enough?

With the above issues, the focus of the two frameworks is shown: Val Log and SCOR. It is clear that Val Log presents an upgrade of SCOR in terms of business and financial perspectives. Thus, both Val Log and SCOR can be combined into the most comprehensive system of knowledge and best practices in logistics we currently have available.

In the text in Table 4.3, we dared to replace the word CobiT with SCOR. Perhaps this move at the moment seems too brave and unfavorable reactions can be expected. It has been called into question of what, if anything can be mentioned as the second, complimentary, framework, standard or any other form of guidelines that compliments the adapted Val IT framework on the field of logistics. We decided that it is better to choose an actual framework, which is SCOR, than to talk about an imaginary document. Studies of the generally adopted documents for the management of logistics, which are complementary to Val Log, remain the subject of future research.

Table 4.4 provides a brief overview of the contents of Val Log.

Table 4.4 Contents of Val Log (Source: adapted from ITGI, 2008c)

In using Log Val, we are dealing with / by:

1. Basic concepts, such as: business benefits, project, program, and portfolio.
2. Principles, which are characteristic both, for investments, focused on logistics resources, as well as for achieving (expected) business benefits.
3. Fields within which we manage the business benefits of individual processes of Val Log, logistics portfolio and investments in logistics.
4. Processes that are defined by Val Log.
5. Guidelines for management (who, what, when, where, how, why, etc.) for each process separately as defined by Val Log.

4.3.2 Basic concepts

Table 4.5 presents the basic concepts used by Val Log. This is the basic dictionary of meanings of key terms used by Val Log.

Table 4.5 Definitions of basic terms (Source: adapted from ITGI, 2008c)

Value or business benefit is the central term in Val Log. It is defined as the total life-cycle benefits net of related costs, adjusted for risk and (in the case of financial value) for the time value of money.

In many cases, however, value defines quantitative measurement. Value is complex, context-specific and dynamic. Value is indeed ‘in the eye of the beholder’. The nature of value differs for different types of enterprises. While commercial enterprises are focusing much more than they have in the past on value of a non-financial nature, executives still tend to view value primarily in financial terms – often simply as the increase in profit to the enterprise that arises from the investment. For the public sector, or non-profit enterprises, value is more complex, and often, though not always, non-financial in nature. The concept of value relies on the relationship between meeting the expectations of stakeholders and the resources used to do so. Taking all this into account, a specific metric has to be defined to measure singular business benefits. Such metrics of course have to be constantly monitored and improved in accordance with changes in goals and values of specific organizations.

Val Log does not define a single metric; therefore it has to be compiled in each specific environment individually. Such an approach is common to people in the business sphere, and less common to people in logistics.

Project – A structured set of activities concerned with delivering a defined capability (that is necessary but not sufficient to achieve a required business outcome) to the enterprise based on an agreed-upon schedule and budget.

Program – A structured grouping of inter-dependent projects that are both necessary and sufficient to achieve a desired business outcome and create value. These projects could involve, but are not limited to, changes in the nature of the business, business processes, the work performed by people, as well as the competencies required to carry out the work, enabling technology and organizational structure. The investment program is the primary unit of investment within Val Log.

Portfolio – Groupings of ‘objects of interest’ (investment programs, IT services, IT projects, other IT assets or resources) managed and monitored to optimize business value. The investment portfolio is of primary interest to Val Log. Logistics service, project, asset or other resource portfolios are of primary interest to Val Log.

Among the above definitions, it may be seen as an interesting fact that the definition of a project does not mention the quality of products and services, while it does contain the time and financial dimension. It might be sensible to add the dimension of "expected quality".

Val Log provides general guidelines and processes to be carried out in accordance with the given guidelines, which hereinafter are defined as key management practices. Relationships between the concepts, processes and management practices are listed in Table 4.6.

Table 4.6 Relationships between the concepts, processes and management practices in Val Log (Source: adapted from ITGI, 2008c)

Val Log supports the enterprise goal of

creating optimal value from logistics-enabled investments at an affordable cost, with an acceptable level of risk
and is guided by
a set of principles applied in value management processess
that are enabled by
key management practices
and are measured by
performance against goals and metrics.

4.3.3 Principles

The fundamental principles on which Val Log is based on are listed in Table 4.7.

Table 4.7 Basic principles of Val Log (Source: adapted from ITGI, 2008c)

1. Logistics enabled investments will be managed as a portfolio of investments.
2. Logistics enabled investments will include the full scope of activities required to achieve business value. Realizing value from logistics enabled investments requires more than delivering logistics solutions and services – it also requires changes to some or all of the following: the nature of the business itself; business processes, skills and competencies; and organization, all of which must be included in the business case for the investment.
3. Logistics enabled investments will be managed through their full economic life cycle (in accordance with other business investments).
4. Value delivery practices will recognize there are different categories of investments that will be evaluated and managed differently. Such categories might be based on management discretion, magnitude of costs, types of risks, importance of benefits (e.g., achievement of regulatory compliance), types and extent of business change.
5. Value delivery practices will define and monitor key metrics and respond quickly to any changes or deviations, to ensure that value is created and continues to be created throughout the investment life cycle.
6. Value delivery practices will engage all stakeholders and assign appropriate accountability for the delivery of capabilities and the realization of business benefits.
7. Value delivery practices will be continually monitored, evaluated and improved.

3.4 Fields and processes

Val Log defines the processes carried out by all participants in the process of investing. These processes are grouped into three fields, as shown in Table 4.8. Detailed descriptions of individual fields are shown in Table 4.9, 4.10 and 4.11.

Table 4.8 Three fields of processes in Val Log (Source: adapted from ITGI, 2008c)

1. Value Governance (VG)
2. Portfolio Management (PM)
3. Investment Management (IM)

Table 4.9 Value management (Source: adapted from ITGI, 2008c)

The goal of value governance (VG) is to ensure that value management practices are embedded in the enterprise, enabling it to secure optimal value from its IT-enabled investments throughout their full economic life cycle.

When management wishes to act towards controlling business benefits, they must implement processes:
VG1 Establish informed and committed leadership.
VG2 Define and implement processes.
VG3 Define portfolio characteristics.
VG4 Align and integrate value management with enterprise financial planning.
VG5 Establish effective governance monitoring.
VG6 Continuously improves value management practices.

Table 4.10 Portfolio management (Source: adapted from ITGI, 2008c)

The goal of portfolio management (PM) – within the context of the Val Log framework – is to ensure that an enterprise secures optimal value across its portfolio of logistics enabled investments as follows:
PM1 Establish strategic direction and target investment mix.
PM2 Determine the availability and sources of funds.
PM3 Manage the availability of human resources.
PM4 Evaluate and select programs to fund.
PM5 Monitor and report on investment portfolio performance.
PM6 Optimize investment portfolio performance.

Logistics enabled business investment programs need to be managed as part of the overall portfolio of investments so that all of the enterprise's investments can be selected and managed on a common basis. The programs in the portfolio must be clearly defined, evaluated, prioritized, selected, and managed actively throughout their full economic life cycles to optimize value for individual programs and the overall portfolio. This includes optimizing the allocation of the finite investment resources available to the enterprise, the management of risk, the early identification and correction of problems (including program cancellation, if appropriate), and board-level investment portfolio oversight. Portfolio management recognizes the requirement for a balanced portfolio. It also recognizes that there are different categories of investment with differing levels of complexity and degrees of freedom in allocating funds.

Table 4.11 Management of investments (Source: adapted from ITGI, 2008c)

The goal of investment management (IM) is to ensure that the enterprise's individual logistics enabled investments contribute to optimal value as:
IM1 Develop and evaluate the initial program concept business case.
IM2 Understand the candidate program and implementation options.
IM3 Develop the program plan.
IM4 Develop full life-cycle costs and benefits.
IM5 Develop the detailed candidate program business case.
IM6 Launch and manage the program.

IM7 Update operational logistics portfolios.
IM8 Update the business case.
IM9 Monitor and report on the program.
IM10 Retire the program.

Although a more detailed description of the processes and fields is beyond the scope of this paper, it can at least be said that the processes, which are listed in Tables 4.9, 4.10 and 4.11 of Val Log, describe key management practices. For each process, inputs and outputs from the process are provided. Inputs and outputs can represent some of the information (documents), which circulate among processes of Val Log as well as between Val Log processes and processes of complementary frameworks, such as SCOR. For each process, envisaged objectives and metrics for performance assessment of goal achievement is also available. In addition, a table is given which defines the responsibility for performance of specific processes. At the end of describing processes from each of the three fields, there is an additional maturity model to assess individual fields. Examples of inputs and outputs of the processes, defined responsibilities and goals and metrics are presented in the following section "Guidelines for management."

We believe, again intuitively, that the processes are set in a manner to fully meet challenges in managing investments in logistics. This is essentially a "universal" business view on the issues of investments, which is enriched with facts, derived from investments in logistics (or business) processes that support other business processes within the organization. Given that Val IT aims to adjust the overall business approach to specifics of IT, and because IT and logistics share much in common, Val Log can be a successful approach used in logistics and based on experience from IT. Figure 4.11 shows fields with groups of processes and relationships between them. Groups that are horizontally on top of others are in principle carried out before those who are below them. Groups that are on the same horizontal axis are in principle carried out parallel to each other.

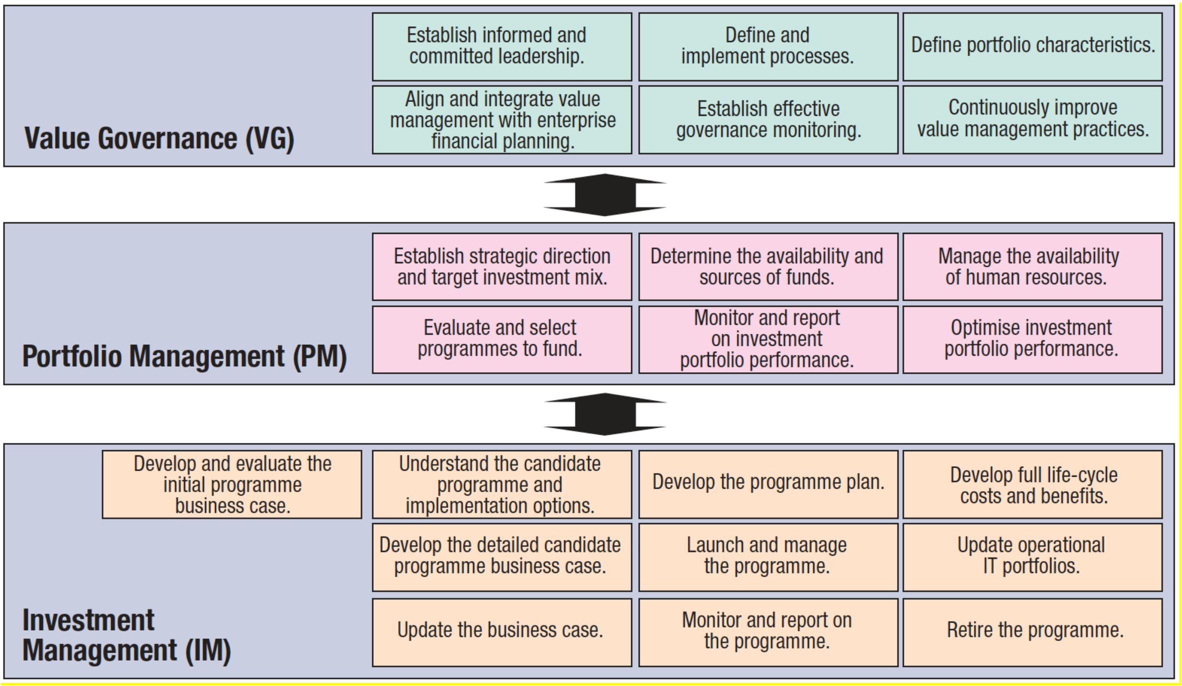


Figure 4.11 General description of the sets of processes and their inter-relationships (Source: ITGI, 2008c)

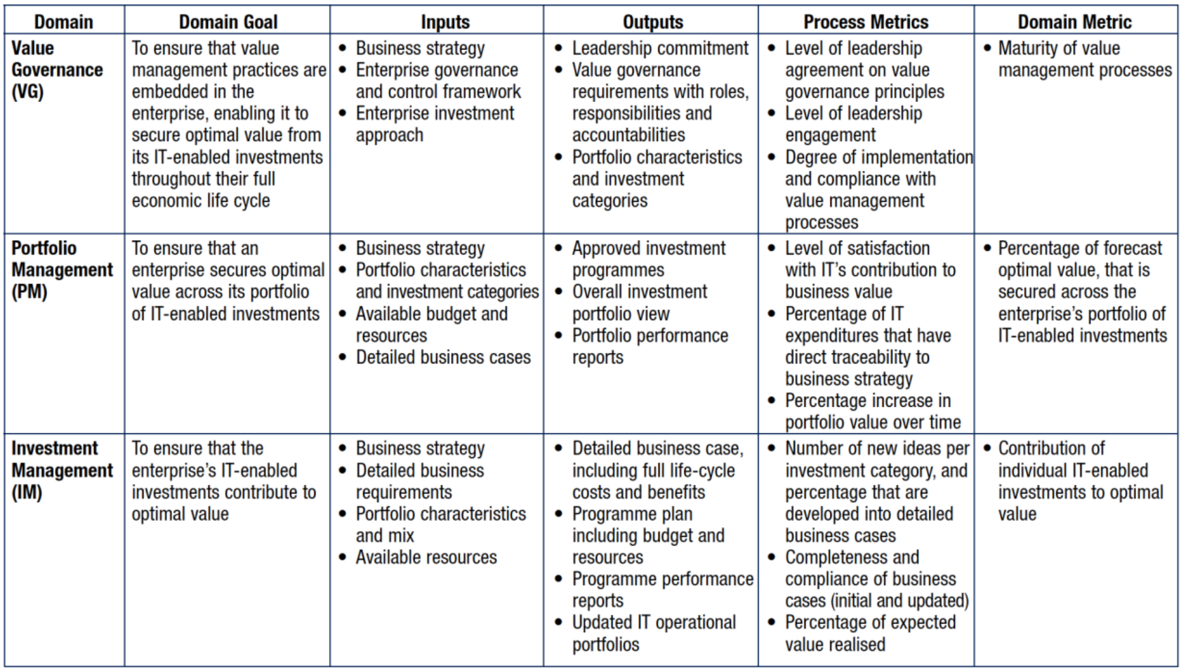
4.3.5 Guidelines for management

Guidelines for the management staff of organizations, which are given in Val Log, aim to aid in the processes of investment management. Instructions provide answers to typical questions of executives and are part of Table 4.12.

Table 4.12 Typical questions of executives, which Val Log responds to (Source: adapted from ITGI, 2008c)

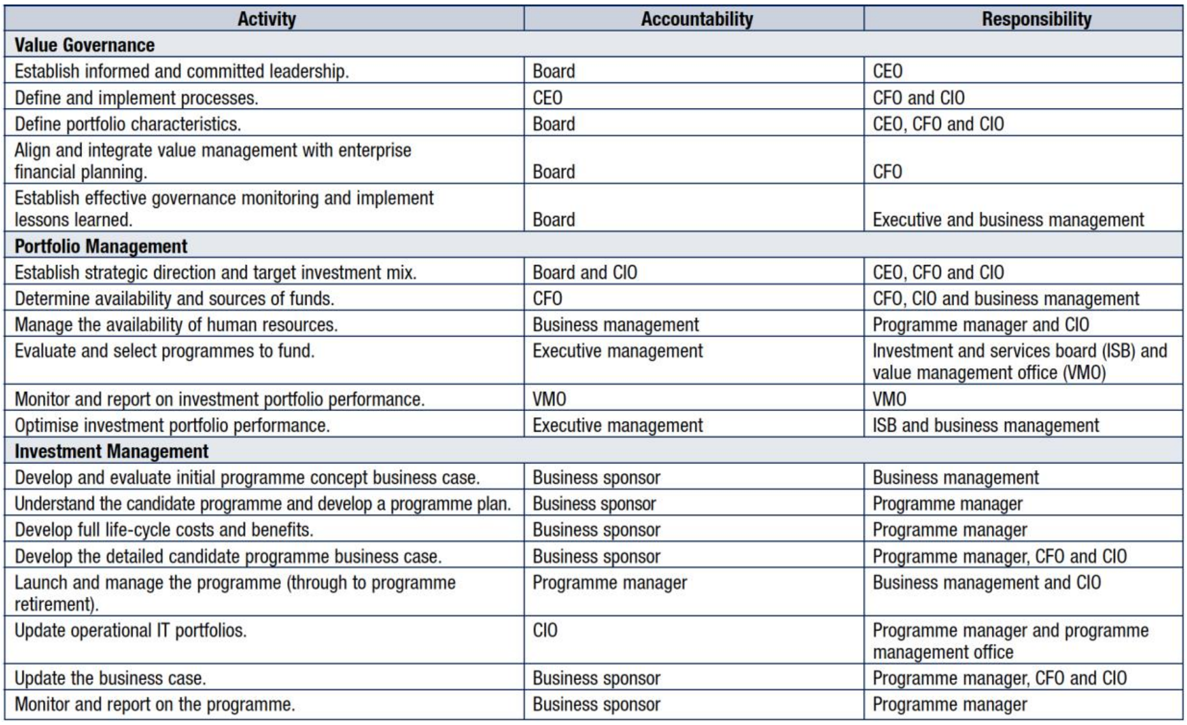
1. How do all the value management processes and activities interrelate?
2. What are the key activities that need to be undertaken or improved?
3. What roles and responsibilities are to be defined for successful value management processes?
4. How do we measure and compare value management processes?
5. What are the indicators of good performance?

Val Log provides guidance on the field level (higher and more general level) and at the level of processes (lower and more detailed level). Figure 4.12 shows the guidelines for all three fields. Figure 4.13 shows a table of general, non-itemized responsibilities at the level of fields. Both original pieces talk about IT and can be reasonably adapted to the field of logistics.



Domain	Domain Goal	Inputs	Outputs	Process Metrics	Domain Metric
Value Governance (VG)	To ensure that value management practices are embedded in the enterprise, enabling it to secure optimal value from its IT-enabled investments throughout their full economic life cycle	• Business strategy • Enterprise governance and control framework • Enterprise investment approach	• Leadership commitment • Value governance requirements with roles, responsibilities and accountabilities • Portfolio characteristics and investment categories	• Level of leadership agreement on value governance principles • Level of leadership engagement • Degree of implementation and compliance with value management processes	• Maturity of value management processes
Portfolio Management (PM)	To ensure that an enterprise secures optimal value across its portfolio of IT-enabled investments	• Business strategy • Portfolio characteristics and investment categories • Available budget and resources • Detailed business cases	• Approved investment programmes • Overall investment portfolio view • Portfolio performance reports	• Level of satisfaction with IT's contribution to business value • Percentage of IT expenditures that have direct traceability to business strategy • Percentage increase in portfolio value over time	• Percentage of forecast optimal value, that is secured across the enterprise's portfolio of IT-enabled investments
Investment Management (IM)	To ensure that the enterprise's IT-enabled investments contribute to optimal value	• Business strategy • Detailed business requirements • Portfolio characteristics and mix • Available resources	• Detailed business case, including full life-cycle costs and benefits • Programme plan including budget and resources • Programme performance reports • Updated IT operational portfolios	• Number of new ideas per investment category, and percentage that are developed into detailed business cases • Completeness and compliance of business cases (initial and updated) • Percentage of expected value realised	• Contribution of individual IT-enabled investments to optimal value

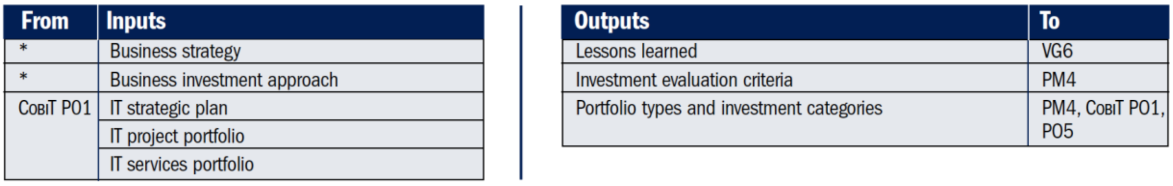
Figure 4.12 Guidelines for management of investments on the field level (higher levels) (Source: ITGI, 2008c)



Activity	Accountability	Responsibility
Value Governance		
Establish informed and committed leadership.	Board	CEO
Define and implement processes.	CEO	CFO and CIO
Define portfolio characteristics.	Board	CEO, CFO and CIO
Align and integrate value management with enterprise financial planning.	Board	CFO
Establish effective governance monitoring and implement lessons learned.	Board	Executive and business management
Portfolio Management		
Establish strategic direction and target investment mix.	Board and CIO	CEO, CFO and CIO
Determine availability and sources of funds.	CFO	CFO, CIO and business management
Manage the availability of human resources.	Business management	Programme manager and CIO
Evaluate and select programmes to fund.	Executive management	Investment and services board (ISB) and value management office (VMO)
Monitor and report on investment portfolio performance.	VMO	VMO
Optimise investment portfolio performance.	Executive management	ISB and business management
Investment Management		
Develop and evaluate initial programme concept business case.	Business sponsor	Business management
Understand the candidate programme and develop a programme plan.	Business sponsor	Programme manager
Develop full life-cycle costs and benefits.	Business sponsor	Programme manager
Develop the detailed candidate programme business case.	Business sponsor	Programme manager, CFO and CIO
Launch and manage the programme (through to programme retirement).	Programme manager	Business management and CIO
Update operational IT portfolios.	CIO	Programme manager and programme management office
Update the business case.	Business sponsor	Programme manager, CFO and CIO
Monitor and report on the programme.	Business sponsor	Programme manager

Figure 4.13 General responsibilities on the field level (higher levels) (Source: ITGI, 2008c)

Val Log provides detailed instructions for the field of IT at the process level. Figure 4.14 shows inputs and outputs of the process VG3 – Defining characteristics of different portfolios.

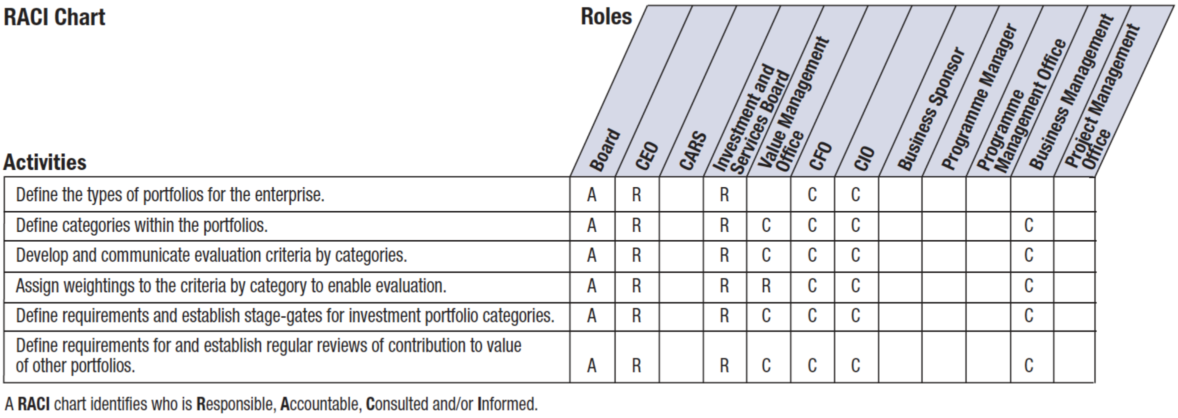


From	Inputs
*	Business strategy
*	Business investment approach
CobiT P01	IT strategic plan
	IT project portfolio
	IT services portfolio

Outputs	To
Lessons learned	VG6
Investment evaluation criteria	PM4
Portfolio types and investment categories	PM4, CobiT P01, P05

Figure 4.14 Inputs and outputs of the process VG3 (Source: ITGI, 2008c)

Detailed table of responsibility for the same process - VG3, is shown in Figure 4.15.



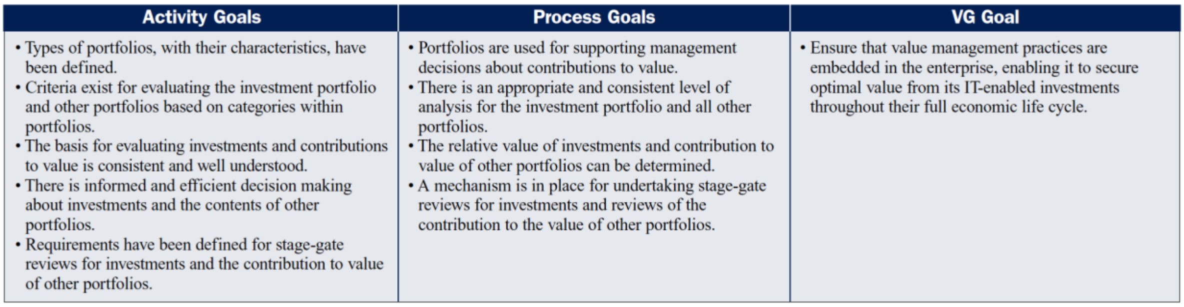
RACI Chart

Activities	Board	CEO	CARS	Investment and Services Board	Value Management Office	CFO	CIO	Business Sponsor	Programme Manager	Programme Management Office	Business Management	Project Management Office
Define the types of portfolios for the enterprise.	A	R		R		C	C					
Define categories within the portfolios.	A	R		R	C	C	C				C	
Develop and communicate evaluation criteria by categories.	A	R		R	C	C	C				C	
Assign weightings to the criteria by category to enable evaluation.	A	R		R	R	C	C				C	
Define requirements and establish stage-gates for investment portfolio categories.	A	R		R	C	C	C				C	
Define requirements for and establish regular reviews of contribution to value of other portfolios.	A	R		R	C	C	C				C	

A **RACI** chart identifies who is **R**esponsible, **A**ccountable, **C**onsulted and/or **I**nformed.

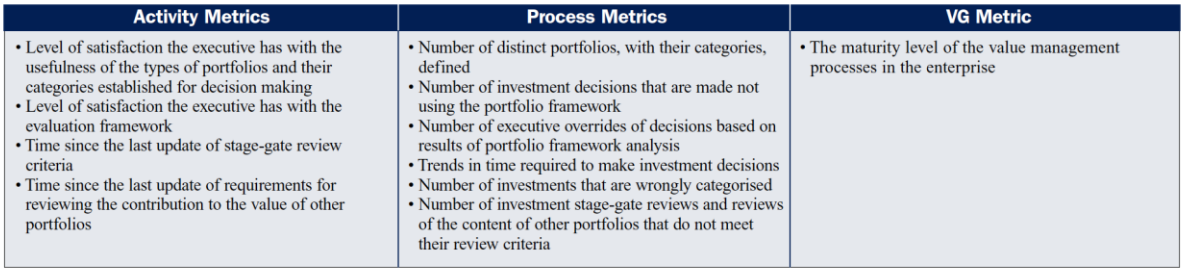
Figure 4.15 Detailed table of VG3 accountability process (Source: ITGI, 2008c)

Goals and metrics for each process and activity also need to be defined, which is shown in Figures 4.16 and 4.17. Due to transparency and ease of use, Val Log also repeats goals and metrics in the fields, which serves in order to not lose the broadness of the overview. Also in this case the text has to be properly adjusted to Val Log.



Activity Goals	Process Goals	VG Goal
• Types of portfolios, with their characteristics, have been defined. • Criteria exist for evaluating the investment portfolio and other portfolios based on categories within portfolios. • The basis for evaluating investments and contributions to value is consistent and well understood. • There is informed and efficient decision making about investments and the contents of other portfolios. • Requirements have been defined for stage-gate reviews for investments and the contribution to value of other portfolios.	• Portfolios are used for supporting management decisions about contributions to value. • There is an appropriate and consistent level of analysis for the investment portfolio and all other portfolios. • The relative value of investments and contribution to value of other portfolios can be determined. • A mechanism is in place for undertaking stage-gate reviews for investments and reviews of the contribution to the value of other portfolios.	• Ensure that value management practices are embedded in the enterprise, enabling it to secure optimal value from its IT-enabled investments throughout their full economic life cycle.

Figure 4.16 The objectives pursued in the process VG3 (Source: ITGI, 2008c)



Activity Metrics	Process Metrics	VG Metric
• Level of satisfaction the executive has with the usefulness of the types of portfolios and their categories established for decision making • Level of satisfaction the executive has with the evaluation framework • Time since the last update of stage-gate review criteria • Time since the last update of requirements for reviewing the contribution to the value of other portfolios	• Number of distinct portfolios, with their categories, defined • Number of investment decisions that are made not using the portfolio framework • Number of executive overrides of decisions based on results of portfolio framework analysis • Trends in time required to make investment decisions • Number of investments that are wrongly categorised • Number of investment stage-gate reviews and reviews of the content of other portfolios that do not meet their review criteria	• The maturity level of the value management processes in the enterprise

Figure 4.17 Metrics, which are used in the process VG3 (Source: ITGI, 2008c)

Guidelines for management are the most important tool that allows for help with investments in real cases. They are a recipe to be used again and again, but every time a little bit differently. Like any recipe, it is used as a checklist, which is based on given principles and use in accordance to experience and with the account of specificity of the environment. Particularly it is important to emphasize the importance of responsibility tables, which are invaluable in practice and are generally not given in different frameworks, guidelines or standards.

4.3.6 Discussion

In mid-2008, the second version of Val IT was published, which through additional explanations added to the idea of the importance of managing IT investments through responsible staff for IT investments in the organization - including heads of departments. Assuming that in the field of logistics investments can use the same general guidelines and approaches as are used in IT, we produced a good management framework with Val Log. Similar frameworks do not exist in logistics, therefore it is very welcome. It also contains a maturity model, which can be used at a higher or lower level. Portfolio of investments is the considered field, which includes logistics services, logistics assets and resources – therefore it is based on a holistic approach to managing investments.

In general, Val Log is a fairly short document, which contains relatively few processes - only 22. Maybe its compact and concise form can be seen as its strong point. Either way it brings a new view into the logistics business and gives managers and other business leaders a new starting point to see the investments in logistics from a different perspective.

Investments in logistics have so far used general guidelines, approaches, methodologies and frameworks for managing them. It is true that all investments can be subject to general principles, but they also have specific fields of features that are worth considering. Logistics is also one of those fields which have their own specificity that has to be detected, recognized and understood so that it can be controlled. Since in general we cannot expect a sufficiently detailed knowledge of logistics from the organization's management, we are dealing with the problems associated with understanding and proper positioning of logistics among the rest of the business processes. Val Log provides a means of bridging the misunderstanding between management and logisticians in an organization regarding investments in logistics, which we unfortunately all too often witness.

Proposal for Val Log is a new concept and a case, where it would be applied in practice, is to this day unknown. In logistics as a service activity in an organization, we firstly ask ourselves whether we are doing things correctly, but soon overcome this situation and we begin to wonder about the benefits brought about by our actions. This means a shift where the business management of organizations begins to manage logistics and therefore the state where logisticians manage logistics is surpassed. Thus, a direct connection between what is happening in the field of logistics and between what is happening in the business field is provided. By this we can overcome the myth that logistics projects cost money while business projects bring money. We believe that Val Log is a promising methodology compared to other general methodologies while talking about investments in the logistics field. Its advantage is the fact that it is complementary to SCOR and consequently understandable to people in the field of logistics. On the other hand, it introduces the language of business into investments in logistics and achieves a new perspective of view at logistics performance. This shows the effectiveness of a business investment, where there are also investments in logistics. Such a view is not new, it has often been tested in practice, but in the field of logistics it is used in a systematic way and as such is new on the specific field.

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Chapter 5

Warehouse Order Size

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Abstract

Economic Order Quantity EOQ model is presented long time ago. This model involves only ordering and inventory (holding) costs.
Looking from logistics costs perspectives there are more costs. Warehouse orders are subdivided into: inbound order and outbound order based on costs nature.
The suggestion is formulated how to find the optimal size of warehouse order which means the minimization of total costs in particular case. This is the main difference from EOQ model where just inbound case is covered. The proposal is formulated based on logic that by optimising one type of costs other costs shouldn't be de-optimised because excluded.

Keywords: warehouse, order, stock, costs.

5.1 INTRODUCTION

There are the numerous sources of literature dedicated to logistics where the role of warehouse operations is highlighted. Organizations find that they must rely on effective stock management or warehouse networks aiming successfully compete in any market and have economy in it. Ultimately the race of labour price fastens the improvement of process. On the other hand, the attention is drawn to the service of customers and there are numerous benefits that come from the economy of scale.

Stock Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. It also includes collaboration with supply chain partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, stock management integrates product and information flow management within and across companies.

It includes all of the logistics management activities noted above, as well as production operations (in wide meaning), and it drives the coordination of processes and activities with and across marketing, sales, product design, finance, and information technology.

Demand based logistics operations exist because producing or purchasing in large lots allows exploiting the economies of scale and such lowers the costs. The presence of fixed costs associated with warehousing and picking in full loads encourages exploiting the economies of scale and the placement of order in large lots.

The primary role of ordering is to allow different stages in a distribution channel to minimize the handling and increase inventory costs. The economies of scale in order picking motivate a manager to increase the lot size. Key manager must make the trade-off when taking order sizing decisions that minimizes total costs.

The attention is drawn to decisions that are taken considering the total costs across the entire distribution channel not to once that are taken independently. The discussion bellow shows the practices that increase the level of inventory costs as well as total costs in logistics.

The main objective of chapter is formulated demand based warehouse order involving logistics costs analysis and optimization approach.

In order to achieve this objective the following research and application tasks are defined:

1. Analysis of stock management principles,
2. Overview of order picking policies and factors,
3. Demand based logistics,
4. Warehouse order size for particular case.

In this chapter the attention is drawn to the needs of small size and large size operations, thus overlooking needs of JIT, etc. Though it is not the best approach to solving problems in real life the topic itself is so vast and the scope is so large that volume of this work would be far too little to give even a slight insight on the whole topic.

Section one is dedicated to theoretical part that are involved in this complex issue. Ideas like economic order quantity EOQ, ABC classification and nature of demand are discussed herein. Also an in depth the selection of different stock management principles and different costs are taken.

Section two takes us further in depth considering the issues of order picking policies. This section discusses the three main order picking policies taking warehouse layout, order picking strategy, etc. – the factors influencing them and the degree of sensitivity that these policies showing changes in different factors.

Section three contains discussion about demand based logistics, the calculation of warehouse order size for particular distribution centre. This section contains financial and warehouse order size calculations. The outcome of this chapter is inter-linked with the findings delivered in the second section.

5.2 STOCK MANGEMENT PRINCIPLES

Cycle inventory exists because producing or purchasing in large lots allows exploiting the economies of scale and thus lower costs. The presence of fixed costs associated with ordering and transportation, quantity discounts in product pricing, and short-term discounts or trade promotions encourages exploiting the economies of scale and placing order in large lots.

The primary role of cycle inventory is to allow to purchase product in lot sizes that minimize the sum of the material, ordering, and holding costs. If a manager considers the holding costs alone (costs for stocking the average quantity in stock (between fully replenished and empty places), he or she will reduce the lot size and cycle inventory. The economies of scale in purchasing and ordering, however, motivate a manager to increase the lot size and cycle inventory. A manager must make the trade-off that minimizes total cost when making lot sizing decisions (Chopra et al. 2010). So, the goal of this chapter is to show what reduce cycle inventory without raising costs.

Nature of demand

The nature of demand over time plays significant role in minimizing ordering and holding costs. Several common types of demand patterns are shown in Fig. 5.1. Such demand pattern is referred to as perpetual. Although demand for the most products rises and falls during their life cycles, many products have a selling life that is sufficiently long to be considered infinite for purposes of planning.

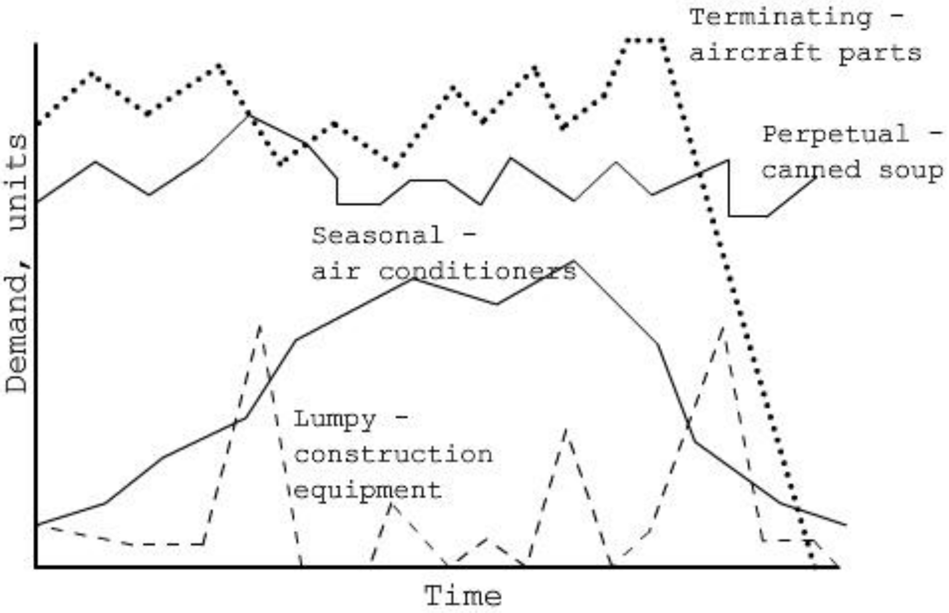


Fig. 5.1 Product demand patterns: different industries

On the other hand, some products are highly seasonal or have a one-time demand pattern.

Similarly, demand may display a lumpy or erratic pattern. The demand may be perpetual, but there are the periods of little or zero demand followed by the periods of high demand. The timing of demand is not as predictable as for seasonal demand, which usually occurs at the same time every year. Items in inventory are usually a mixture of lumpy and perpetual demand items. A reasonable test to separate these is to recognize that lumpy items have high variance around their mean demand level.

There are products whose demand terminates at some predictable time in the future, which is usually longer than one year. Inventory planning here involves maintaining inventories to just meet demand requirements, but some re-ordering activities within the limited horizon are allowed.

Finally, the demand pattern for an item may be derived from demand for some other items (Chopra et al., 2010).

ABC product classification

A common practice is products differentiation into a limited number of categories and then to apply a separate inventory control policy to each. This makes sense since all products are not of equal importance to a firm in such terms as sales, profits, market share or competitiveness. By selectively applying inventory policy to these different groups, inventory service goals can be achieves with lower inventory levels than with a single policy applied to all products.

It is well known that product sales display a life-cycle phenomenon where sales begin at product introduction with low levels, increase rapidly at some point, level off, and finally decline. The products of a firm or sales items in the case of a retailer are usually in various stages of their life cycles and, therefore, are contributing disproportionately to sales and profits. That is, a few items may be contributing to the high proportion of the sales volume. This disproportionality between the percent of items in the inventory and the percent of sales has generally been referred to as the 80-20 principle. The 80-20 principle serves as the basis for the ABC classification items: A items are called fast movers, B items - medium movers, and C items – slow movers. There could be the higher number of categories to be used (Aquilano et al., 1999). In Fig. 5.2 the principle 85-15 is embedded.

Class-based (or ABC storage): It is based on the division of items and storage locations which falls in the same number of classes, in order to assign the items to one location.

Category A: for items which turnover rate is high and the number of locations is small, these items are stored near to the depot area.

Category C: items which average storage time is much longer than the storage of A items, these products need much space in the warehouse.

Category B: these items are between category A and C, concerning turnover rate and space occupied.

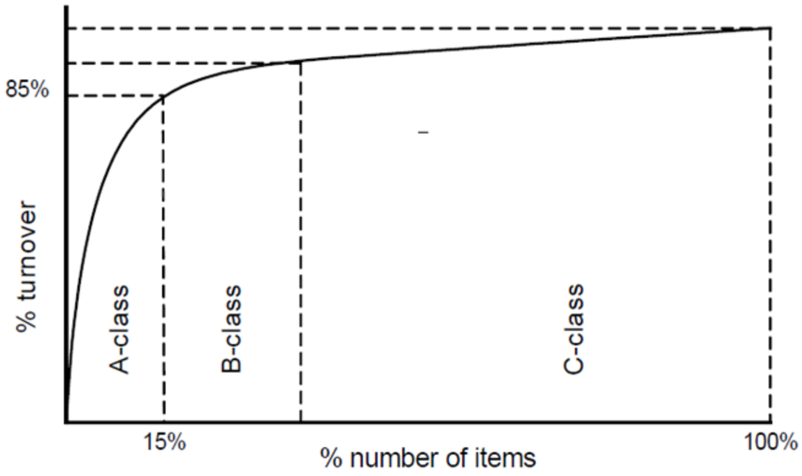


Fig. 5.2 ABC based assignment

The aggregate planning of inventory levels often involves projecting how they will change as the number of stocking locations and the throughput on the items is altered. In planning a logical network, it is common to consolidate or expand the warehouse to meet customer service and costs objectives. The square-root rule for inventory consolidation can be useful.

Assuming that an inventory policy is being followed based on economic order quantity EOQ and that all stocking points carry the same amount of inventory, the square-root rule can be stated as follows (5.1):

$$I_T = I_i + \sqrt{n} \tag{5.1}$$

Where I_T – the optimal amount of inventory to stock, if consolidated into single location; I_i – the amount of inventory in each of n locations in the same size of units as I_T; n – the number of stocking locations before consolidation.

Although the square-root rule of inventory consolidation is generally useful, the assumptions of equal amounts of inventory in all warehouses and that inventory consolidate precisely may be too limiting.

An alternative, not so limiting approach, for estimating average inventory levels is Poisson distribution, but this requires the assumptions that:

1. The demand during the lead time is distributed on a Poisson manner.
2. The policy used to control inventories is a reorder point or a periodic review method.

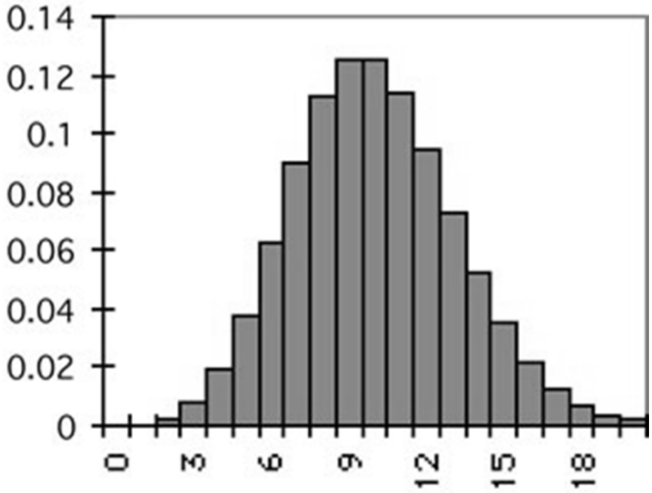


Fig. 5.3 Poisson distribution

Each knows the standard deviation *s`d* of a lead-time *LT* distribution in the square root of its mean; which is (5.2):

$$\mathrm{s`d} = \sqrt{X`} \qquad (5.2)$$

The average inventory level *AIL* of an item is then found as follows (5.3):

$$AIL = \frac{dT}{2} + z(s`_d) \qquad (5.3)$$

Where $\mathrm{s`d} = \sqrt{d(T + LT)}$ assuming that demand *d* during the order review time *T* plus lead time *LT* is distributed according Poisson manner. The safety factor *z* based on desired service level and is found from Fig. 5.4, where *z* = 1.28 for an area under the curve equal to 0.90.

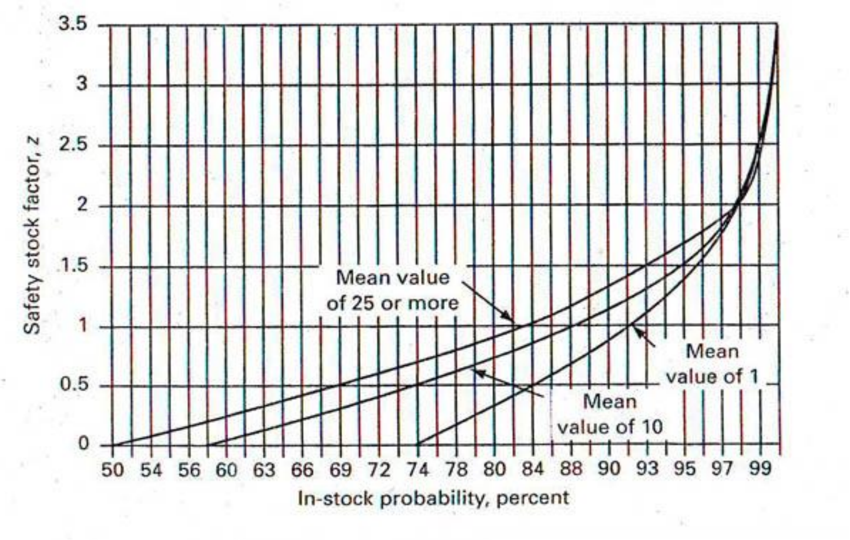


Fig. 5.4 Safety stock factor curves for various values of the mean demand during lead time

Economic order quantity

Economic order quantity (also known as the Wilson EOQ Model or simply the EOQ Model) is a model that defines the optimal quantity to order that minimizes total variable costs required to order and hold inventory (Fig. 5.5).

EOQ models provide several key insights. The most important one is that the optimal order quantity *Q** varies with the square root of annual demand — NOT directly with annual demand.

This provides an important economy of scale; if demand doubles, for example, the optimal inventory does NOT double — it goes up by the square root of 2, or approximately 1.4 (Varley, 2006).

This also means that inventory rules based on time-supply are not optimal. For example: many inventory managers maintain a "month worth" of inventory. If demand doubles, then a "month worth" of inventory is twice as large. As noted above, this is more than is optimal; double demand should increase inventory by the square root of 2, or about 1.4.

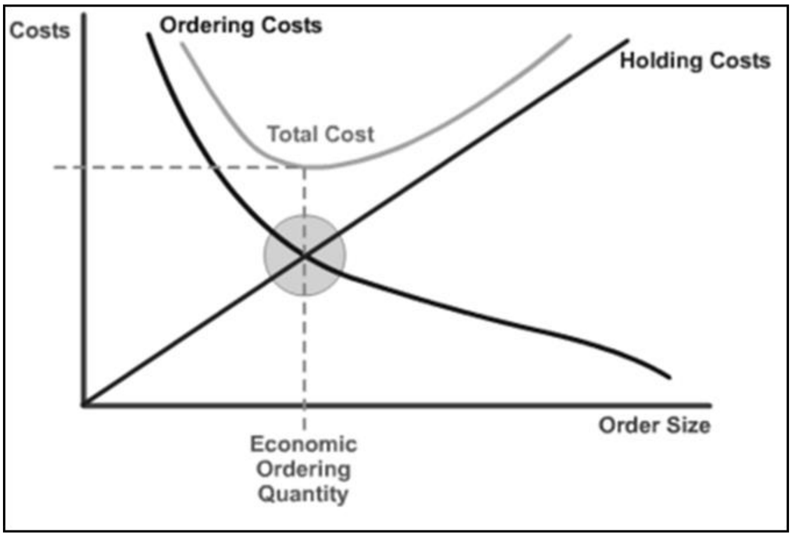


Fig. 5.5 Minimizing total costs

Total inventory costs (*TIC*) (5.4):

$$TIC = OC + CC \tag{5.4}$$

Where *OC* – Ordering costs; *CC* – Holding costs

Ordering costs (5.5):

$$OC = U / Q \cdot F = U \cdot F / Q \tag{5.5}$$

Where *U* – Annual usage; *Q* – Quantity ordered; *F* – Fixed costs per order.

Holding costs (5.6):

$$CC = Q / 2P \cdot C = Q \cdot P \cdot C / 2 \tag{5.6}$$

Where *Q* – Quantity ordered (Average level); *P* – Purchase price per unit; *C* – Holding costs as percentage.

As the lead-time (i.e., time required for the procurement of material) is assumed to be zero an order for replenishment is made when the inventory level reduces to zero.

The level of inventory will be equal to the order quantity (*Q* units) to start with. It progressively declines (though in a discrete manner) to level Zero by the end of period. At that point an order for replenishment will be made for *Q* units. In view of zero lead-time, the inventory level jumps to *Q* and a similar procedure occurs in the subsequent periods. As a result of this the average level of inventory will remain at (*Q*/2) units, the simple average of the two end points *Q* and Zero.

From the above discussion the average level of inventory is known to be (*Q*/2) units.

From the previous discussion, it is known that as order quantity increases the total ordering costs decrease while the total holding costs increase. The economic order quantity, denoted by *Q**, is that value at which the total cost of both ordering and holding will be minimized. It should be noted that total costs associated with inventory (5.7 or 5.8)

$$TIC = U \cdot F / Q + Q \cdot P \cdot C / 2 \tag{5.7}$$

or

$$2U \cdot F = Q^2 \cdot P \cdot C = EOQ \tag{5.8}$$

Where the first expression of the equation represents the ordering costs and the second expression holding costs.

The total costs curve reaches its minimum at the point of intersection between the ordering costs curve and the holding costs one. The value of *Q* corresponding to it will be the economic order quantity *Q**. We can calculate the EOQ according formula.

The behavior of costs associated with inventory changes based on order quantity. For order quantity *Q* to become EOQ the ordering costs at *Q* should be equal to the holding costs. To distinguish EOQ from other order quantities (5.9):

$$EOQ = Q * \cdot P \cdot C \tag{5.9}$$

In the above formula, when *U* is considered as the annual usage of material, the value of *Q** indicates the size of the order to be placed for the material, which minimizes the total inventory-related costs. When *U* is considered as the annual demand *Q** denotes the size of production run.

5.3 ORDER PICKING POLICIES AND FACTORS

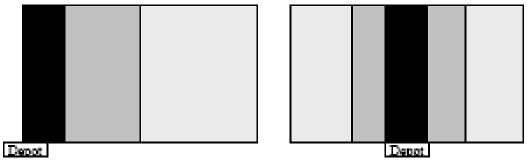
Order picking strategies suggest route for picker and picking sequence for the products from the customer order. The most famous picking strategies were introduced by Roodbergen (2001) and Dukic (2004). They are:

- S-shape (or traversal). Any aisle containing at least one product is transferred through entire length. Aisles without pick are not entered.
- Largest gap. Similar to midpoint strategy except that picker enters an aisle as far as the largest gap within an aisle, instead of the midpoint (De Koster, Le-Duc and Roodbergen, 2007).
- Combined. Aisles with picks are either entirely traversed or entered and left at the same end (De Koster, Le-Duc and Roodbergen, 2007), in a way, that makes possibility to look one aisle ahead.
- Optimal. Obtains the shortest route strategy, which is capable consider all possibilities for travelling in and between aisles. (Roodbergen and Petersen, 1999). De Koster & Van der Poort (1998) noted, that optimal route usefulness is limited, because equipment requires time to change aisle (Roodbergen & Petersen, 1999) in VNA pallets warehouse.

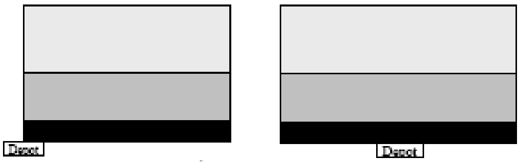
For studying picking strategies are often chosen warehouses with aisles narrow enough for picker to retrieve products from both sides without changing position (De Koster, Le-Duc & Roodbergen, 2007). Caron, Marchet & Perego (2000) study order picking process in warehouse with wide aisles. They modify S-shape route.

Product placement strategies. In literature, product placement strategies are classified as follows:

- Random storage. Petersen's (1997) random storage definition: all empty locations have equal probability to be filled (De Koster, Le-Duc & Roodbergen, 2007), ('random storage' Roodbergen, 2001; Le-Duc, 2005; 'purely random' Dukic, 2004).
- Volume based storage (also could be called as Full turnover storage strategy) - products with highest sales rates located at closest to depot location or close to each other by ABC rule: A products – high volume, B products – medium volume, C products – low volume products ('ABCD' there D products – no volume, Saenz, 2005) (Roodbergen, 2001; Dukic, 2004; Caron, Marchet & Perego, 2000). Heskett (1963, 1964) used COI 'cube-per-index' term (De Koster, Le-Duc & Roodbergen, 2007).
- Volume based storage methods are presented in Figure 5.6. Methods definitions presented by Roodbergen & Petersen (1999):
- Within-Aisle method rule means that the highest volume products shall be located in the aisle closest to the depot while the lowest volume products - in the aisles farthest from the depot.
- Across-Aisle storage method is based on the rule that the highest volume products shall be located along the front aisle and the lowest volume products - along back aisle.



Within-Aisles



Across-Aisles

Fig. 5.6 Volume based storage methods. (Dark grey colour means A products, medium grey - B products, light grey - C products).

Layout strategies. Layout strategies are classified as follows:

- Number of cross-aisles in multiple blocks warehouse (Roodbergen, 2001).
- The size of aisles, the number of aisles (De Koster, Le-Duc & Roodbergen, 2007), and cross-aisles positioning.

Factor analysis

The goal of this practical case is to make scenario analysis and to find which order picking method suits better in each situation. In order to achieve it, a tool developed by the Rotterdam School of Management and the Erasmus School of Economics has been used; it allows calculating order picking time in a wide area warehouse.

The tool was selected among others because is the one that allows changing different parameters, thus realize an exhaustive study. Changeable parameters are such: aisle length, centre distance between aisles, number of aisles (N of aisles), number of cross-aisles (blocks), depot location, average speed inside/outside aisles, additional time to change aisles, storage strategy (random/ ABC-1 or ABC-2), the average number of lines per order, administration time/order, time to pick a line, order picking strategy (S-shape, largest gap, combined or optimal), and the number of simulations.

Minitab, which is a statistic package, has been used to analyse the data obtained from the picking calculating time tool and try to reach some conclusions.

The method that has been performed for analysing this experiment is a factorial design. It lets you study the effects that several factors can have on a response. It allows varying the levels of all factors at the same time instead of varying one at a time, and thanks to that the interaction between different factors can be studied.

Design of experiments (DOE)

Among all the possibilities which the simulation tool gives, three parameters have been chosen to experiment with them. Prior to the experiment it may be logical to think that the parameters that can influence more on the travel time are the aisle length, the number of aisles, and the number of cross aisles, apart from the order picking strategy. Therefore, the experiment will have four factors, and each factor will have four levels (44 experiments), in consequence 256 experiments. The simulation tool is able to generate the result of the four strategies delivered with order picking at the same time, thus only 64 simulations are needed. In the following table 5.1 these four factors and their levels are presented.

Table 5.1 Level of analysis

Factor	**Levels**			
Aisle length (m)	50	100	150	200
Number of aisles	5	10	15	20
Number of cross aisles	1	2	3	4
Order picking strategy	S-shape (S)	Largest Gap (LG)	Combined (C)	Optimal (O)

Other considerations to take into account in all the simulations are: depot location is on the left, average speed inside/outside aisles is 0,7 m/s, additional time to change aisles 2 s, the average number of lines/order 15, administration time/order 60 s, time to pick a line 8 s, for the first experiment storage strategy is random, while in the second an ABC-1 method is selected.

The variable which the analysis covers is the average travel time, representing the travel time spent by the picker to collect the items of the order list. The final result given by the simulation tool is averaged over 1000 simulation runs.

Findings

After creating a 256x5 matrix for the factorial design and obtaining the travel time from the tool simulation, the results of general full factorial design are the following (check table 5.2 below).

Table 5.2 The analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	174	$40,01x10^{6}$	$22,9\ x10^{4}$	$4,3x10^{2}$	0,000
Linear	12	$35,40x10^{6}$	$29,5x10^{5}$	$5,6x10^{3}$	0,000
Aisle’ length	3	$16,58x10^{6}$	$55,2x10^{5}$	$10,5x10^{3}$	0,000
Number of aisles	3	$36,0x10^{5}$	$12,0x10^{5}$	$2,2x10^{3}$	0,000
Cross-aisles	3	$31,9x10^{5}$	$10,6x10^{5}$	$2,0x10^{3}$	0,000
Order picking strategy	3	$120,1x10^{5}$	$40,0x10^{5}$	$7,6x10^{3}$	0,000
2-Way Interactions	54	$42,0x10^{5}$	$77,7x10^{3}$	$0,1x10^{3}$	0,000
Aisle’ length*N of aisles	9	$23,7x10^{4}$	$26,3x10^{3}$	50,29	0,000
Aisle’ length*Cross-aisles	9	$12,4x10^{5}$	$13,8x10^{4}$	$0,2x10^{3}$	0,000
Aisle’ length*Order picking strategy	9	$14,6x10^{5}$	$16,2x10^{4}$	$0,3x10^{3}$	0,000
N of aisles*Cross-aisles	9	$11,7x10^{4}$	$13,0x10^{3}$	24,85	0,000
N of aisles*Order picking strategy	9	$31,8x10^{4}$	$35,3x10^{3}$	67,38	0,000
Cross-aisles*Order picking strategy	9	$82,3x10^{4}$	$91,4x10^{3}$	$0,1x10^{3}$	0,000
3-Way Interactions	108	$40,8x10^{4}$	$3,7x10^{3}$	7,21	0,000
Aisle’ length*N of aisles*Cross-aisles	27	$26,6x10^{4}$	$9,8x10^{3}$	18,82	0,000
Aisle’ length*N of aisles*Picking strategy	27	$38,2x10^{3}$	$1,4x10^{3}$	2,70	0,000
Aisle’ length*Cross-aisles*Picking strategy	27	$79,4x10^{3}$	$2,9x10^{3}$	5,61	0,000
N of aisles*Cross-aisles*Picking strategy	27	$24,3x10^{3}$	$0,9x10^{3}$	1,72	0,033
Total		$40,054x10^{6}$			

Using α-level of 0,05 as a reference we can determinate that the four main effects are statically significant in the model. The *p-value* of all four is less than 0,05. As it could be assumed, not only the main effects are significant in the model, but also the interactions do. All the two and three way interactions are significant. The *p-value* for the four way interaction could not be calculated due to the lack of degrees of freedom for the error.

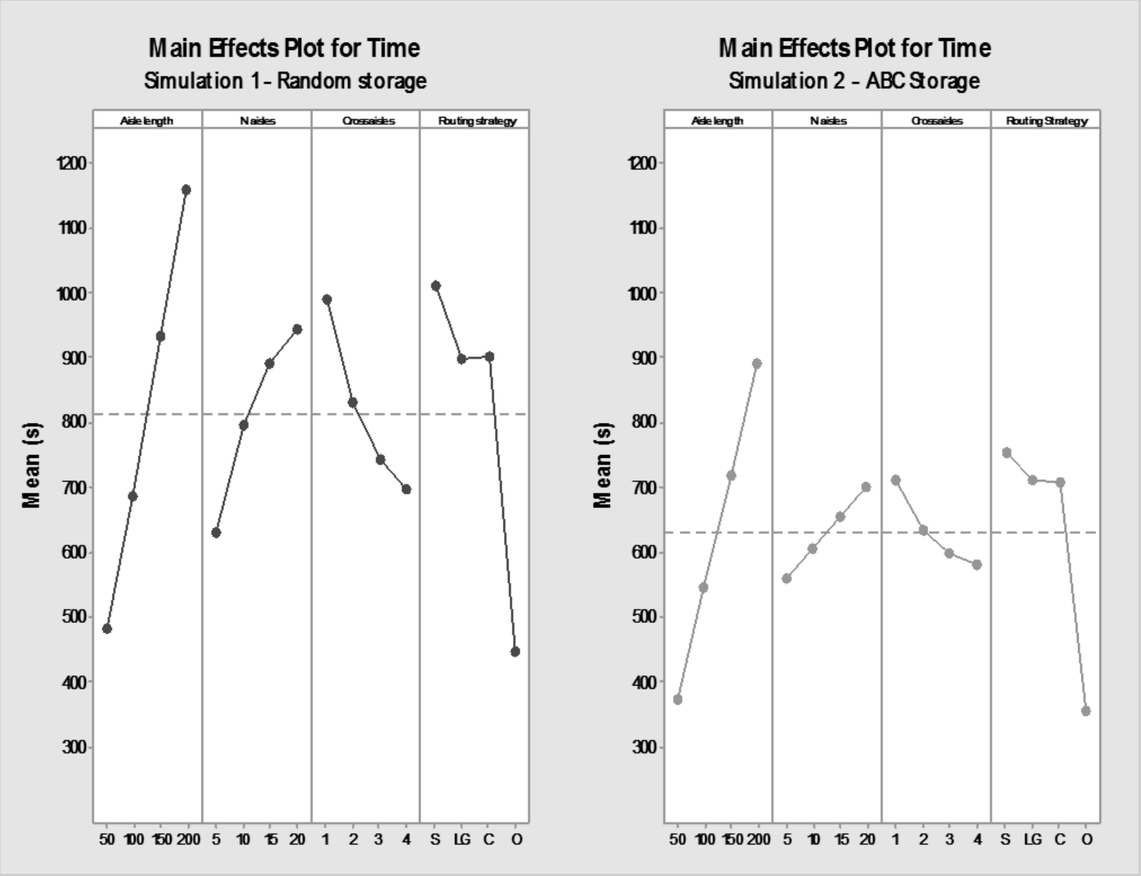


Fig. 5.7 Main effects defined during performed analysis

The main effects of the response are represented in Fig. 5.7 above. Logically, between the travel distance and the factor of aisle length there is a linear relationship. The larger the aisle is, the longer picking distance is. With regard to the number of aisles its graph follows a parabolic pattern. The attention is drawn to the insertion of cross aisles when such gives the possible effect on travel distance.

Finally, in this graph we can see clearly that the optimal strategy is the one that provides the shortest route by far. While the average travel distance for the S-shape is 1011,7 m, for the Largest Gap 898,5 m, for the Combined 900,8 m, and for the Optimal is only 448,0 m. Results represent the variety of travel distance from 125,83% to 101,07% over the optimal strategy (see table 5.3 below).

Table 5.3 The results of statistical analysis

Picking strategy	N	Mean	SE Mean	s'd	Minimum	Median	Maximum
S	64	1011,7	50,7	405,8	398,2	972,8	2140,8
LG	64	898,5	38,2	305,4	382,8	888,6	1645,3
C	64	900,8	41,6	332,7	376,8	859,2	1760,0
O	64	448,0	34,6	276,4	119,2	349,7	1330,3

The following graph shows the interaction between the order picking strategy and the number of cross aisles. First, one of these considerations is more important to be taken into account if clearly decrease the travel distance (Fig. 5.8). Therefore, the increase of cross aisles in a warehouse benefits the saving in terms of travel distance for all the order picking strategies analysed. And second figure shows the interaction effect across Largest Gap and Combined strategies (Fig. 5.9).

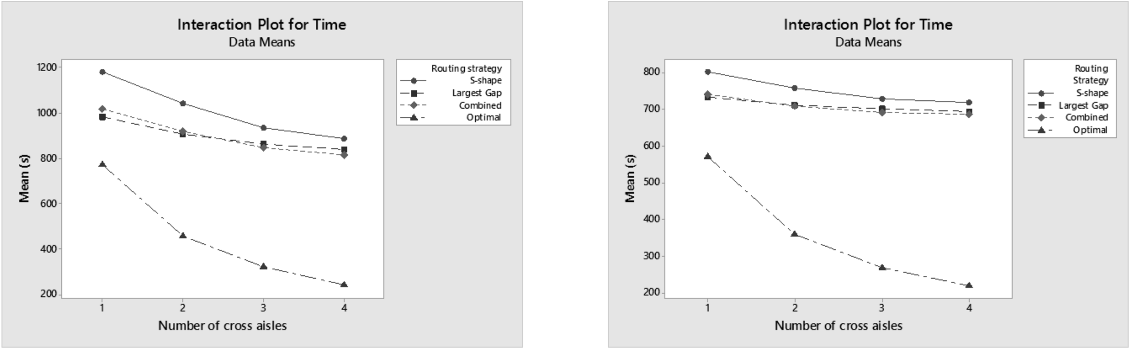


Fig. 5.8 Order picking strategy and the number of cross aisles

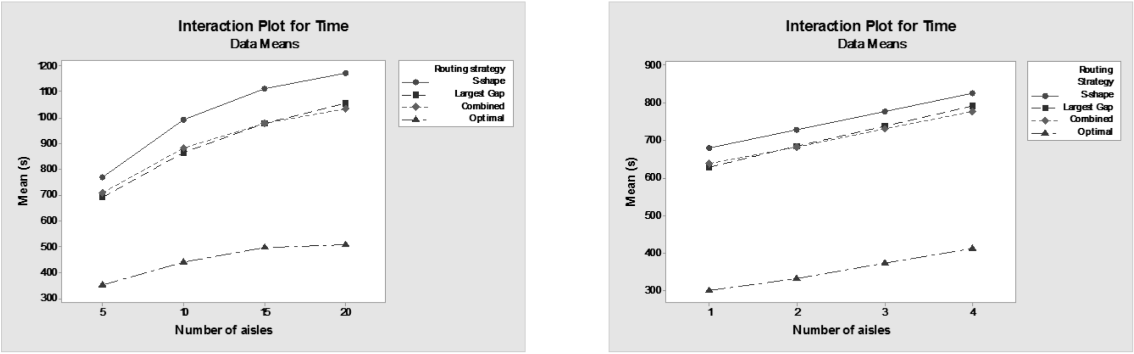


Fig. 5.9 Order picking strategy and the number of aisles

Correlational study between factors and order picking time

The optimal strategy is the best order picking strategy for every situation (table 5.4). Then there are Combined and Largest Gap order picking strategy, whose performance is very similar for both. And finally the S-shape, which is the worst by far.

Table 5.4 Correlation analysis: outcomes

R^2	Cross-aisles	N of aisles	Average number of lines per order
Optimal policy & random storage	**0,8346**	**0,9657**	**0,9150**
Optimal policy & ABC-1 storage	**0,8350**	**0,9760**	**0,9168**
S-shape policy & random storage	**0,8839**	**0,9690**	**0,7478**
Largest Gap policy & random storage	**0,8534**	**0,9528**	**0,9495**
Combined policy & random storage	**0,9721**	**0,9612**	**0,8628**

The number of cross aisles can decrease the travel time, but only optimal strategy results benefited from any number of aisles. Heuristic strategies do not benefit as much as optimal does with any number of aisles. It seems that for the large number of cross aisles the travel time increases for heuristic order pickings, it may be due to the increase in distance travelled.

The use of ABC storage method benefits notably all the order picking strategies. In general, the layout optimisation may affect 10% reduction of total logistics costs.

5.4. DEMAND BASED LOGISTICS: THE SIZE OF WAREHOUSE ORDER

There are different view levels: (1) the implementation of demand driven concept and having benefits from the fulfilment of customer demand in costs effective way; (2) the implementation of economic driven concept and having benefits from the minimisation of total costs.

Demand driven logistics covers such topics:

- Maximize market potential and meet customer needs with planning demand-driven business,
- Enable efficient demand networks with response following supply constraints, and inventory requirements,
- Manage end-to-end operations with real-time analysis, signals, and constant monitoring.

The second stream is linked with the optimization of freight and warehouse operations connected economic volumes and resources.

As an example the costs of warehouse operations may be distributed in the following manner:

- 40% – Storage costs,
- 50% – Personnel costs for manual operations (these costs may amount till 55% in same warehouses),

- 10% – Costs linked with forklift operations (that are semi-automated).

It follows that space reduction to the absolute minimum requires a more detailed and precise planning.

Both cases are analysed further on and called as inbound and outbound cases. For inbound order some costs components are included such as storage costs, inbound costs. And for outbound order other type of costs components are taken such as picking costs, transportation costs, and outbound costs (instead of ordering costs and inventory holding costs).

The size of warehouse order: particular inbound case

Of course, factors reviewed earlier (in the first section) are just a small portion of all the factors that can influence logistics costs. It is necessary to take into account the economies of scale and different shelf-life for some goods that are perishable.

For the case study Vilnius distribution centre (DC) was selected to revise the nature of costs:

- 36% of costs are part dedicated for storage (this also shows lower building costs in Baltics (particular in Lithuania)),
- 16% forklift costs for inbound and outbound operations,
- 48% costs for handling (picking) products and empties.

So, seeking to specify the economic size of inbound order costs and benefits have to be scaled for orders that are delivered directly into warehouse. In addition, more costs components have to be included:

- Ordering costs (*OC*),
- Inventory costs (*R*),
- Inbound costs (*IC*),
- Storage costs (*SC*),
- Shortages, if any due to expire dates.

If, for example, *OC*=2 €; *R*= 8% yearly interest rate as the percentage, the average pallet purchase price (*PPP*) – 325 €; *IC*= 0.55 € per transport unit and operation; *SC*=0.4 € a day (*N*= 1) per transport unit (table 5.5).

The formula shows the balance between costs (5.10)

$$OC + PPP \cdot (R/365 \cdot N) = IC + SC \cdot N \tag{5.10}$$

For decision making different alternatives are important: (1) to buy more or (2) to buy less but more frequent

The calculation of financial result (*FR*) helps to answer this question (5.11 & 5.12).

$$FR = OC + PPP \cdot (R/365 \cdot N) - (IC + SC \cdot N) \tag{5.11}$$

Let’s take that the size of warehouse order is one pallet (5.12):

$$FR = 2 + 325 \cdot (0.08/365 \cdot N) - 0.55 + 0.4 \cdot N \tag{5.12}$$

Table 5.5 Financial results: case analysis

N	1(JIT)	2	3	5	15
FR	1.12	0.79	0.46	-0.19	-3.48

In case pallet purchase price is 576 € and 144 product units on the pallet layer such results are foreseen (Fig. 5.10):

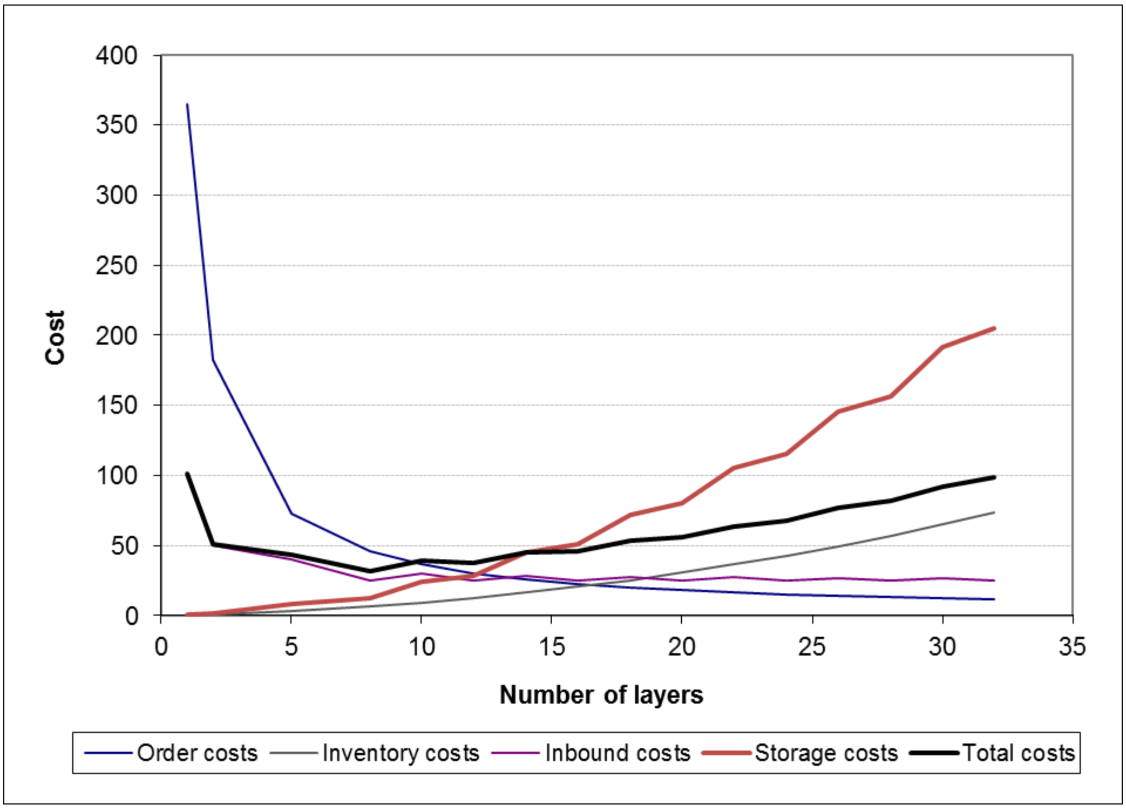


Fig. 5.10 The size of warehouse order: inbound case

In general, demand based warehouse orders falls under such levels: the receipt of 29% orders are in pallets; 42% – in layers; 19% – in cases, because the ABC analysis shows that in particular case:

- 70 % of products mainly (in 80% of cases) are delivered in pallets (as A products are high turnover products ‘high mowers’),
- 20 % of products that falls under middle turnover level are ordered in layers or half pallets (as B products – ‘middle mowers’)
- 10 % of products are delivered mainly (in 65% of cases) in boxes (as C products – ‘slow mowers’).
- All products based on turnover amount (demand level) after inbound operations have to place in warehouse according ABC placing rules seeking to have lower order picking costs later on.

The size of warehouse order: particular outbound case

Further on, outbound orders have to proceed in warehouse where products have been placed according ABC rules. This effect the lower picking costs for outbound orders.

So, seeking to specify economic size of outbound order costs and benefits have to be scaled. In addition, more costs components have to be included:

- Ordering costs (*OC*),
- Inventory costs (*R*),
- Picking costs (*PC*),
- Outbound costs (*LC*),
- Transportation costs (*TC*) if the order from warehouse have to be delivered according incoterm DDP delivery conditions,
- Damages, if any during transportation.

In general, the transportation costs amount up to 50% of logistics costs.

Then *OC*= 2, *R*= 8% yearly interest rate as the percentage, the average pallet purchase price (*PPP*) – 576 €; *PC*= 0.13 € per case or 0.64 € per pallet; *LC*= 0.55 € per transport unit and operation; *TC*= 2 € per transport order and 0.26 € per case.

In case the pallet purchase price is 576 € and 144 product units fit on the pallet layer such results are foreseen and presented bellow (Fig. 5.11):

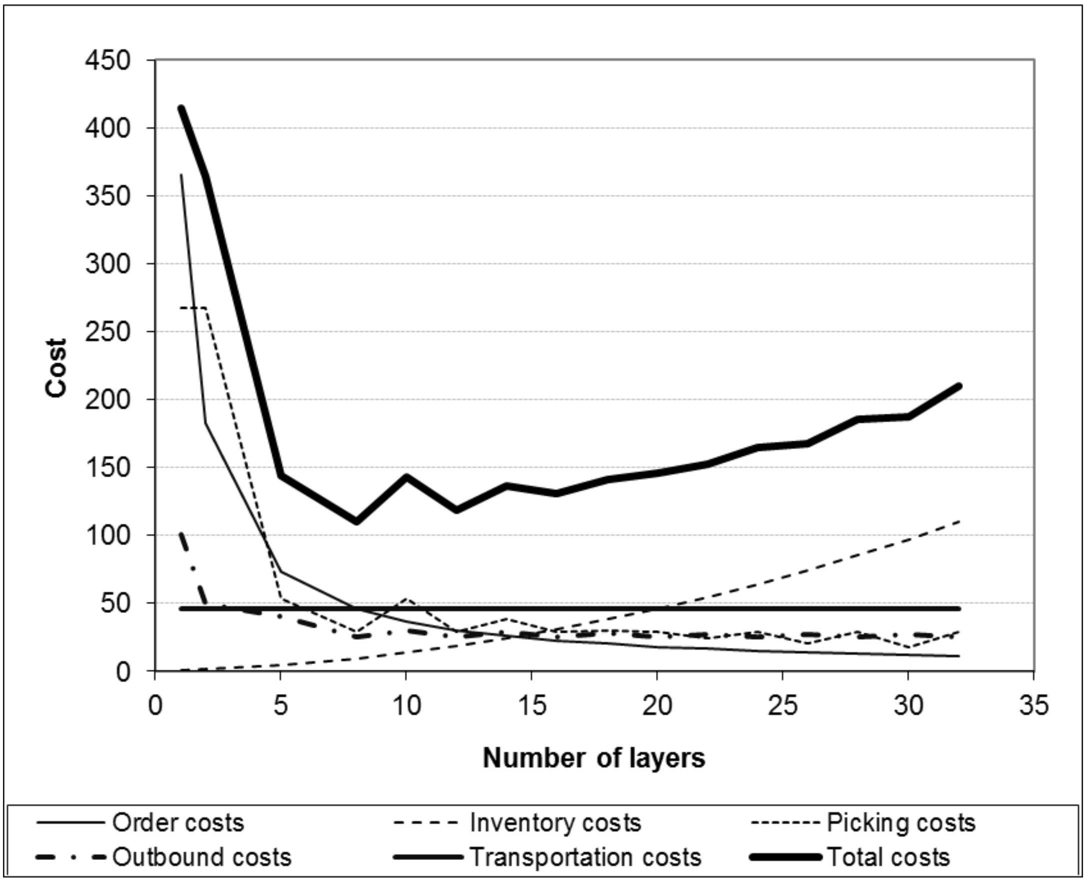


Fig. 5.11 The size of warehouse order: outbound case

The instrument itself helps to analyse both types of warehouse orders and answers the question what is the economic size of yearly planned volumes.

5.5 CONCLUSION

The aim of economic order quantity EOQ is to offer quantity that minimizes the ordering costs and do not maximises inventory holding costs.

Large variety of costs are appear in logistics. Lithuania is lower income country, so ordering costs are not the most critical ones, based on which the decision is made that is the size of warehouse order. Here on storage costs, inbound costs, and outbound costs also play the important role.

There are a lot of ways to optimise costs affecting the order size. One of such way demonstrated in the second section.

The study presented in the second section prove that all products based on turnover amount (demand level) after inbound operations have to be placed in warehouse according ABC placing rules seeking to have lower order picking costs further on. All the order picking strategies notably benefits from the use of ABC storage method. In general, the layout optimisation may affect 10% reduction of total logistics costs. Such reduction is already taken into the estimation of warehouse order size.

In the third section the author presented the estimation of warehouse order size. The outcome of this section is inter-linked with the findings delivered in the second section.

The instrument itself helps to analyse both types of warehouse orders (having inbound and outbound aspects) and answers the question what is the economic order size or the minimal size of the order. The decision could be taken based on costs nature for inbound order and for outbound order as well. This is the main difference from economic order quantity model where just inbound case is covered. The suggested instrument is formulated based on logic that by optimising one type of costs (ordering and inventory holding costs) other costs that appear in logistics shouldn’t be de-optimised (like storage costs, order picking costs, inbound costs, outbound costs, and transportation costs).

In the chapter author is using existing classic knowledge. Author hope this research will stimulate further surveys in the area of warehouse order size.

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Chapter 6

Investigations on flow rack automated storage and retrieval systems

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Abstract

Automated storage/retrieval systems (AS/RS) are computer-controlled automated material handling systems, widely used in industry and warehousing. They have interesting advantages, the majors of which are a high throughput, efficient use of space and improvement of safety. AS/RSs represent a significant investment; therefore they should be optimally used. This implies the importance of careful design of the AS/RS by taking into account all constraints. In this chapter, extensive investigations are conducted to evaluate performances of a flow rack automated storage retrieval system (flow-rack AS/RS) when considering a large mix of different product types. Although flow-rack AS/RS are typically used only for a few types of items, where each bin is dedicated to a particular item, severe competition faced by manufacturing companies requires adoption of various technologies in order to provide practical solutions. The results presented in this chapter, show that flow-rack systems may be beneficial to reducing inventory levels, while maintaining product variety and responding to customers' needs in a timely manner; thus they may be used to generate realistic production schedules that lower costs and increase customer satisfaction.

First, closed-form travel-time expressions for flow-rack AS/RS are developed. These expressions, which are based on a continuous approach, are compared for accuracy, via simulation, with exact models, based on a discrete approach, which have been developed for the purpose of closed form model validation.

There is no significant difference between the results obtained from the continuous-approach-based closed-form expressions and the ones from the discrete-approach-based exact solutions.

The closed-form expressions are easy to calculate due to their simplistic forms, even without a computer, while the exact solutions are extremely complex. On the basis of computation time, the proposed closed-form expressions are extremely practical when compared with the discrete-approach-based expressions, which require extensive computation time.

The closed-form travel-time expressions developed in this study can be used to (1) establish performance standards for existing AS/RS, (2) evaluate throughput performance for flow-rack AS/RS alternative design configurations, and (3) compare different storage techniques for improved system performance. Due to their simplistic, yet accurate, definitions, the closed-form expressions, as well as the results of this study, are applicable to industry.

Then, an analysis of the impact of pickup/delivery stations and restoring conveyor locations based on randomised storage and retrieval is conducted. From comparison of results, a number of remarks are stated and used to further work related to flow-rack AS/RS.

finally performance measure models are derived, namely space utilization and travel time, for flow-rack Automated Storage and Retrieval Systems (AS/RS). The proposed models build directly on models for unit load AS/RS. Different configurations of flow-rack systems are compared with unit load systems. A detailed analysis is carried out in order to demonstrate the *impact of load rate, number of rack layers, shape factor, and location of restoring conveyor and pickup/drop-off stations on space utilization and expected travel time. Overall, a flow-rack AS/RS system, when compared to an equivalent unit load system (i.e., same storage capacity, same number of S/R machines, and same height), requires less space, has a lower expected storage time, and an equivalent expected retrieval time. The performance measure models proposed in this study can be used to (1) determine what type of an AS/RS system, flow-rack or unit load, will perform better under certain operating conditions and (2) evaluate alternative design configurations of flow-rack AS/RS on the basis of space utilization and travel time performance.*

Keywords: travel time models, modeling, AS/RS, flow rack.

NOTATIONS

A	AS/RS base area
$\%A$	percent area saving
b	shape factor
$\overline{E(SC)}$	expected single cycle travel time for unit load and expected storage time for flow rack
$\overline{E(DC)}$	expected dual cycle travel time
$\overline{E(RC)}$	expected retrieval cycle travel time for flow rack
L , H, D	length, height and depth of the flow rack AS/RS rack.
l, h, d	length, height, and depth of a storage segment
M	number of storage segments in a bin on flow rack (i.e. number of layers in the rack)
m	layer rank on flow rack
N	storage capacity (i.e. total number of storage segments)
N_l	number of bins on each row for flow rack
N_u	number of bins on each row for unit load
N_h	number of bins on each column (both flow rack and unit load)
r	ratio of aisle width to storage segment depth
s_h	horizontal speed of storage/retrieval machine
s_v	vertical speed of storage/retrieval machine
T	normalization factor
t_h	horizontal travel time from the pickup/drop-off point to the farthest column
t_v	vertical travel time from the pickup/drop-off point to the farthest row
t'_h	horizontal travel-time between two consecutive bins
t'_v	vertical travel-time between two consecutive bins
w	aisle width
ρ	load rate
(x,y)	bin position
$(x,y)_d$	dwell point position

* Subscripts *u* and *f* have been used in the equations presented in the chapter in order to represent *unit load* and *flow rack* configurations, respectively.

6.1 INTRODUCTION

Since an automated storage and retrieval system (AS/RS) was introduced in the 1950th, the technology has advanced far beyond its original function, which was to eliminate the walking that accounted for 70% of manual retrieval time (Lee 1997). AS/R systems have been adopted not only as alternatives to traditional warehouses but also as a part of advanced manufacturing systems. This is because AS/R systems have many benefits such as saving in labor cost, improved material flow and inventory control, improved throughput level, high flow-space utilization, and increased safety and stock rotation (Allen 1992, MHI 1977).

In today's manufacturing environments, inventories are maintained at lower levels than in the past. These reduced inventories have led to smaller storage systems, which, in turn, have created the need for quick access to the material being held in storage. Hence AS/RS used in manufacturing, warehousing, and distribution applications must be designed to provide quick response times to service requests as well as minimum space utilization.

AS/R systems composed mainly of storage racks, storage/retrieval (S/R) machines and pickup/delivery (P/D) stations, are used for all kind of products, from the very small electronic components to the large car coaches, all over the industrial chain, from the raw material warehousing to the distribution applications. AS/RS cannot be of the same type in all these warehousing conditions. During the three last decades many types of AS/RS have been developed to embrace all area of their operation. Different types of AS/RS exist according to size and volume of items to be handled, storage and retrieval methods, and interaction of a storage/retrieval machine and human worker. Some of the important types include unit-load, mini-load, man-on-board, deep-lane, automated item-retrieval system, flow rack.... The unit load system is the generic AS/RS. The other systems represent it variations. All these types of AS/RS have not been studied with the same interest. Unit-load AS/RS are very well known and modeled. On the other hand, other type of AS/RS like flow rack or, automated item-retrieval system are not much encountered in literature. The scope of this work is to study the so called flow rack AS/RS.

In this chapter, investigations on flow rack AS/RS are conducted:

- Firstly, analytical expressions are derived for retrieval-time. A variety of storage rack sizes and shapes, are examined. Two approaches are considered :
  - a continuous rack face approximation approach, that gives a closed form approximate model for the expected retrieval-time
  - a discrete rack face approach, that can be considered to give the exact expected retrieval time.

  Randomized storage assignment, and Tchebychev travel (simultaneous travel in the horizontal and vertical directions) have been assumed. Computer simulation is used to validate the continuous approach versus the discrete one.

  The closed form expected retrieval time expressions, presented in this work, can be used to : establish performance standards on existing systems, evaluate throughput performance for flow rack AS/RS design configurations as well as comparison with other types of AS/RS for choice decision. Also, they can be used as a basis of comparison for evaluating performance improvements of different storage techniques.
- Secondly, the impact of load rate, number of rack layers, shape factor, and location of restoring conveyor and pickup/drop-off stations on space utilization and expected travel time criteria are investigated. Travel times models for different configurations are derived. Then, computer simulation is conducted to compare these models and to find the best possible configuration.
- Thirdly, performances of flow-rack AS/RS are investigated by considering a large mix of different product types, and compares it with unit-load AS/RS. For a large mix of different product types, each bin can no more be dedicated to a particular

item and first-in-first-out rule cannot be used. Instead, a random storage policy can be adopted, as is the case in this chapter. In random storage, each bin on the storage rack has equal probability of usage for storage. Once a product is deposited in a bin, it will slide on it due to gravity all the way to the nearest empty segment from the retrieval face. Random storage can provide a reference performance level, which can be used for benchmarking other storage policies.

This chapter is organized as follows: A literature survey on automated storage and retrieval systems is presented in section 2. Section three is devoted to unit load AS/RS travel times models as presented in the literature. These models represent the base line used to develop models for flow rack AS/RS. Travel time models flow-rack system are presented in Section 4. Section 5 includes investigate the impact of pickup/delivery station and restoring conveyors position on the travel time. Section 6 presents performance evaluation of flow rack versus unit load AS/RS in terms of space utilization and expected travel time. Each of these sections is organized in sub sections presenting respectively mathematical models and simulation results. Finally, the conclusions are given in Section 7.

6.2 LITERATURE SURVEY

Various simulation-based studies that analyze throughput performance of AS/RS exit in the literature (Sand 1976, Barrett 1977, Schwarz et al. 1978, Koenig 1980). These studies compare different operating policies for a given system configuration. Various analytical approaches to develop cost models for AS/RS have been proposed. Bozer and White (1980) present a design package that uses Zollinger’s cost model (Zollinger 1975). Karaswa et al. (1980) propose a cost model for single command cycles.

There is extensive research in the area of dwell point of S/R machine. Bozer and White (1984) suggest static dwell point rules, although they provide no quantitative comparison of their performance. Egbelu (1991) presents a model for dynamic positioning of S/R machines with the objective of minimizing the expected travel-time. In their study, Hwang and Lim (1993) show that the formulation, proposed by Egbelu (1991) could also be applied to facility location problems. In another study, Egbelu and Wu (1993) compare the performance of several dwell point rules, adopted from Bozer and White (1984) and Egbelu (1991), using simulation. Peters et al. (1996) develop a closed form solution for dwell point location under a variety of AS/RS configurations. Chang and Egbelu present formulations for pre-positioning of S/R machines in order to minimize the maximum system response time (Chang and Egbelu 1997a) and minimize the expected system response time (Chang and Egbelu 1997b) for multi-aisles AS/RS. Park (2001) developed an optimal dwell point policy for automated storage/retrieval systems with uniformly distributed racks. He proposed, for non-square-in-time racks, closed form solution for the optimal dwell point in terms of the probability of the next transaction demand type: storage or retrieval.

Development of expected travel-time (i.e. average travel-time) models for S/R machine is another research area. A comparative study based on expected travel-time of S/R machine for randomized and dedicated storage policies has been presented by Hausman et al. (1976). The rack configuration has been assumed square in time (i.e. horizontal maximum travel-time is equal to vertical maximum travel time) with single and dual command cycles. An extension on the model of Hausman et al. (1976) has been proposed by Graves et al. (1977). They present analytical and empirical results for various combinations of alternative storage assignment rules and scheduling policies. Each alternative is compared on the basis of expected travel-time of the S/R machine. Based on a continuous rack approximation approach, Bozer and White (1984) present expressions for expected cycles times of an AS/RS performing single and dual command cycles. Hwang and Lee (1990) present travel-time models, which include constant acceleration and deceleration rates with a maximum-velocity restriction. Chang et al. (1995) propose travel-time models that consider various travel speeds with known acceleration and deceleration rates. Chang and Wen (1997) extend the work presented by Chang et al. (1995) by investigating the rack configuration problem. Sarker and Babu (1995) presented a brief critical review and comparative study of some design aspects of AS/RS systems with special emphasis on travel time models. Kouvelis and Papanicolaou (1995), presented explicit formulae for the expected single command cycle time for an optimally designed rack, for a two-class-based automated storage/retrieval system. Lee (1996) presented a stochastic analysis by using a single-server queuing model to predict cycle time (a mix of single and dual command) of a unit load AS/RS. Mansuri (1997) presented a computerised algorithm for cycle time computation and storage allocation for AS/RS under dedicated storage. Kulturel *et al.* (1999) used the average travel time of S/R machine as the main performance measure, to compare two storage policies for AS/RS using simulation. Dallari *et al.* (2000), investigated the performance evaluation of a man-on-board AS/RS under different storage policies. The S/R machine travel time is derived for each storage policy as a function of the shape of the storage area, the number of picking points and the sequencing algorithm used. Van Den Berg and Gademann (2000) presented a simulation study of an automated storage/retrieval system and examined a wide variety of control policies. For the class-based storage policy, they applied an algorithm which enables evaluation of the trade-off between storage space requirements and travel times. Ashayeri *et al.* (2002) presented an exact geometry-based analytical model which can be used to compute the expected cycle time for a storage/retrieval (S/R) machine, executing single-commands, dual-commands, or both, in a rack structure which has been laid out in pre-specified storage zones for classes of goods. Ghomri *et al.* (2009) Presented new models for single and dual cycle time of multi-aisle AS/RS. Their study was based on a continuous rack face and aisle approximation. The closed form models they developed were compared to more complicated models for validation. Kouloughli *et al.*, (2008 and 2009) determined optimal dimensions of multi aisle AS/RS that minimize single and dual cycle time. Park (2006) and Park et al. (2006) studied performances of different AS/RS with class based storage policy. De Koster *et al.*, (2006) and Yugang and de Koster (2009) studied the design of optimal rack of 3D compact storage under different storage policies. For a more detailed literature review, one can refer to Roodbergen, and Vis (2009) who gave a comprehensive explanation of the current state of the art in AS/RS design, travel time estimation, storage assignment, dwell-point location, and request sequencing.

6.3 BACKGROUND KNOWLEDGE: UNIT LOAD AS/RS ANALYSIS

In their study, Bozer and White (1984) develop expected cycle time expressions for a unit load AS/RS (See figure 6.1), based on continuous rack face approximation approach, by using a statistical model. The assumptions made in their study are as follows:

- The rack is considered to be a continuous rectangular pick face where the P/D station is located at the lower left-hand corner of the rack.
- The S/R machine operates either on a single or dual command basis.
- The rack length and height, as well as the S/R machine speed in the horizontal and vertical directions, are known.

- The S/R machine travels simultaneously in the horizontal and vertical directions (i.e. Tchebychev travel). In calculating the travel-time, constant velocities are used for horizontal and vertical travel.
- Randomized storage is used (i.e. any point within the pick face is equally likely to be selected for storage or retrieval).
- Pickup and drop-off times associated with load handling are ignored. These times are generally independent of the rack shape and travel velocity of the S/R machine, and could be added, posteriori, to the travel-time expressions.

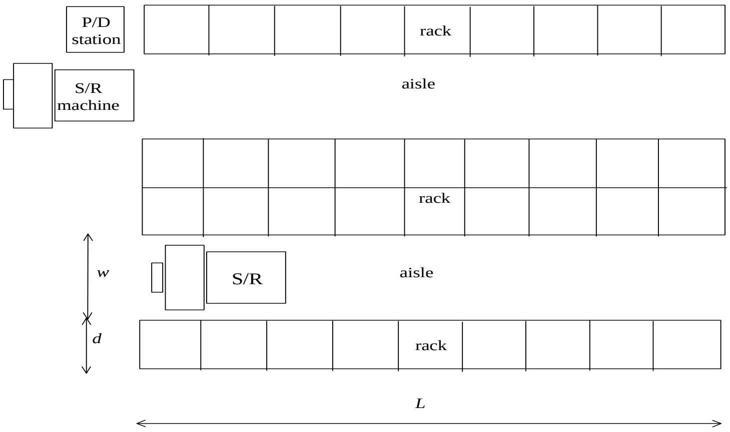

Fig.6.1 Unit load AS/RS (top view)

They define t_h as the horizontal travel-time from the P/D station to the farthest column, and t_v as the vertical travel-time from the P/D station to the farthest row. In their model, they define normalization factor and shape factor as $T_u=max(t_h,t_v)$ and $b_u=min(t_h/T_u,t_v/T_u)$, respectively, which implies that $0 < b_u \le 1$. They assumed that $t_h>t_v$, which leads to $T_u=t_h$, and $b=t_v/T_u$. Due to randomized storage policy, the expected location for storage or retrieval is assumed to be randomly distributed between 0 and 1 for horizontal direction (i.e. x-axis) and between 0 and b for vertical direction (i.e. y-axis). Therefore, if two random locations are represented by (x_1,y_1) and (x_2,y_2), then the normalized travel-time between these two locations is given by $max(|x_1-x_2|,|y_1-y_2|)$. Using these expressions, they present the following equations (Bozer and White 1984):

For expected single cycle travel-time: $\overline{E(SC)}_u = T_u\left(\frac{b_u^{2}}{3}+1\right)$ (6.1)

For expected dual cycle travel-time: $\overline{E(DC)}_u = T_u\left(\frac{4}{3}+\frac{b_u^{2}}{2}-\frac{b_u^{3}}{30}\right)$ (6.2)

As a consequence of the precedent analysis, the expected travel-time from one corner to any location of the rack, and similarly from any location to one corner of the rack can be written as follows (Peters et al. 1996):

$$\overline{\mathrm{E1}}_u = T_u\left(\frac{b_u^{2}}{6}+\frac{1}{2}\right) \tag{6.3}$$

Similarly, the expected travel-time from the midpoint to any location of the rack, and similarly from any location to the midpoint of the rack can be formulated as follows (Peters et al. 1996):

$$\overline{E2_u} = \frac{T_u}{2}\left(\frac{{b_u}^2}{6}+\frac{1}{2}\right) \tag{6.4}$$

The abovementioned models, which have been developed by Bozer and White (1984) for unit load AS/RS, forms the basis of the models presented in this paper. Their formulation has been extended to apply to flow-rack AS/RS.

6.4. FLOW RACK AS/RS TRAVEL TIMES MODELS

6.4.1. Continuous rack face approach.

Sari *et al.* (2005) developed continuous and discrete travel time models for storage and retrieval operations of a flow rack AS/RS. They validated the approximate continuous models by comparing them with an exact discrete models that will be shown in next section. This section shows how the continuous models have been developed.

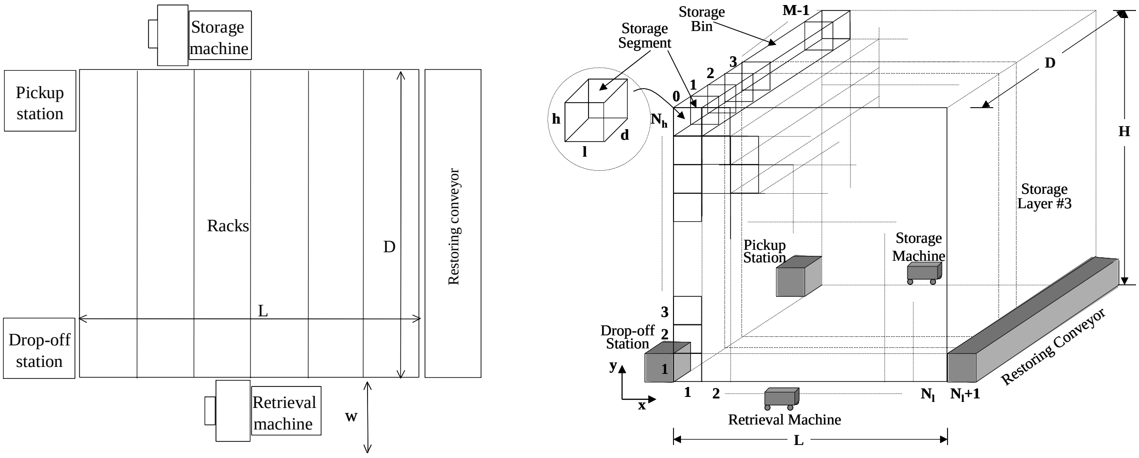

Fig.6.2 Configuration of a typical flow-rack AS/RS (top view and 3-D schematics)

As shown in figure 6.2, a flow-rack AS/RS includes a rack, which consists of sloping bins, where items loaded by a storage machine at one end of the rack on the store-face travel along sloping wheels or rollers to the other end of the rack on the pick-face to be retrieved by a retrieval machine. Both the retrieval and storage machines can travel on the x-y plane to reach any bin on the rack. A drop-off station and a pickup station are located at the pick-face and the store-face of the rack, respectively (i.e. lower-left corner of the rack). A restoring conveyor, located at the lower-right corner, is used to link the storage and the retrieval machines.

As shown in figure 6.2, a rack, which consists of bins, has a length *L*, height *H*, and depth *D*. The rack has N_l bins on each row and N_h bins on each column. Each bin has *M* storage segments, numbered from *1* to *M*. Each segment has a storage capacity of one item. The length, height, and depth of each segment are $l=L/N_l$, $h=H/N_h$, and $d=D/M$, respectively. The segments having the same rank form a layer. The storage and retrieval machines have the same horizontal speed, s_h, and the same vertical speed, s_v. Therefore, the travel-times, t_h, t_v, t'_h, and t'_v, can be calculated as follows:

$$t_h = \frac{L}{s_h} \quad ; \quad t_v = \frac{H}{s_v} \quad ; \quad t_h^{'} = \frac{t_h}{N_l} \quad ; \quad t_v^{'} = \frac{t_v}{N_h} \tag{6.5}$$

For a storage operation, the storage machine in a flow-rack AS/RS operates exactly the same as the one in a unit-load AS/RS. Therefore, the expected cycle time for storage operation from the pick-up station located at the lower left-hand corner of the rack to a random location, and then back to the pick-up station, can be calculated by using equation (6.1):

$$\overline{E(SC)}_f = T_f \left(\frac{b_f^{\ 2}}{3} + 1 \right) \tag{6.6}$$

The storage machine is responsible for two basic activities: (1) storing items waiting at the pickup station, and (2) restoring items that are on the restoring conveyor. Equation (6.6) assumes that "restoring of items" is performed only when there is no item waiting for "storage" at the pickup station. In other words, the "restoring of items" activity is assumed not to cause a bottleneck during the "storage of items" activity. Therefore, "restoring of items" is not included in Equation 6.

However, a retrieval operation for a particular item requires the retrieval machine to remove all the items stored in front of the requested item until it reaches the very first bin on the pick-face of the rack. Thus, the expected retrieval-time of a particular item stored in layer m can be calculated as follows:

$$\overline{E(RC)}_m = \overline{E(V_1)}_f + \overline{E(V_2)}_f + (m-1).\overline{E(V_3)}_f \tag{6.7}$$

Where

m is the layer rank of the requested item (1 ≤ m ≤ M)

$\overline{E(V_1)}_f$ is the expected travel-time between dwell point and retrieval point

$\overline{E(V_2)}_f$ is the expected travel-time between retrieval point and drop-off station

$\overline{E(V_3)}_f$ is the expected travel-time from the retrieval point to the restoring conveyor and back to the retrieval point

The optimal dwell point location for the storage machine is the pickup station and the optimal dwell point location for the retrieval machine is the midpoint of the rack face (Peters et al. 1996). Expressions for $\overline{E(V_1)}_f, \overline{E(V_2)}_f, \overline{E(V_3)}_f$ can easily be derived based on the previous work presented in (Bozer and White 1984):

$$\overline{E(V_1)}_f = \frac{T_f}{2} \left(\frac{b_f^{\ 2}}{6} + \frac{1}{2} \right) \tag{6.8}$$

$$\overline{E(V_2)}_f = T_f \left(\frac{b_f^{\ 2}}{6} + \frac{1}{2} \right) \tag{6.9}$$

$$\overline{E(V_3)}_f = T_f \left(\frac{b_f^{\ 2}}{3} + 1 \right) \tag{6.10}$$

Equation (6.7) can be rewritten by using equations (6.8), (6.9), and (6.10):

$$\overline{E(RC)}_m = \frac{3}{4} T_f \left(\frac{b_f^{\ 2}}{3} + 1 \right) + (m-1).T_f \left(\frac{b_f^{\ 2}}{3} + 1 \right) \quad (6.11)$$

Expected travel-time for retrieval machine depends on rack configuration, storage capacity, and number of items stored in the rack. Using the notation given for a typical flow-rack AS/RS (See figure 6.2), storage capacity can be calculated as $N=N_l.N_h.M$. Load rate of a system, ρ, is the ratio of the number of locations loaded in the rack to the storage capacity. Therefore, ρ varies between *0* and *1*. The storage density at each layer (i.e. $1 \leq m \leq M$) in the rack depends on the load rate and the number of storage segments, M, on each bin. Assuming randomized storage, various scenarios can be presented:

Case – 1: If $\rho \leq 1/M$ then stored items are highly populated in storage layer #1
Case – 2: If $1/M < \rho \leq 2/M$ then stored items are highly populated in storage layers #1 and #2
Case – 3: If $m/M < \rho \leq (m+1)/M$ then storage layers #1 through #m+1 contains most of the stored items
Case – 4: If $(M-1)/M < \rho \leq 1$ then storage capacity is almost fully utilized

For each case defined above, an expected retrieval time expression can be approximated based on equation (6.11). For Case – 1, only the very first storage layer is utilized (i.e. $m=1$), then there will be no restoring since all items can be directly reached. Therefore, the expected retrieval time becomes:

$$\overline{E(RC)}_f = \frac{3}{4} T_f \left(\frac{b_f^{\ 2}}{3} + 1 \right) \quad \text{for } \rho < \frac{1}{M} \quad (6.12)$$

For the other three cases, the number of storage layers that will be highly-populated can be calculated by dividing the number of stored items by the layer storage capacity (i.e. $N_l.N_h$). In other words, it can be stated that the last highly-populated layer for a given load rate ρ is:

$$m = E(\rho M) + 1 \quad (6.13)$$

where $E(\rho M)$ is the integer value of ρM

The expected retrieval-time for any item stored in any layer for a system with m layers highly-populated is:

$$\overline{E(RC)}_f = \frac{1}{m} \sum_{i=1}^{m} \overline{E(RC)}_i \quad (6.14)$$

Replacing equation (6.11) in (6.14), expected retrieval time can be rewritten as:

$$\overline{E(RC)}_f = \frac{3}{4} T_f \left(\frac{b_f^{\ 2}}{3} + 1 \right) + \frac{(m-1)}{2}.T_f \left(\frac{b_f^{\ 2}}{3} + 1 \right) \quad (6.15)$$

Finally, replacing equation (6.13) in (6.15), the expected retrieval-time expression for a flow-rack AS/RS becomes:

$$\overline{E(RC)}_f = T_f \left(\frac{b_f^{\ 2}}{3} + 1 \right) \left(\frac{1}{4} + \frac{1}{2} \rho.M \right) \quad \text{for } \frac{1}{M} \leq \rho \leq 1 \quad (6.16)$$

6.4.2. Discrete rack face approach

To be able to validate the expressions of the expected retrieval time derived, it is necessary to compare the results of these expressions with some others obtained by either experiment or analytical methods considered to be exact ones. It is very difficult to determinate the expected retrieval-time by experiment. In fact, it is necessary to make experiments on a very long lapse of time. Add to this, that it is necessary to validate the derived expressions on a large area of rack shape and size configurations. Hence, AS/RS were not accessible for such experiment. This was possible only by simulation. So, it was decided to devise a discrete expression of the expected retrieval time that can be considered to be exact. The way to obtain the exact expected travel time is to sum the travel times of all the rack segments and then divide by the number of segments (Bozer and White 1984). In our case, the expected time will depend mainly on the load rate. Since to reach an item in the m^{th} layer, it is necessary to discharge items preceding it.
Let us consider the front rack shape as shown in figure 6.3.

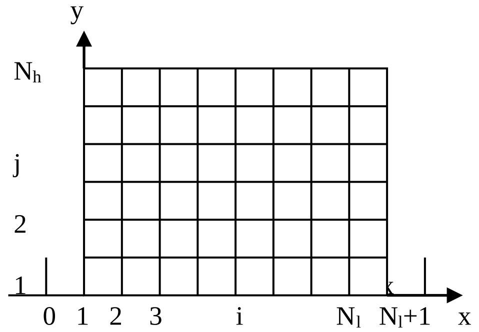

Fig.6.3 Retrieval rack face configuration.

Each bin has M segments, delivery station is at position *(x,y)=(0,1)*. Restoring conveyor is at position *(x,y)=(N*$_l$*+1,1)*. Dwell point of the retrieval machine is at the midpoint of the rack.

So its position is: $$(x,y)_d = \left(\left[\frac{N_l+1}{2} \right]; \left[\frac{N_h+1}{2} \right] \right) \tag{6.15}$$

The displacement time from bins *(i,j)* to *(i',j')* is :

$$t((i,j);(i',j')) = \max\left(t_h^{'} |i'-i|, t_v^{'} |j'-j|\right) \tag{6.16}$$

From this, we can deduce the displacement time: E_1 from the dwell point to bin *(i,j)*; E_2 from bin *(i,j)* to delivery station and E_3 from bin *(i,j)* to the restoring conveyor as:

$$E_1 = \max\left(t_h^{'} \left| i - \left[\frac{N_l+1}{2} \right] \right|, t_v^{'} \left| j - \left[\frac{N_h+1}{2} \right] \right| \right) \tag{6.17}$$

$$E_2 = \max\left(t_h^{'} |0-i|, t_v^{'} |1-j|\right) \tag{6.18}$$

$$E_3 = \max\left(t_h^{'} |N_l + 1 - i|, t_v^{'} |1-j|\right) \tag{6.19}$$

The retrieval time for an item in the k^{th} layer of bin *(i,j)* will be:

$$E(RC)_{ijk} = E_1 + E_2 + 2k.E_3 \tag{6.20}$$

The expected retrieval time of items in bin *(i,j)* with m_{ij} occupied segments is:

$$\overline{E(RC)}_{ij} = \frac{1}{m_{ij}} \sum_{k=0}^{m_{ij}} E_1 + E_2 + 2k.E_3 \tag{6.21}$$

Finally, considering the whole rack, the expected retrieval time will be:

$$\overline{E(RC)} = \frac{1}{N_l N_h} \sum_{i=1}^{N_l} \sum_{j=1}^{N_h} \frac{1}{m_{ij}} \sum_{k=0}^{m_{ij}} E_1 + E_2 + 2k.E_3 \tag{6.22}$$

Replacing expressions (6.17-20) in expression (6.22), we obtain:

$$E(RC) = \frac{1}{NlNh} \sum_{i=1}^{Nl} \sum_{j=1}^{Nh} \frac{1}{mij} \sum_{k=0}^{mij-1} \left(\begin{aligned} & \max\left(t'_h \left| i - \left[\frac{Nl+1}{2} \right] \right| ; t'_v \left| j - \left[\frac{Nh+1}{2} \right] \right| \right) + \max\left(t'_h \left| 0 - i \right| ; t'_v \left| 1 - j \right| \right) \\ & + 2.k.\max\left(t'_h \left| Nl + 1 - i \right| ; t'_v \left| 1 - j \right| \right) \end{aligned} \right) \tag{6.23}$$

$$with : \sum_{i=1}^{Nl} \sum_{j=1}^{Nh} mij = \left[\rho.N \right] \cong \rho.N$$

6.4.3. Pickup/delivery and acceleration/deceleration delays.

In the previous sections, pickup/delivery times and acceleration/deceleration of the retrieval machine have not been considered. In unit load AS/RS, these times can be accounted for constant and added to the final expressions (Bozer and White 1984, Peters 1996). They can be also taken into account for the construction of the models (Hwang and Lee 1990, Chang et al. 1995, Chang and Wen 1997).

In this section, the influence of pickup/delivery times and acceleration/deceleration on the developed models of the expected retrieval time will be investigated. For item comparable size and weight, P/D times and acceleration/deceleration can be considered to be constants. The manipulation of each item is associated to one pickup time, one delivery time, two acceleration time and two deceleration time. Let us name t_c the sum of all these times. Adding t_c to each item manipulation, let determine the expected retrieval time, using the continuous and discrete approaches.

For the continuous approach, the expected retrieval time of an item in layer m is:

$$\overline{E(RC)}_{mtc} = \overline{E(V_1)} + \overline{E(V_2)} + t_c + m\left(\overline{E(V_3)} + t_c \right) \tag{6.24}$$

Consequently, replacing (6.24) in (6.11), the expected retrieval time of any item present in any layer is:

$$\overline{E(RC)}_{tc} = T\left(\frac{b^2}{3} + 1 \right)\left(\frac{1}{4} + \frac{1}{2}\rho.M \right) + \frac{M\rho + 1}{2} t_c \tag{6.25}$$

Let us state that: $$\overline{T_{cc}} = \frac{M\rho + 1}{2} t_c \tag{6.26}$$

Consider now the discrete approach, from expression (6.22) the expected retrieval is:

$$\overline{E(RC)}_{tc} = \frac{1}{N_l N_h} \sum_{i=1}^{N_l} \sum_{j=1}^{N_h} \frac{1}{m_{ij}} \sum_{k=0}^{m_{ij}} E_1 + E_2 + t_c + k\left(2E_3 + t_c \right) \tag{6.27}$$

$$\overline{E(RC)}_{tc} = \overline{E(RC)} + \frac{1}{N_l N_h}\frac{t_c}{2}\sum_{i=1}^{N_l}\sum_{j=1}^{N_h} m_{ij} + 1 \qquad (6.28)$$

Let us state that: $$\overline{T_{cd}} = \frac{1}{N_l N_h}\frac{t_c}{2}\sum_{i=1}^{N_l}\sum_{j=1}^{N_h} m_{ij} + 1 \qquad (6.29)$$

Developing expression (6.29) leads to: $$\overline{T_{cd}} = \frac{M\rho + 1}{2} t_c = \overline{T_{cc}} \qquad (6.30)$$

It can be noticed, that the two approaches give the same expression, for pickup/delivery and acceleration/deceleration delay. This delay is ρ-dependent, which is foreseeable, since the number of discharges before reaching the needed item is ρ-dependent.

6.4.4. Simulation

The closed form expressions, obtained with the continuous approach, are straight forward to compute, their parameters: T, b and M are constants for a given rack configuration. However, the expressions, obtained from the discrete approach, are very complex. In addition to this, when the load rate ρ is less than 1, there is a large number of rack filling arrangements. So, the expected retrieval time determination based on a single filling arrangement will be inaccurate. So, the expected retrieval time should be calculated for a large number of randomized filling arrangements and averaging should be performed on these results.

One may ask how many filling arrangements are necessary to get an enough precise discrete value? To answer this question, we made a simulation for different increasing numbers of filling arrangements. For this we simulated a 36 bins square in time flow rack AS/RS with a load rate of 70%. The filling arrangements number (FAN) was varied from 2000 to 120000. Discrete value of the expected retrieval time (DERT), its standard deviation and the computing time were calculated (on a Pentium 166MHz). Results are displayed in table 6.1. From this table, we notice that the DERT precision is of 3 digits when FAN is less than 12 000. It becomes 4 digits for FAN from 14 000 to 120 000. To get more digits, it seems that larger FAN are needed. One may say that the computing method may be responsible for variation of DERT. To verify our computing method, we simulate a flow rack AS/RS with 100% load rate on 20 000 FAN. Since at 100% load rate all filling arrangements are identical, all obtained discrete values are equal, then the standard deviation should be equal to zero. The computing method error will then be equivalent to the standard deviation obtained by simulation. The standard deviation for the above simulation was of the order of 10^{-12}. Hence, it can be stated that the computing method is not responsible of DERT variations noticed in table 6.1. Because of long computing time for larger FAN, it was decided to keep only 4 digit precision. Then a FAN of 20 000 was chosen for next simulations.

Computer simulation has been performed on different rack size and shapes. For size, it was chosen to use racks of *36, 144, 225, 400* and *630* bins, each of which containing *4, 6, 8,* and *10* layers. The shape factor *b* was varied from *b=1* (square in time system) to *b=0.014*. The load rate ρ was varied, in increment of *10%,* from $\rho_{min}=1/M$ to *1*. ρ_{min} is the minimum load rate for which expression (6.14) is defined. Tables 6.2-6 display the percent error between continuous and discrete approaches, for the different rack shape and size, versus the load rate. From these tables, we notice:

Table 6.1 Standard deviation, discrete expected retrieval time (DERT), and computing time with respect to filling arrangement number (FAN)

FAN	Standard deviation	DERT	Computing time	FAN	Standard deviation	DERT	Computing time
2 000	0.2737	13.2448	4 min 37 s	32 000	0.2750	13.2492	1 h 13 min
4 000	0.2738	13.2455	9 min 09 s	36 000	0.2734	13.2481	1 h 21 min
6 000	0.2753	13.2466	13 min 25 s	40 000	0.2725	13.2467	1 h 33 min
8 000	0.2764	13.2511	18 min 29 s	50 000	0.2752	13.2495	1 h 54 min
1 000	0.2769	13.2453	26 min 09 s	60 000	0.2744	13.2482	2 h 14 min
12 000	0.2744	13.2507	27 min 33 s	70 000	0.2742	13.2480	2 h 38 min
14 000	0.2755	13.2460	32 min 22 s	80 000	0.2740	13.2462	3 h 05 min
16 000	0.2736	13.2490	40 min 45 s	90 000	0.2744	13.2481	3 h 25 min
20 000	0.2739	13.2461	45 min 10 s	100 000	0.2742	13.2475	3 h 48 min
24 000	0.2732	13.2469	54 min 14 s	110 000	0.2747	13.2488	4 h 04 min
28 000	0.2748	13.2474	1 h 3 min	120 000	0.2755	13.2477	4 h 28 min

- For any size or shape of the rack, the error at ρ_{min} ($\rho_{min}=1/M$) is always about *13%*. This large error can be justified by the fact that the continuous approach is defined only for $\rho \geq 1/M$.
- For square in time systems ($b=1$), the error is relatively small. It is less than *2%* for a *36* bins rack when the load rate is larger than $2\rho_{min}$. For larger systems it get smaller, and for a *400* rack system, the error is often less than *0.1%*.
- For non-square systems, the error depends on the size of the system, It is somehow important for small systems (less than *5.9%* for *36* bins rack) and get smaller for larger systems (less than *2.4%* for *630* bins rack) for an load rate larger than $2\rho_{min}$.
- A very small increase of the error is noticed when the number of layers (M) increases.
- At design, AS/RS are always dimensioned to work at a maximum of *85%* of their total capacity (White & Kinney 1982). However, for economic reasons, systems are made to work at their best possible performances (Groover 1987). So, in practice, systems work in most of the time, slightly under *85%* of their capacity. According to this, we can define a so called "useful zone" of operation for the system between $\rho=0.7$ and $\rho=0.85$. In this useful zone, we notice that the error is relatively small. For square in time systems, the error is less than *1.2%* for *36* bin rack and lower to *0.1%* for *400* bin rack. On the other hand, for non-square systems, the error lowers when systems get larger (*<2.9%* for *144* bins, *<2.4%* for *225 bins*, *<1.8%* for *400* bins and *<1.4%* for *630* bins). However, for very small systems (*36* bin rack), the error is important (*<5.8%*).
- In addition to the fact that the error is size dependent, we notice, also, that it is also shape dependents. For square in time systems, the error is minimum, it get increasing when the shape factor (b) decreases until a maximum error happening at b between *0.36* and *0.25*. Then this error decreases when b decreases. More simulation can give a better information on these phenomena. Unfortunately, simulation of the discrete approach is very computer time consuming.

Generally, it is noted that the error between the two methods is acceptable, and can be totally justified by computer time gain. However, continuous approach is not suitable for predicting the expected retrieval time for small systems of for low occupying factor (less than $2\rho_{min}$). The continuous rack face approach can give, in a simple hand operation, the expected retrieval time of the flow rack AS/RS with an acceptable error. When the systems are large the error get very small.

Table 6.2 Percent error between continuous and discrete expected retrieval times versus the load rate ρ, for a 36 bins flow rack AS/RS.

M-N	4 - 144				6 – 216				8 - 288				10 – 360			
b	1.00	0.571	0.444	0.250	1.00	0.571	0.444	0.250	1.00	0.571	0.444	0.250	1.00	0.571	0.444	0.250
ρ(%)	Percent error between continuous and discrete expected retrieval times															
10													13.4	10.5	8.52	8.43
20					9.49	6.22	4.77	4.78	3.70	1.58	0.823	0.864	2.04	0.678	2.48	2.57
25	13.3	10.4	8.38	8.27	5.22	1.60	0.626	0.539	2.01	0.709	2.51	2.52	0.603	2.65	3.90	3.93
30	9.44	6.23	4.70	4.63	2.70	0.285	1.83	1.87	1.18	1.93	3.27	3.32	0.157	2.93	4.68	4.71
40	3.57	1.43	0.986	1.03	1.19	1.96	3.36	3.40	0.174	3.11	4.72	4.74	0.764	3.55	5.30	5.35
50	1.83	0.885	2.68	2.74	0.153	2.94	4.65	4.74	0.732	3.59	5.30	5.32	0.952	3.82	5.57	5.56
60	0.945	2.20	3.57	3.61	0.869	3.40	5.40	5.45	1.05	3.76	5.61	5.65	1.03	3.92	5.67	5.74
70	0.339	2.94	4.85	4.90	0.709	3.66	5.29	5.32	1.19	3.90	5.8	5.83	1.09	4.03	5.78	5.77
80	0.454	3.37	4.96	5.00	1.04	3.81	5.64	5.67	0.913	3.96	5.56	5.58	1.14	4.08	5.80	5.80
85	0.430	3.49	4.98	5.01	1.19	4.11	5.77	5.81	1.17	3.99	5.81	5.83	1.14	4.24	5.82	5.83
90	10.8	3.61	5.62	5.64	0.836	3.90	5.46	5.46	1.02	4.05	5.70	5.71	1.15	4.12	5.82	5.86
100	0.917	3.73	5.47	5.50	1.06	3.95	5.69	5.71	1.13	4.07	5.80	5.82	1.18	4.14	5.87	5.88

Table 6.3 Percent error between continuous and discrete expected retrieval times versus the load rate ρ, for a 144 bins flow rack AS/RS.

M-N	4 - 576				6 – 864				8 - 1152				10 - 1440			
b	1.00	0.563	0.250	0.111	1.00	0.563	0.250	0.111	1.00	0.563	0.250	0.111	1.00	0.563	0.250	0.111
ρ(%)	Percent error between continuous and discrete expected retrieval times															
10													13.8	11.7	11.3	11.8
20					9.43	7.37	6.97	7.50	5.04	2.96	2.64	3.14	2.58	0.56	0.16	0.68
25	13.7	11.6	11.2	11.8	5.72	3.67	3.32	3.80	2.60	0.556	0.173	0.71	1.20	0.88	1.24	0.74
30	9.35	7.25	6.90	7.41	3.62	1.54	1.21	1.72	1.28	0.789	1.12	0.63	0.504	1.59	1.96	1.42
40	4.85	2.80	2.44	2.95	1.26	0.79	1.16	0.64	0.274	1.77	2.18	1.61	0.012	2.17	2.56	1.99
50	2.36	0.30	0.05	0.46	0.457	1.59	1.96	1.44	0.032	2.15	2.52	1.99	0.188	2.37	2.72	2.17
60	1.01	1.03	1.38	0.86	0.146	1.97	2.34	1.83	0.156	2.28	2.69	2.10	0.246	2.42	2.83	2.22
70	0.476	1.59	1.95	1.43	0.155	2.28	2.68	2.13	0.195	2.34	2.75	2.17	0.273	2.46	2.86	2.29
80	0.009	2.07	2.43	1.91	0.191	2.33	2.70	2.16	0.322	2.47	2.90	2.29	0.283	2.47	2.88	2.30
85	0.132	2.23	2.60	2.06	0.191	2.32	2.74	2.16	0.262	2.43	2.84	2.26	0.282	2.48	2.89	2.32
90	0.085	2.18	2.55	2.01	0.308	2.45	2.84	2.27	0.292	2.48	2.89	2.32	0.295	2.50	2.90	2.32
100	0.231	2.34	2.72	2.17	0.266	2.43	2.83	2.26	0.285	2.48	2.89	2.30	0.297	2.51	2.92	2.33

Table 6.4 Percent error between continuous and discrete expected retrieval times versus the load rate ρ, for a 225 bins flow rack AS/RS.

M-N	4 - 900				6 – 1350				8 - 1800				10 - 2250			
b	1.00	0.36	0.111	0.040	1.00	0.36	0.111	0.040	1.00	0.36	0.111	0.040	1.00	0.36	0.111	0.040
ρ(%)	Percent error between continuous and discrete expected retrieval times															
10													13.9	11.8	12.2	12.8
20					9.61	7.62	8.03	8.60	4.95	2.96	3.38	3.95	2.68	0.687	1.12	1.69
25	13.8	11.7	12.2	12.7	5.65	3.68	4.10	4.66	2.67	0.679	1.09	1.68	1.19	0.807	0.370	0.206
30	9.51	7.52	7.93	8.51	3.60	1.64	2.04	2.66	1.48	0.536	0.076	0.482	0.577	1.45	0.984	0.397
40	4.77	2.78	3.23	3.79	1.44	0.564	0.11	0.472	0.428	1.62	1.16	0.583	0.0430	2.01	1.56	0.934
50	2.43	0.46	0.887	1.45	0.556	1.48	1.05	0.437	0.049	2.02	1.55	0.943	0.106	2.19	1.72	1.09
60	1.19	0.79	0.354	0.225	0.142	1.90	1.44	0.810	0.090	2.20	1.70	1.11	0.169	2.26	1.82	1.14
70	0.498	1.51	1.06	0.468	0.358	2.11	1.63	1.02	0.146	2.27	1.78	1.16	0.181	2.31	1.83	1.19
80	1.15	1.89	1.45	0.859	0.116	2.20	1.73	1.11	0.166	2.29	1.80	1.17	0.179	2.34	1.84	1.20
85	0.001	2.02	1.57	0.972	0.187	2.28	1.80	1.18	0.176	2.30	1.82	1.18	0.207	2.37	1.88	1.23
90	0.072	2.11	1.65	1.05	0.154	2.26	1.78	1.16	0.177	2.33	1.83	1.19	0.186	2.36	1.86	1.21
100	0.148	2.20	1.74	1.13	0.171	2.29	1.81	1.18	0.183	2.34	1.84	1.20	0.190	2.37	1.87	1.21

Table 6.5 Percent error between continuous and discrete expected retrieval times versus the load rate ρ, for a 400 bins flow rack AS/RS.

M-N	4 -1600				6 – 2400				8 - 3200				10 - 4000			
b	1.00	0.640	0.250	0.0400	1.00	0.640	0.250	0.040	1.00	0.640	0.250	0.0400	1.00	0.640	0.250	0.040
ρ(%)	Percent error between continuous and discrete expected retrieval times															
10													13.9	12.8	12.4	13.1
20					9.66	8.57	8.13	8.90	4.99	3.91	3.51	4.23	2.72	1.65	1.22	1.97
25	13.9	12.7	12.3	13.1	5.83	4.77	4.36	5.09	2.72	1.65	1.23	1.98	1.31	0.23	0.165	0.581
30	9.56	8.46	8.03	8.80	3.65	2.58	2.17	2.90	1.52	0.433	0.0297	0.774	0.628	0.45	0.876	0.112
40	4.82	3.76	3.34	4.07	1.49	0.415	0.498	0.764	0.479	0.613	1.07	0.293	0.110	1.00	1.43	0.639
50	2.48	1.42	1.00	1.74	0.601	0.473	0.898	0.151	0.123	0.997	1.44	0.653	0.027	1.16	1.61	0.810
60	1.23	0.16	0.24	0.497	0.203	0.893	1.33	0.560	0.016	1.14	1.60	0.801	0.074	1.22	1.68	0.865
70	0.55	0.52	0.96	0.203	0.035	1.09	1.54	0.737	0.076	1.22	1.67	0.860	0.094	1.25	1.72	0.901
80	0.19	0.90	1.33	0.568	0.054	1.17	1.62	0.832	0.091	1.23	1.70	0.881	0.100	1.26	1.73	0.897
85	0.07	1.02	1.46	0.694	0.076	1.20	1.66	0.856	0.094	1.24	1.71	0.884	0.106	1.26	1.73	0.894
90	0.01	1.11	1.54	0.770	0.083	1.22	1.68	0.867	0.097	1.25	1.72	0.893	0.107	1.27	1.74	0.905
100	0.08	1.19	1.63	0.850	0.096	1.24	1.70	0.883	0.103	1.26	1.73	0.900	0.107	1.28	1.75	0.911

Table 6.6 Percent error between continuous and discrete expected retrieval times versus the load rate ρ, for a 630 bins flow rack AS/RS.

M-N	4 – 2520				6 – 3780				8 – 5040				10 – 6300			
b	0.700	0.357	0.129	0.0143	0.700	0.357	0.129	0.014	0.700	0.357	0.129	0.0143	0.700	0.357	0.129	0.014
ρ(%)	Percent error between continuous and discrete expected retrieval times															
10													13.2	12.7	12.9	13.6
20					8.93	8.44	8.67	9.32	4.30	3.82	3.99	4.64	2.01	1.52	1.72	2.39
25	13.1	12.6	12.8	13.5	5.13	4.63	4.86	5.49	2.01	1.51	1.71	2.36	0.596	0.11	0.320	0.986
30	8.84	8.34	8.55	9.21	2.95	2.47	2.67	3.32	0.809	0.324	0.527	1.18	0.085	0.58	0.351	0.306
40	4.11	3.63	3.84	4.49	0.778	0.29	0.496	1.16	0.245	0.740	0.541	0.128	0.615	1.12	0.902	0.207
50	1.77	1.29	1.50	2.14	0.121	0.61	0.404	0.269	0.621	1.13	0.905	0.217	0.774	1.30	1.07	0.364
60	0.526	0.046	0.249	0.903	0.517	1.03	0.807	0.138	0.760	1.28	1.05	0.350	0.828	1.36	1.12	0.424
70	0.156	0.641	0.430	0.232	0.703	1.22	0.983	0.311	0.817	1.34	1.12	0.405	0.847	1.38	1.14	0.431
80	0.539	1.03	0.822	0.157	0.788	1.31	1.08	0.390	0.835	1.36	1.14	0.421	0.865	1.40	1.17	0.435
85	0.650	1.15	0.933	0.267	0.811	1.33	1.11	0.416	0.848	1.38	1.16	0.435	0.864	1.40	1.17	0.444
90	0.728	1.23	1.02	0.343	0.825	1.35	1.13	0.424	0.853	1.38	1.15	0.437	0.866	1.41	1.17	0.442
100	0.810	1.32	1.10	0.417	0.843	1.37	1.14	0.433	0.860	1.40	1.16	0.441	0.870	1.41	1.18	0.446

6.5 ALTERNATIVE LOCATIONS FOR P/D STATION AND RESTORING CONVEYOR

When displacing the pickup and drop-off stations, as well as the restoring conveyor, important variation in the expected times are noticed. Pickup and drop-off stations and the restoring conveyor can have two main locations: either at one corner or at the middle of the rack. Placing them at the middle of the rack will reduce travel-time since the distance between them and any bin in the rack will be reduced. The restoring conveyor, when placed at one corner will occupy a complete row of the rack; however, if it is place at the middle, it will occupy only the equivalent of two or three bins (depending on the rack depth since its slope is opposite to bin slope). $\overline{E(V_1)}, \overline{E(V_2)}, \overline{E(V_3)}$ can be determined using equations (6.3) and (6.4) for each P/D stations and restoring conveyor location. Results are shown in Table 6.7, including the original configuration described in Section 4.A.

Table 6.7 Travel-time Expressions by Location

Location	Middle	Corner	$\overline{E(V_1)}$	$\overline{E(V_2)}$	$\overline{E(V_3)}$
P/D Station*		X	$\frac{T}{2}\left(\frac{b^2}{6}+\frac{1}{2}\right)$	$T\left(\frac{b^2}{6}+\frac{1}{2}\right)$	$T\left(\frac{b^2}{3}+1\right)$
Rest. Conveyor*		X			
P/D Station		X	$\frac{T}{2}\left(\frac{b^2}{6}+\frac{1}{2}\right)$	$T\left(\frac{b^2}{6}+\frac{1}{2}\right)$	$\frac{T}{2}\left(\frac{b^2}{3}+1\right)$
Rest. Conveyor	X				
P/D Station	X		$\frac{T}{2}\left(\frac{b^2}{6}+\frac{1}{2}\right)$	$\frac{T}{2}\left(\frac{b^2}{6}+\frac{1}{2}\right)$	$T\left(\frac{b^2}{3}+1\right)$
Rest. Conveyor		X			
P/D Station	X		$\frac{T}{2}\left(\frac{b^2}{6}+\frac{1}{2}\right)$	$\frac{T}{2}\left(\frac{b^2}{6}+\frac{1}{2}\right)$	$\frac{T}{2}\left(\frac{b^2}{3}+1\right)$
Rest. Conveyor	X				

*as shown in Figure 6.2 and 6.3.

Then, Equation (6.11) is reevaluated, and similarly to analysis in Section 4.1., the following equations are derived:

Case A: the restoring conveyor is at the midpoint of the rack.

$$\overline{E(RC)_f} = T_f\left(\frac{b_f^2}{3}+1\right)\left(\frac{1}{2}+\frac{1}{4}\rho.M\right) \text{ for } \frac{1}{M} \le \rho \le 1 \tag{6.31}$$

$$\overline{E(RC)_f} = \frac{3}{4}T_f\left(\frac{b_f^2}{3}+1\right) \text{ for } \rho < \frac{1}{M} \tag{6.32}$$

Case B: the drop-off station is at the midpoint of the rack

$$\overline{E(RC)_f} = T_f\left(\frac{b_f^2}{3}+1\right)\left(\frac{1}{2}\rho.M\right) \text{ for } \frac{1}{M} \le \rho \le 1 \tag{6.33}$$

$$\overline{E(RC)_f} = \frac{T_f}{2}\left(\frac{b_f^2}{3}+1\right) \text{ for } \rho < \frac{1}{M} \tag{6.34}$$

Case C: the restoring conveyor and the drop-off station are at the midpoint of the rack.

$$\overline{E(RC)_f} = T_f\left(\frac{b_f^2}{3}+1\right)\left(\frac{1}{4}+\frac{1}{4}\rho.M\right) \text{ for } \frac{1}{M} \le \rho \le 1 \tag{6.35}$$

$$\overline{E(RC)_f} = \frac{T_f}{2}\left(\frac{b_f^2}{3}+1\right) \text{ for } \rho < \frac{1}{M} \tag{6.36}$$

6.5.1 Performance Comparison between flow rack AS/RS configurations

In order to compare flow-rack AS/RS performance with alternative P/D stations and restoring conveyor locations, we determine the expected retrieval time per unit for each alternative location, with the expected retrieval time of the flow-rack AS/RS with P/D stations and restoring conveyor at the corner of the rack as the base. Thus, when the restoring conveyor and drop-off station are at lower right and left corners of the rack:

$$\overline{E(RC)}_{pu}=1 \text{ for any } \rho \tag{6.37}$$

For Cases A – C, divide Equations (6.31) to (6.36) by the base expression, Equations (6.12) and (6.16) to obtain the resulting expected retrieval times per-unit for the four following cases are:

Case A: the restoring conveyor is at the midpoint of the rack.

$$\overline{E(RC)}_{pu}=\frac{2+\rho.M}{1+2\rho.M} \text{ for } \frac{1}{M}\leq\rho\leq 1 \tag{6.38}$$

$$\overline{E(RC)}_{pu}=1 \text{ for } \rho<\frac{1}{M} \tag{6.39}$$

Case B: the drop-off station is at the midpoint of the rack.

$$\overline{E(RC)}_{pu}=\frac{2\rho.M}{1+2\rho.M} \text{ for } \frac{1}{M}\leq\rho\leq 1 \tag{6.40}$$

$$\overline{E(RC)}_{pu}=\frac{2}{3} \text{ for } \rho<\frac{1}{M} \tag{6.41}$$

Case C: the restoring conveyor and the drop-off station are at the midpoint of the rack.

$$\overline{E(RC)}_{pu}=\frac{1+\rho.M}{1+2\rho.M} \text{ for } \frac{1}{M}\leq\rho\leq 1 \tag{6.42}$$

$$\overline{E(RC)}_{pu}=\frac{2}{3} \text{ for } \rho<\frac{1}{M} \tag{6.43}$$

6.5.2 Simulation results

Per unit models derived in section 5.1 are simulated and results are presented in figures 6.4-9. Since M is a constant given rack shape, it can be seen from Equations (6.38)-(6.43) that the expected retrieval time in per unit of a given flow-rack AS/RS depends only on the load rate ρ.

Figures 6.4-6 represent the expected travel-time behavior versus the load rate. Similarly, Figures 6.7-9 represent the expected travel-time behavior versus the number of rack layers. Since the case where the P/D stations and restoring conveyor are at the corner of the rack is used as the base case, per-unit retrieval times less than 1 indicate an improvement in system performance. It should be mentioned that the pickup/drop-off and acceleration/deceleration delays have not been taken into account in this comparison; however, the results presented in the figures provide insight into the general behavior of each system. From these figures, remarks can be made with regarding the expected retrieval time behavior with respect to load rate and the number of rack layers, as well as regarding the expected retrieval time behaviour with respect to the location of P/D stations and restoring conveyor.

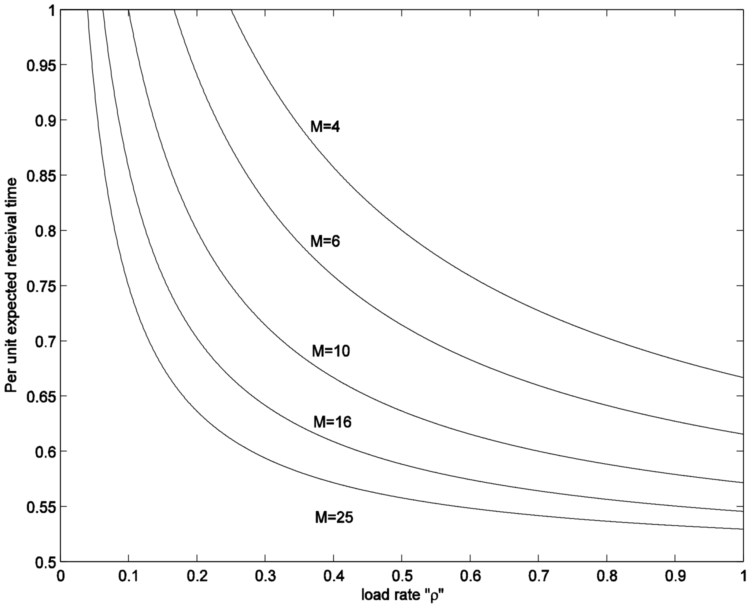

Fig.6.4 Per- unit expected retrieval time versus load rate of flow-rack as/rs with P/D station at the corner and restoring conveyor at the midpoint of the rack.

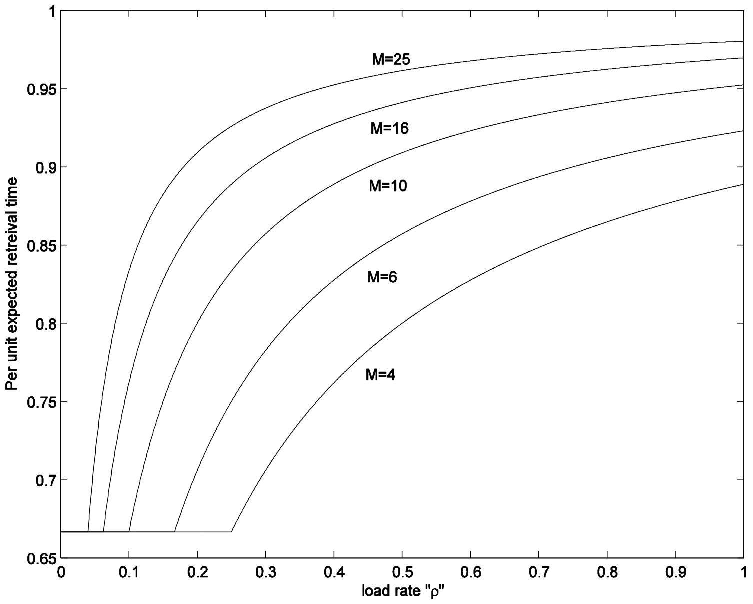

Fig.6.5 Per-unit expected retrieval time versus load rate of flow-rack AS/RS with P/D station at the midpoint and restoring conveyor at the corner of the rack

Expected retrieval time behaviour with respect to load rate and number of rack layers

- In case where the drop-off station is at the corner of the rack and the restoring conveyor is at its midpoint (Figures 6.4 & 7), we notice that as M or ρ increases the per-unit expected time decreases.
- In case where the drop-off station is at the midpoint of the rack and the restoring conveyor is at it corner (Figures 6.5 & 8), we notice that as M or ρ increases the per-unit expected time increases.
- In case where the drop-off station and the restoring conveyor are at the midpoint of the rack Figures 6.6 & 9), we notice that as M or ρ increases the expected time decreases.

- Finally, we can say that as *M* or ρ increases, the per-unit expected retrieval time increases when the restoring conveyor is at the corner of the rack and decreases when it is at the midpoint of the rack. This is expectable since as *M* or ρ increases the restoring time part will increase in the expected retrieval time. As *M* goes to infinity, the drop-off station position has no effect on the expected retrieval time.

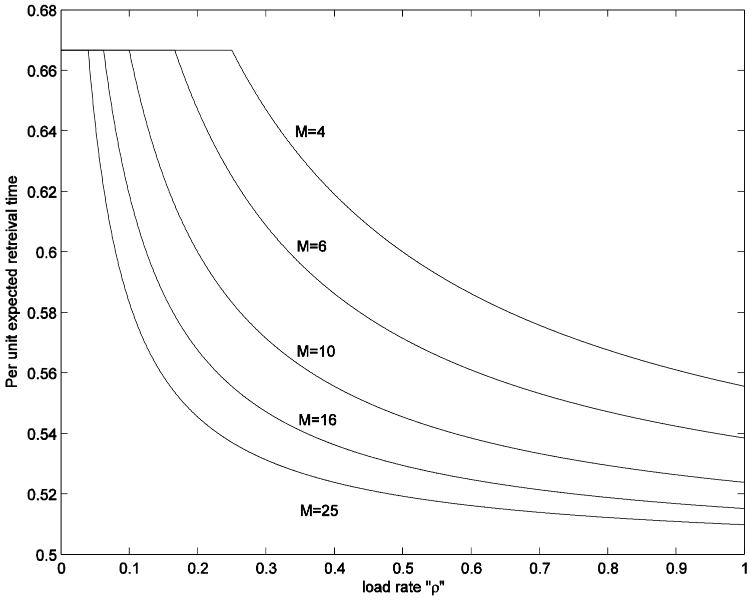

Fig.6.6 Per-unit expected retrieval time versus load rate of flow-rack AS/RS with P/D station and restoring conveyor at the midpoint of the rack.

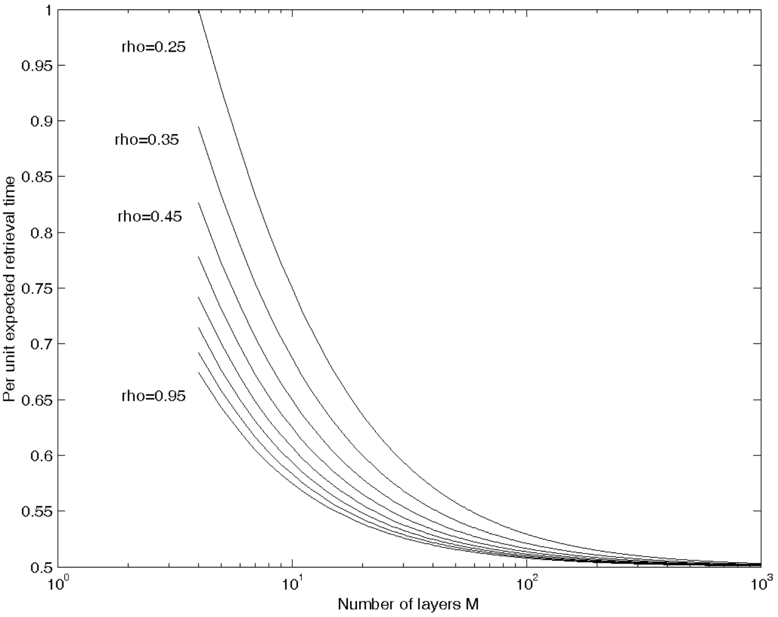

Fig.6.7 Per-unit expected retrieval time versus number of layers of flow-rack AS/RS with P/D station at the corner and restoring conveyor at the midpoint of the rack.

Expected retrieval time behaviour with respect to P/D stations and restoring conveyor locations.

- We notice that the best system is when the restoring conveyor is at the midpoint of the rack except for small values of *M* or ρ.

- The P/D station location has a weak effect on expected retrieval time except for small *M* or ρ.
- Finally, we can say that the best system is when P/D station and restoring conveyor are at the midpoint of the rack, followed by P/D station at the corner and restoring conveyor at the midpoint, then P/D station at midpoint and restoring conveyor at the corner, and finally the least interesting system with respect to expected retrieval time is when P/D station and restoring conveyor are at the corner of the rack.

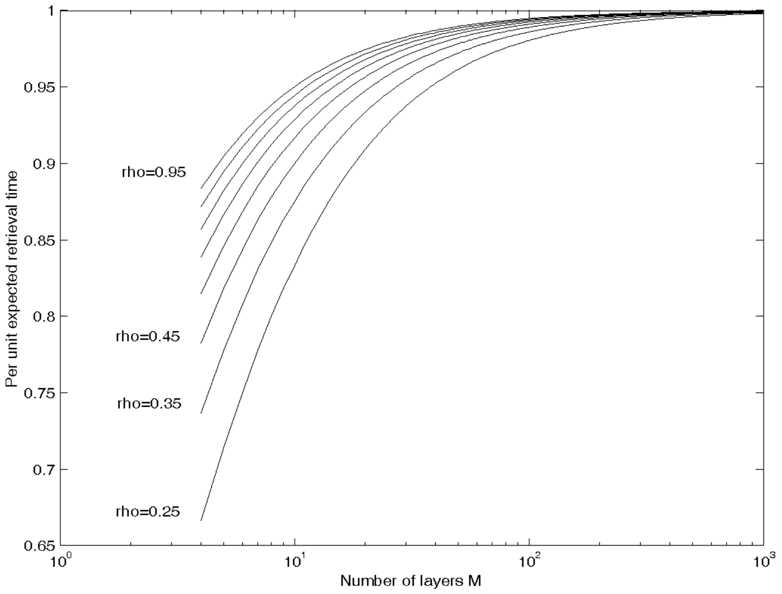

Fig.6.8 Per-unit expected retrieval time versus number of layers of flow-rack AS/RS with P/D station at the midpoint and restoring conveyor at the corner of the rack.

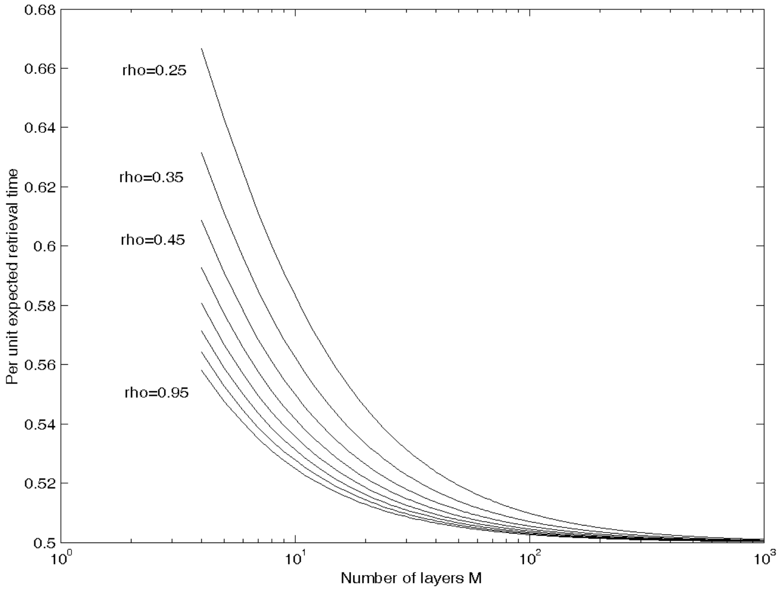

Fig.6.9 Per-unit expected retrieval time versus number of layers of flow-rack AS/RS with P/D station and restoring conveyor at the midpoint of the rack.

6.6. PERFORMANCE EVALUATION OF FLOW RACK VS UNIT LOAD AS/RS

In order to compare unit load and flow-rack configurations, which require the same initial investment, the performance of a flow rack AS/RS with one storage and one retrieval machine has been compared with a 2-aisle unit load AS/RS (i.e., two S/R machines are used) on the basis of space utilization and expected travel time. S/R machines used in unit load AS/RS are assumed to be technically identical to storage machine and retrieval machine used in flow rack AS/RS. While the two S/R machines in the unit-load system are used for both storage and retrieval, the flow-rack system utilizes one storage machine and one retrieval machine. In addition, both configurations are assumed to have the same storage capacity, *N*. The system height is kept the same in both configurations. Therefore, the space utilization comparison is made on the difference in the base areas that the systems occupy. In addition, pickup/drop-off and clearance areas are assumed to be the same for the two systems in order to eliminate their effect on the performance measures chosen.

6.6.1. Space utilization: models and simulation results

The base areas of the two systems, unit load and flow rack, can be calculated using the dimensions given in figures 6.1 and 6.2:

$$A_f = N_l.l.(M.d + 2w) \qquad \text{(Flow rack)} \qquad (6.44)$$

$$A_u = N_u.l.(4.d + 2w) \qquad \text{(Unit load)} \qquad (6.45)$$

Both systems have the same storage capacity:

$$N = M.N_l.N_h \qquad \text{(Flow rack)} \qquad (6.46)$$

$$N = 4.N_u.N_h \qquad \text{(Unit load)} \qquad (6.47)$$

Therefore, the number of horizontal bins in unit load can be derived as:

$$N_u = \frac{M.N_l}{4} \qquad (6.48)$$

Using equations (6.44), (6.45), and (6.48), percent area saving can be defined as follows:

$$\%A = \frac{A_u - A_f}{A_u} = \frac{r(M-4)}{M(r+2)} \qquad (6.49)$$

Where $r = \frac{w}{d}$ is the aisle width to segment depth ratio (6.50)

The above-mentioned models are simulated and results are presented in figure 6.10. This figure shows the variation of percent area saving (*%A*) with respect to the number of storage segments in a bin (*M*) for various aisle width to segment depth ratios (*r=1.1*, *r=1.2*, *r=1.3*). The flow rack configuration, when compared to the unit load system, provides a significant area saving as *M* and *r* increase, except for *M<4* where the unit load presents better performances. The space utilization is the same for both systems when *M=4*.

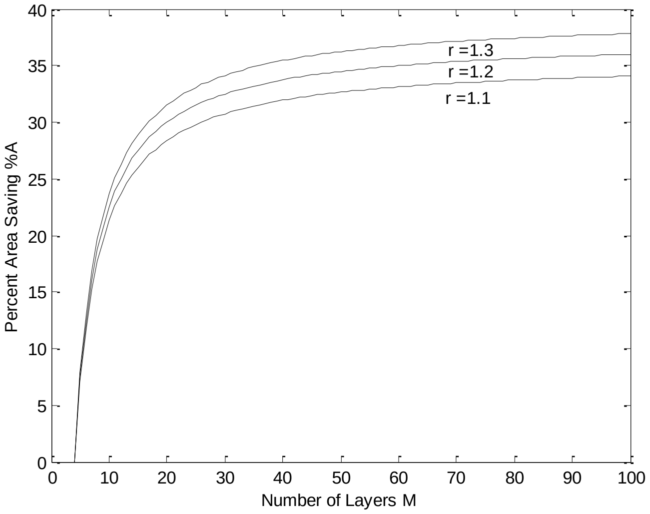

Fig.6.10 Percent area saving for a variety of configurations

6.6.2. Travel time: models and simulation results

Total travel time depends on vertical and horizontal travel times. Since both systems have the same height and have identical storage and retrieval machines (i.e. speeds are the same), the vertical travel time for the two systems is the same. Therefore, normalization and shape factor for a unit load AS/RS can be written as follows:

$$T_u = \frac{M}{4}.T_f \tag{6.51}$$

$$b_u = \frac{4}{M}.b_f \tag{6.52}$$

Furthermore, expected travel time (single cycle, storage or retrieval), as in equation (6.1), can be rearranged using equations (6.51) and (6.52):

$$\overline{E(SC)}_u = T_u\left(\frac{b_u^2}{3}+1\right) = \frac{M}{4}T_f\left(\frac{4b_f^2}{3M}+1\right) \tag{6.53}$$

In order to conduct a comparative analysis of travel time performance of flow rack system and unit load configuration, two measures have been defined. *Expected Storage Time Ratio* (ESTR) is the ratio of expected storage time of a flow rack system to that of a unit load. Similarly, *Expected Retrieval Time Ratio* (ERTR) is defined as the ratio of expected retrieval time of a flow rack system to the expected storage time of a unit load system since storage time equals to retrieval time for unit load systems (i.e. $\overline{E(SC)}_u = \overline{E(RC)}_u$= *Cycle Time*). Therefore, ESTR can be obtained by dividing equation (6.6) by (6.53):

$$ESTR = \frac{\overline{E(SC)}_f}{\overline{E(SC)}_u} = \frac{4.b_f^2+12}{4.b_f^2+3.M} \tag{6.54}$$

Similarly to ESTR determination, ERTR *(Expected Retrieval Time Ratio)* can be derived using equations (6.12), (6.16), and (6.53):

$$ERTR = \frac{\overline{E(RC)}_f}{\overline{E(SC)}_u} = \frac{2b_f^2 + 6}{4b_f^2 + 3M}\left(\frac{1}{2} + \rho.M\right) \text{for} \frac{1}{M} \le \rho \le 1 \tag{6.55}$$

$$ERTR = \frac{\overline{E(RC)}_f}{\overline{E(SC)}_u} = \frac{3b_f^2 + 9}{4b_f^2 + 3M} \text{for } \rho < \frac{1}{M} \tag{6.56}$$

It can be concluded that ERTR depends only on the load rate ρ, where b_f and M are constant parameters of the system that depend on rack shape and retrieval machine speed.

Similarly to the previous section, the above-mentioned models are simulated and results are presented in figures 6.11-17.

Figure 6.11 shows the expected storage time behavior of a flow rack AS/RS with respect to number of rack layers. The rack shape factor *b* has been varied from *0* to *1* with an increment of *0.1* in order to show the range of behavior for ESTR.

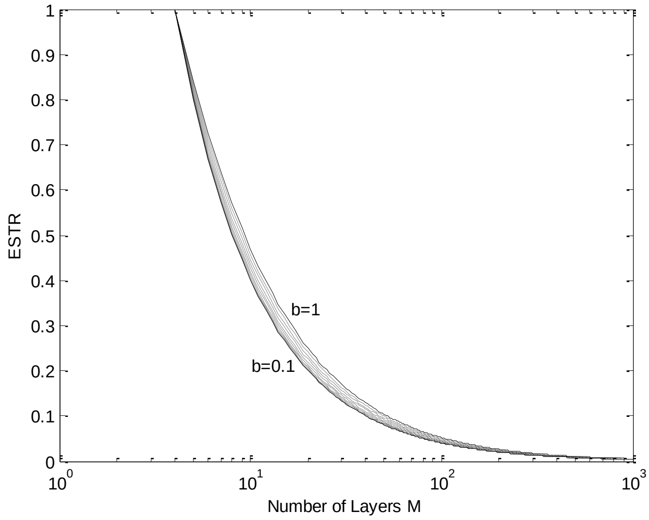

Fig.6.11 ESTR versus Number of Rack Layers

ESTR decreases as a faster rate as *M* increases, which is due to the fact that storage time expression does not depend on *M* or ρ but is only a function of rack face size and shape. Hence, when *M* increases, the rack face dimensions of the flow-rack decrease, so ESTR decreases.

This analysis did not take into account storage of items form the restoring conveyor, which can be performed when the storage machine is idle. However, storage of items from the restoring conveyor should be taken into account for determination of machine utilization.

Figures 6.12-14 depict the expected retrieval time behavior versus load rate for a flow rack AS/RS. The figures show the variations of ERTR for *10-layer, 6-layer,* and *4-layer* configurations. In addition, rack shape factor *b* has been varied between *0* and *1* with an increment of *0.1* in order to show the range of behavior for ERTR. Figures 6.5 and 6.6 show the range of behavior due to change in the shape factor, while Figure 6.14, the *4-layer* configuration, shows that the shape factor has no influence, which can be explained in equations (6.55) and (6.56) by replacing *M* by *4*.

Figures 6.12-14 can be used for selecting the type of AS/RS (i.e., flow rack or unit load) for a particular application on the basis of travel time performance. The horizontal "*Time Ratio = 1*" line represents the behavior of a unit load AS/RS. Up to a certain load rate, flow rack AS/RS outperforms unit load configuration, whereas after that point unit load AS/RS performs better on the basis of travel time.

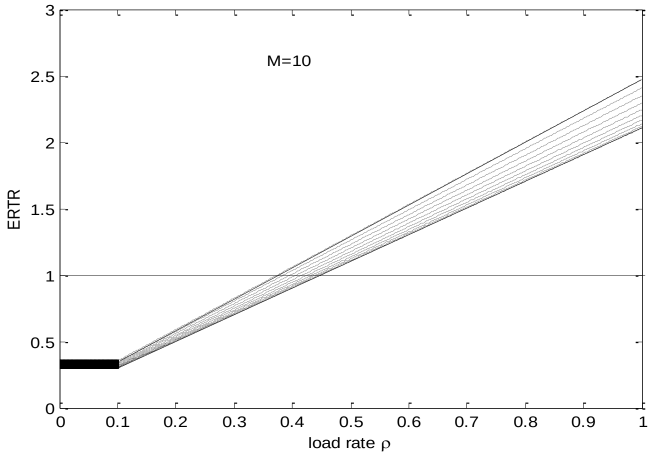

Fig. 6.12 ERTR versus Load Rate (*10-layer* flow rack AS/RS)

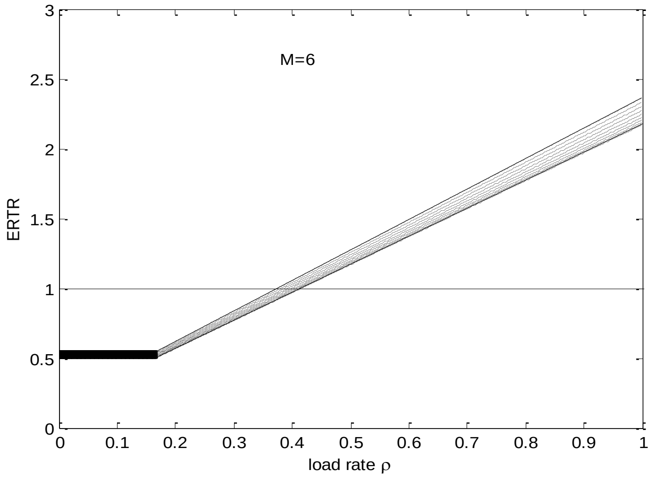

Fig. 6.13 ERTR versus Load Rate (*6-layer* flow rack AS/RS)

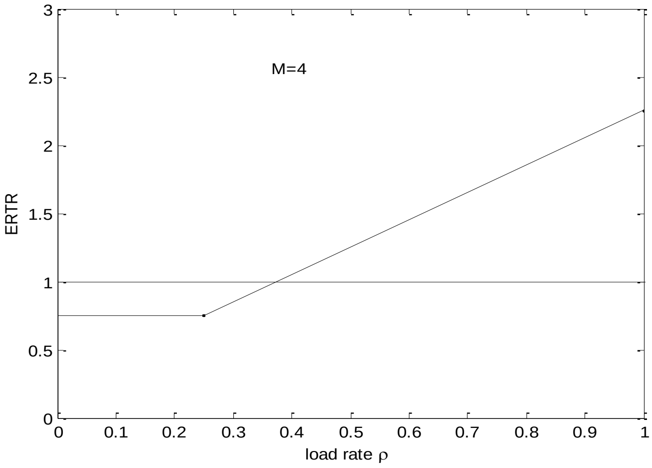

Fig. 6.14 ERTR versus Load Rate (*4-layer* flow rack AS/RS)

Figures 6.15-17 show the expected retrieval time behavior of a flow rack AS/RS with respect to number of rack layers for various load rates. The rack shape factor *b* has been varied from *0* to *1* with an increment of *0.1* in order to show the range of behavior for ERTR.

From figures 6.15-17, we notice that ERTR increases as *M* increases when the shape factor *b* is greater than a threshold value, which is shown by b_0 in figure 6.8. For $\rho=1$, b_0 is approximately *0.6*, for $\rho=0.75$, b_0 is *0.7*, and for $\rho=0.5$, b_0 is between *0.8* and *0.9*. For $\rho=0.75$, which is defined as the zone of actual operation (White and Kinney 1982, Groover 1987), ERTR is between *1.5* and *2* which means that flow rack expected retrieval time is between *1.5* and *2* times greater than the expected cycle time of the unit load AS/RS, which is equal to *1*.

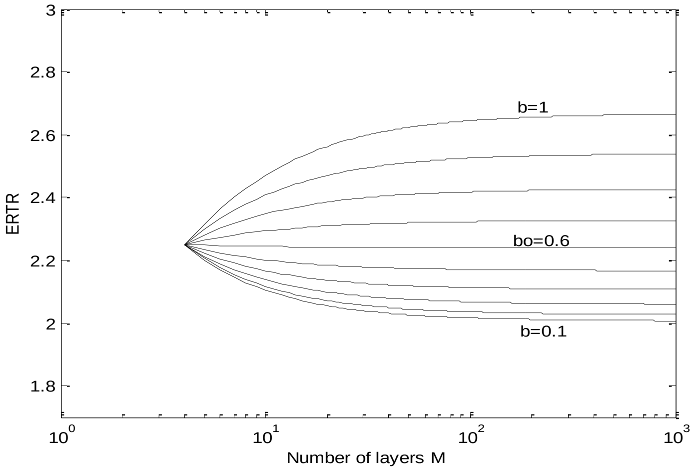

Fig. 6.15 ERTR versus Number of Rack Layers ($\rho= 1$)

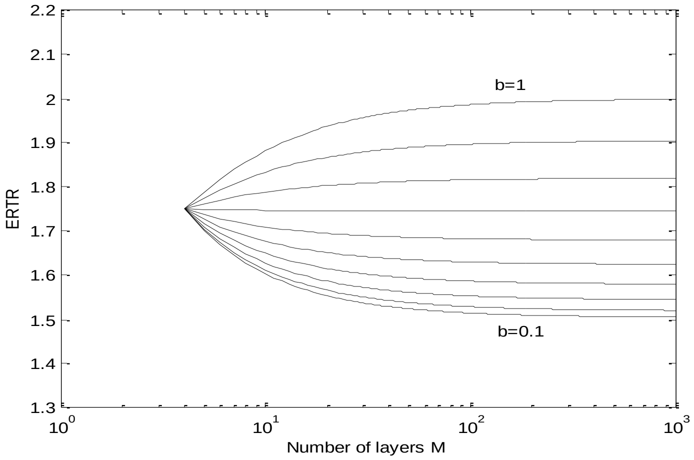

Fig. 6.16 ERTR versus Number of Rack Layers ($\rho= 0.75$)

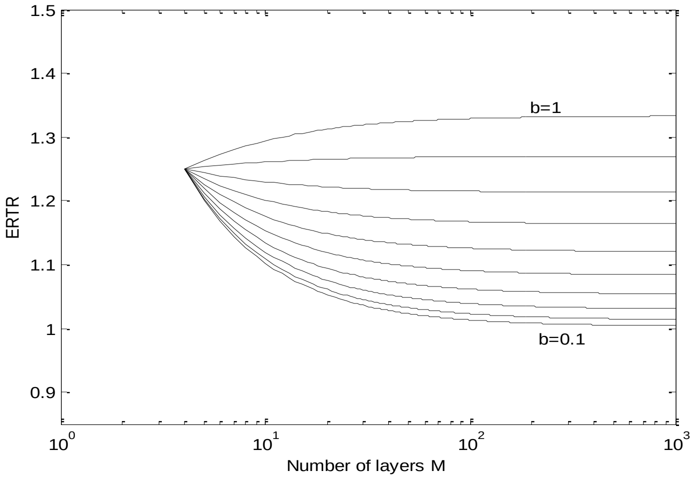

Fig. 6.17 ERTR versus Number of Rack Layers ($\rho= 0.5$)

6.7 CONCLUSION

Unit load AS/RS have been widely studied during the last 20 years. Travel times models and dwell point position of their S/R machines are well known. However, this models are not always suitable for other types of AS/RS.

In this chapter, we developed retrieval time models for a flow rack AS/RS. The first model that consists of a closed form expression of the expected retrieval time is based on the Bozer travel time model (Bozer and White 1984). To validate this closed form expression, the second model was developed. It consists of an “exact value” expression of the expected travel time. It was devised on the basis of the averaging of retrieval times of all storage segments.

Computer simulation of the two expected retrieval times models, leads to validate the closed form continuous approximate expression, with respect to the discrete exact expression, on various rack shapes and sizes. This computer simulation showed that the error, of the continuous approximate expression relative to the discrete exact expression, is acceptable for medium to large systems. However, for very small systems, the closed form expression predict the expected retrieval time with a significant error.

The closed form expected retrieval time expressions, presented in this work, can be used to : establish performance standards on existing systems, evaluate throughput performance for flow rack AS/RS design configurations as well as comparison with other types of AS/RS for choice decision. Also, they can be used as a basis of comparison for evaluating performance improvements of different storage techniques.

In a second step, impact of P/D stations and restoring conveyors positions on travel time was investigated. To do so, new models were derived. Different pickup/drop-off stations and restoring conveyor locations are analyzed, and performance evaluation is made for a large range of load rates and number of rack layers. From comparison of results, a number of remarks can be stated:

The best system is when the restoring conveyor is at the midpoint of the rack except for small values of M or ρ.

The P/D station location has a weak effect on expected retrieval time except for small M or ρ.

As M or ρ increases, the per-unit expected retrieval time increases when the restoring conveyor is at the corner of the rack and decreases when it is at the midpoint of the rack.

Finally we can say that the best system is when the restoring conveyor and the P/D stations are at the midpoint of the rack.

Finally, two performance measure models were proposed, namely space utilization and travel time, for flow-rack AS/RS systems. The models are built directly on models for unit load AS/RS that are well known in the literature. Flow-rack systems are compared with unit load systems on the basis of space utilization and expected travel time.

The analysis presented in this chapter demonstrates the impact of load rate, number of rack layers, and shape factor on space utilization and expected travel time. For a flow-rack and a unit-load system where both have the same storage capacity, same number of storage and retrieval machines, and same height, the flow-rack configuration occupies less space than unit load. Expected storage time of a flow-rack system is equivalent to the one of unit load for $M=4$ and decreases rapidly as M increases. Expected retrieval time of flow-rack system increases as load rate increases.

Overall, a flow-rack AS/RS system, when compared to an equivalent unit load system (i.e., same storage capacity, same number of storage and retrieval machines, and same height), requires less space, has a lower expected storage time, and an equivalent expected retrieval time for small load rates (about *0.4*). However the expected retrieval time of the flow-rack gets larger as the load rate increases. The results presented in this chapter can be used to determine what type of an AS/RS system, flow-rack or unit load, will perform better under certain operating conditions. In addition, the performance measure models can be used as a design tool to determine the configuration of flow-rack systems.

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Chapter 7

Classical algorithms and small package backload solution

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Abstract

Large variety of Fleet Routing Problem (FRP) solutions is available. The aim of these is to offers the lowest possible transportation costs.
Basically in these cases planning of transportation is static. But dynamic algorithms could be implemented then pre-defined routes are revised using up-to-the date information.
The suggested backload algorithm is formulated based on logic: that route typically starts from empty solution when more and more clients are inserted until all of them are routed. In particular, some clients are selected to form workday route; other are placed into pre-defined routes. Using existing knowledge, FRP solution is suggested for picking small backload parcels.

Keywords: fleet, routing problem, backload.

7.1 INTRODUCTION

Although a “last-mile” delivery service is convenient for the client, it creates significant logistical challenges for companies. The classical Fleet Routing problem (FRP) analyses routes for the set of customers so that the total travel distance and costs are minimized.
Two types of travel distances are used in literature:

- Average travel distance per route;
- Total travel distance (for a set of routes). By minimizing an average travel distance, total travel distance is also minimized.

Mathematical models, analytic techniques, linear programming techniques, and simulation. Some of the methods involve demand factor into fleet analysis, but overall objective is to minimize the total costs. The search of routing problem (FRP) publications yields more than 36,400 entries on Google Books. Backload issues are discussed in 143 of them. Both heterogeneous and backload variants were introduced early in the FRP literature. The portfolio of techniques for modelling and solving the standard, capacitated FRP and its many variants has changed significantly. Researchers and practitioners have developed faster and more accurate solution algorithms and better models that give them the ability to solve large-scale problems.
The classical FRP and its variants have been utilized in a variety of studies. However, small package pickup and delivery services have a number of characteristics that distinguish it from the classical FRP model. The classical FRP looks at route planning in one day planning horizon. Other constrains such as Customer Schedule Consistency and the Service Territory Management, both dealing with questions that arise from multiple day planning horizons, are not applied in the classical FRP.

Next there are some models offered for backload, still all of them are static (Eriksson and Rönnqvist, 2003; Forsberg et al., 2005; Lepage, 2012).

FRP considers situations in which a commodity is supplied from a single or multiple plants, selected from a set of potential location sites to serve demand points (Silva et al., 2007).

For example, each day 103,500 drivers at UPS follow computer-generated routes. These drivers visit 7.9 million clients and serve around 15.6 million packages.

In some studies clients are allocated to a cluster, and the vehicle routing is done within a cluster. A request specifies a volume and client, where to pick and the site where it's to be delivered. Time constraints can be added on request (e.g. time window when the pick-up must be made).

Author describes the mathematical model used to solve complex pickup problem.

In the chapter author also presents what will be the effect related to the minimization of costs through scenario analysis.

7.2 CLASSICAL ALGORITHMS

Some travel-time models estimate the time required to complete tasks, considering lead time, travel time, and non-efficient time (Cormier, 2005).

In companies' economics science, there are a lot of ways to solve routing problems. There are different ways to solve FRP: route construction methods, two-phase methods, and route improvement methods. These are FRP classical methods.

First, about route construction methods are described. Route construction methods are used to formulate first heuristics for CFRP. This typically starts from empty solution when more and more customers are inserted until all customers are routed. These algorithms are subdivided into sequential and parallel routes. Using sequential method single route at a time is expanded, on the other hand, using parallel method more than one route is considered simultaneously. Using these methods it is easy to decide and locate customers into the current routes.

The famous heuristic was proposed by Clarke and Wright in 1964. The heuristic is based on the costs savings with the logic that to visit two customers sequentially in single route is cheaper than in separate ones. In the Clarke and Wright algorithm two routes are merged whenever this is less costly (the savings are not negative). New heuristic appeared in 1976. Authors Mole and Jameson used sequential method for new customer, when such is inserted between two consecutive customers. It is also taking the distance of customers from the departure depot. Christofides et al. (1979) used two-step insertion heuristic which includes, first, sequential insertion approach and, second, parallel insertion approach. Finally, these are used for scenario comparison.

Second, two-phase methods are presented. These are proposed by authors for solving two separate sub-problems: clustering and sequential routing.

(1) A cluster is the set of customers attached to one route. When first is clear the sequence of customers in the route is analysed. Various techniques are proposed for the clustering part. This algorithm adds vehicle to a customer. Each vehicle is assigned a representative. The assignment cost of a customer (seed) to a vehicle is equal to its distance to this customer. If the vehicle is full (the fleet capacity is reached), a new group is started. Seed algorithm consists of two steps: initial clustering based on some seed selection rule and the addition of remaining customers to a group based on seed increase rule. Saving algorithm is used for the comparison of combined two customer orders in one route with the situation where both orders are collected individually. Savings in saving algorithm are taken based on calculated distances.

Authors Bramel and Simchi-Levi (1995) use two-phase method working with the fixed number of vehicles. This algorithm determines route with *n* customers by minimizing the total distance between customers in the route and including the total demand associated with each customer. When next customer can’t be assigned to the current vehicle, a new route is initialized for it.

Another early two-phase method is the branch-and-bound method. The decision tree is formulated from the number of all un-routed vehicles, where at each level of the decision tree partial solution made to get some complete routes.

One of two phase methods is cluster-first-route-second method. In a first phase customers are grouped into clusters and later on the routes are determined within each cluster. The algorithm starts with an initial customer and then sequentially other customers are assigned to the vehicle with respect to the depot. The final routes are formulated seeking to solve travelling salesman problem in each cluster.

Also hybrid technique has been proposed for solving FRP. For example, Caseau and Laburthe (1998) proposed method, which is dedicated for solving large FRP (big number of customers (equal several thousands) and large number of vehicles (equal to couple of hundreds)). The method is flexible and adaptable and this is the main improvement comparing with other solutions. The method is based on progressive local optimization when the 3-steps are used for improvement at each insertion.

Finally, there is an option to use route-first-cluster-second method: in a first phase gigantic tour, which include all customers, is constructed and, later on, it is subdivided into logical routes in the second phase. The second routing phase is used to formulate sequential routing to solve travelling salesman problem.

The classical FRP is the most popular problem in combinatorial optimization. It generalizes the traveling salesman problem (TSP).

The most of papers focus on single vehicle cases: TSP with Divisible Deliveries and Pickups (TSPDDP) and TSP with Deliveries and Selective Pickups (TSPDSP). Mosheiov (1994) proposed TSPDDP heuristic, where depot is inserted to different positions of route. Gribkovskaia, Laporte and Shyshou (2008) extend above mentioned method into TSPDSP, where several pickups are added.

TSP is also treated as the order-picking problem and defined as follows. Suppose the company receives an order – a list of items demanded from customer *j*. A vehicle leaves the loading dock to collect the items mentioned in the single order and to transport them back to the loading dock. Assumption is made that the capacity of the vehicle is sufficient to pick up all the items mentioned in the order. The objective of the task is to minimize the total distance traversed by the vehicle in a rectangular warehouse.

The authors may use a new constraint named CBC (Can Be Connected) which can be used to solve TSP or FRP instances.

Ratlif and Rosenthal (1983) showed dynamic programming algorithm for solving the order-picking problem in a rectangular warehouse. Later on this problem was also solved by Carlier and Villon (1987). The order-picking problem in a rectangular warehouse is called as a Steiner TSP.

Cornuejols, Fonlupt and Naddef (1985) developed extended algorithm to solve the Steiner TSP. Authors consider well-solvable special cases using constraint of the classical TSP and stating that every city is visited exactly once and every edge is used at most once (so-called graphical TSP analysed by Cornuejols, Fonlupt and Naddef (1985); Fonlupt and Nachef (1993); Van Dal (1992)). Van Dal (1992) considered the Steiner TSP for problem analysis and showed that these problems could be solved using dynamic programming algorithm. Additional works for similar approach were given by Fonlupt and Nachef (1993).

Third, route improvement methods. Different methods are often used to improve pre-generated solutions with other heuristics. Such starts from neighbourhood search aiming to get better costs. If an improvement is found, the new solution is fixed.

The large variety of neighbourhoods are available. These may be subdivided into intra-route neighbourhoods, if they operate on a single route at a time or inter-route neighbourhoods (if they consider more than one route simultaneously) (Cordeau et al. 2007). Very large neighbourhood search (VLNS) was developed by Ergun et al. (2003). Tabuchain algorithm proposed by Rego and Roucairol (1996) is used to define neighbourhoods. The extraction process is applied in some cases to identify routes that are not overlapping with previously selected ones.

The classical algorithms include the Un-capacitated and Capacitated fleet routing problem (UFRP and CFRP) model. One of the assumptions of the Capacitated Fleet Routing Problem (CFRP) is that demand is known and fixed. In the literature, UFRP and CFRP models are divided into these categories: models with linear transportation costs, models with non-linear transportation costs. Models with linear transportation costs hav been developed for un-capacitated and capacitated fleets (as resources). Some of authors used a continuous version of the problem, where client can be located anywhere and are not restricted to a set of predefined potential locations. They solved the problem with an adaptive fleet-allocation. Kelly et al. (1982) modelled the problem as a transportation problem and solved this problem iteratively using marginal costs that depend on the current volume allocated to each fleet. Later on, iterative linearization techniques have been used for a multi-product problem and a multi-period problem.

In the number of models, the authors analyse the design of multi-products; consider a model with comprehensive costs functions, for example, taking into account full truckload discounts and various transportation modes. They solve the problem with variable neighbourhood search algorithms. Lin et al. (2006) determined transportation costs based on total flow and assumed that they are independent from orders sizes. Gumus et al. (2002) suggested cross-docking model that combines full truckloads. Other authors optimized transport frequencies.

Authors use demand constrains to analyze capacity constraints, and most of the authors assume that demand is fixed (especially for CFRP). Also some of the authors deal with clustering clients (seeking to assign to different territories).

Fleet routing problem with multiple tasks, with and without time windows, has been addressed through heuristic that can efficiently handle the different types of constraints and the multiple uses of vehicles. The higher number of multiple tasks means the significant reduction of total travel distance. It’s usually referred to as one vehicle with multiple task allocation.

A recent heuristics also include time windows. For real-world applications the heuristic is used to solve home delivery problem. When new order occurs, “real” routes must be generated when time window for delivery is determined. These are particular cases of the classical vehicle routing problem (VRP). In this problem, a fleet of vehicles must leave the depot, serve customers at minimum cost and return to the depot without the capacity of the vehicles restriction at the time windows specified by customers (Ribas et al. 2011). It is that VRP is often defined under capacity and route length restrictions. When capacity constraint is presented the problem called as CVRP. The most of algorithms have capacity constraints but some of them have also distance constrains included. Hoff and Løkketangen (2006) presented model VRP with Restricted Mixing of Divisible Deliveries and Pickups (FRPRMDDP). In FRPRMDDP model, both deliveries and pickups require free space for demand.

If deliveries and pickups are served separately, the model dealing with this is called VRP with Divisible Deliveries and Pickups (VRPDDP). If VRPDDP model is changed into Mixed deliveries and Pickups VRPMDP: the first part is pure delivery and the second one – pure pickup.

Moreover, by adding zero values for delivery and pickups, the VRPMDP may be modelled into VRPSDP. The number of vehicles required is different: the number is less in VRPDDP model than in VRPSDP model. The difference between VRPSDP and VRPDDP solutions are pickups, which are added or removed. Vehicle visits first customers having delivery, then, customers having delivery and pickup, which are served simultaneously. Finally, the vehicle returns to depot. Some experiments of VRPSDP show cases when the customer is split across two vehicles.

Also VRPDDP is similar to Split Delivery VRP (SDVRP). SDVRP there is always the most optimal solution. In such case one visit to a customer is used.

Vehicle routing problem with time windows (VRPTW) is common for maritime transportation where delays are frequent and must be taken into considerations. There are inputs: depot and the set of vehicles. The vehicle routing problem aims at prescribing routes for the vehicles starting at and returning to the depot in such a way that each client is visited by exactly one vehicle. Rousseau et al. (2004) used constraint programming to solve the shortest elementary route problem. In addition, authors consider that each vehicle has also a capacity that cannot be exceeded along its route (problem version without the capacity constraint, is named as m-TSPTW and used in the cases when ship carries only one cargo at the time, from loading depot to unloading depot).

A little number of constraints but a very large number of variables is included into these formulations. So, the efficient branch-and-price algorithms are required. Ship routing and scheduling problem aligns time windows and uncertain travel times when delays are important and schedules must account for them.

There are also the numerous applications of these formulations in distribution, transport, and logistics.

There is an exact algorithm used for solving a problem where the same vehicle performs several routes to serve the set of customers with time windows. A method based on an elementary shortest path algorithm with resource constraints is proposed to solve this problem. This method is divided into two phases: in the first phase, all non-dominated feasible routes are generated; in the second phase, some routes are selected and sequenced to form the vehicle workday (Azi, Gendreau & Potvin, 2007).

An exact algorithm for solving routing problem when vehicle performs several routes over scheduling horizon is presented by authors (Azi et al., 2007).

Inventory routing problem (IRP) is different from FRP. FRP occur when customers place orders and route planner assigns the orders into the routes for vehicles. IRP is an extension of FRP combining routing solutions with inventory cases. When Vendor Managed Inventory (VMI) are employed vendor chooses the delivery time window and the size of deliveries ensuring cases without stock outs. In a more traditional inventory planning, where customers are calling their orders, supply chain inefficiency may occur due to realization of customers' orders (with high distribution costs and inventory level). To save distribution costs with VMI is not easy task, especially when it is big variety and the large number of customers.

The IRP is solved by determining logistics strategy that minimizes distribution costs. IRP focuses primarily on distribution. Inventory control is taken to ensure that no out-of-stocks will be at the customers. Inventory control has more prominent role comparing with inventory holding costs. In the literature, authors mention one warehouse multi-retail environment. The first key reference is system without customer orders but with restriction that customers have no stock-outs. The second key reference is time horizon. FRP deals with single day planning horizon with requirement that all orders are distributed at the end of the day. IRP is defined on a longer time horizon. Each day supplier makes selection which customers to visit and what volume to deliver to each, thinking about delivery costs and planning horizon with restriction that customers have no stock-outs. IRP is especially difficult to solve but there are some common elements. The most of algorithms take short term planning. First algorithms run on single day and earlier ones took several days. Several issues rise here: how to model long period effect and which customers to visit in short period delivery schedule. A short term planning approach with minimum costs may lead to many deliveries in future. The decision has to capture not only the costs but also benefits of deliveries to the customer in specified volumes. This usually means delivering to a customer earlier than necessary reduces the risk to have urgent deliveries.

When the short period planning is delivered on a single day, the extension of FRP can be applied. Authors Campbell and Savelsbergh (2004) discussed implementations where delivery amount is higher or lower around the average as an opposite solution to delivery volume that is fixed. The same authors have also studied an optimal delivery schedule, i.e., the sequence of customers to be visited determining the time of visits by maximizing the amount delivered to the customer per route. Using single day approach, it is easier to predict the inventory usage for particular day by avoiding the difficulty of long-term forecasting.

In first phase time-discrete integer programming model is used to determine the number of customers to be planned in a short-term route as well as the volume to transport to chosen ones. In order to minimize costs, the integer linear programming is used to work with the number of potential routes. Fisher et al. (1982) and Bell et al. (1983) studied the IRP for Air Products. They determined the delivery volumes to customers, after assigned customers to routes, later on assigned vehicle to routes, and planned the start time for each route. In the model, the value per unit for each delivery is used to make scenario analyses for events occurring in the planning horizon. Short-term planning period considered to estimate discretion in the amount of product to deliver. In the long-term planning the amount determined by customer is used but each unit delivered to a customer reduces the amount to be delivered in the future. The estimation of delivery costs at a point in time is made outside the planning horizon of the model. Inventory usage rates at a customer are incorporated into the model, varying from lower to upper the average amount to be delivered to a customer during time period.

The solution depends on the chosen parameters: time discretization and the set of routes.

Campbell and Savelsbergh (2004) used two phase approach. They determined which customers to visit in a few days (even the time horizon is two weeks) and suggested volumes and delivery schedule to these customers. In a second phase, they determined the actual delivery routes and quantities. Such approach gave higher accuracy and could take into account details such as the shift of drivers. This also helped to bring the higher vehicle utilization and to use an option with rolling horizon framework.

In this field, some works are presented by authors Crainic et al. (1993), Del Castillo & Cochran (1996), Krikke et al. (1999), Duhaime et al. (2001) forward to reverse logistics topic. Only Duhaime et al. (2001) study was dedicated to small parcels delivered by Canada Post. They used a minimum cost flow model showing that stock out can be avoided if containers are returned quickly. Feillet et al. (2002) studied the problem of the tactical planning of transport. They developed FRP models for the combined transport of containers and the positioning of empty trucks; the practical application of particular model was dedicated for automotive industry.

To the best of my knowledge, no work was published which considers the three different types of flows simultaneously on a multi-periodic context. Moreover, good results obtained by hybrid approaches to somewhat related problems incited me to use them in order to solve the problem.

7.3 PLANNING METHODS FOR STATIC PICKUP AND DELIVERY PROBLEM

Several planning methods of pick-up and delivery problem (PDP) have been proposed in the literature.

For the problem the solution aiming to answer how many full loaded trucks is delivered into phases. The number of trucks is obtained in the first phase and the schedule for single trucks is generated in the second phase.

Shen and Sessions (1989) proposed a network-based method that is used to generate one day truck schedule containing customer expected deliveries with multiple time frames.

Linnainmaa et al. (1995) suggested three phase method. First phase is used for the distance between the supply and demands points' calculation and for the volume to demand point's allocation. In second phase mathematical programming methods and heuristics are used to propose weekly truck and driver schedule. Third phase is dedicated for the daily routes modifications.

Weintraub et al. (1996) proposed a simulation based method with heuristic that follows rules: on a moving time horizon assigns one-load at a time to available trucks and based on such the constant generation of daily truck schedule is constructed. Other authors (like, McDonald et al. (2001a,b) and Mendell et al. (2006)) also proposed simulation based methods to generate daily route schedules for trucks.

McDonald et al. (2001a,b) studied the drop of unloaded trailers at distribution sites and the picks of already loaded ones (instead of waiting first ones to be loaded). Different heuristic rules were developed seeking to find solution leading to the more efficient operations. Mendell et al. (2006) delivered the heuristic that can deal with different combinatorial aspects. For example, the rule assigns trucks to supply sites when it is efficient taking into account two days planning horizon. As a result it is evident which truck may stay at depot for the next day delivery.

Audy et al. (2011) proposed method to solve small size PDP. The method has three phases. The first phase is used to generate the large set of potential routes for driver shift. In the second phase, routes per truck are selected to satisfy weekly demand. In the last phase, machine-job scheduling model is used to provide optimization.

The fleet routing problem with pick-up and delivery (FRPDP) extends the FRP by having products delivered from depot to clients and from clients to delivery point. If there is a combination between pick-up and delivery at customer locations, fleet routing problem with backload will appear.

There are some subcases:

1) If the service of delivery and pick-up is accepted in one stop, the situation is called fleet routing problem with simultaneous delivery and pick-up (FRPSDP) of combined demand. In such cases the same client receives and sends items.
2) If there is limited traveling distance and high vehicle capacity is required, when FRPB as special instance of FRPSDP is used.

Moreover, FRPB is a special case of single demands, built on the logic that all deliveries must be finished before pick-up is started. FRP with Mixed Deliveries and

Pick-ups or Restricted Deliveries and Pick-ups (FRPMDP) is harder to solve than the FRPB. At this case deliveries and pick-ups occur in any order. There is no route that contains only backload. Also at the same time, all pick-ups are based on single demand (e.g. pure delivery and pure pick-up).

7.4 BACKHAULAGE

Backload important for reverse logistics and means the physical activities handled with products from consumer locations to delivery points. To achieve the objective of minimizing the costs as well as integrating it with forward logistics, backload (FRPB) becomes as the organic part of logistics system.

The transportation costs comprise about half of logistics costs. This shows that even small reduction in transportation costs is important for suggestion.

General target for planning is to find efficient routes for individual trucks. Usually FRP is looking for efficient delivery from central delivery point to multiple supply point, but FRP covers both primary transportation and backload. Usually, backload is used as an important tool to support transport planners to deliver significant costs savings.

Fleischmann et al. (1997) reviews the literature which is dealing with backhauling. Sometimes products allocation is optimized together with sorting at distribution centre.

The aim of this paper is to deliver algorithm to the backload problem. Author also provides the scenario analysis and the components of model where backload is main component with intention to give the reader understanding on how the mathematical model performs in real cases and is an indication of the potential for costs gains to be achieved through increased the use of backload in practice.

Many optimization algorithms are developed for FRP in the 1980s and 90s.

The algorithm suggested by author is based on recent research on the FRP. The suggested algorithm has a different approach in comparison with earlier algorithms or surveys on FRP.

The optimization algorithm is developed under the authority of VGTU (January 2015).

The estimated savings from the algorithm are at least 5% of transportation costs.

The algorithm specifies which truck should take the task and in what order to deliver getting the lowest transportation costs. As this is small size the constraint such as vehicle capacity is not the case in this study.

Other aspect handled in the algorithm is the efficient use of the fleet of vehicles.

The generated solution contains multi-stop up to 25 stops per driver shifts.

Further development will be focused on multi-depot and the assignment of delivery frequency and delivery times and a module for forecasting transport volumes.

First, author reviewed techniques that are used for solving vehicle routing problems and reverse logistics problems (this review is based on Bostel et al. (2005)). Second, author reviewed classical hybrid approaches that are used to solve vehicle routing problems. However as far as found in the literature, none exist for reverse logistics problems. Further on the study will focus to the operational level of reverse logistics.

7.5 ALGORITHM

The FRP is used to specify which truck should collect parcels at clients in order so as to minimize the transport costs (Fig. 7.1). In small package parcel case the capacity of vehicle is not applicable.

Assumption is made that all vehicles have to drive each day, that why only the costs per transport unit are analyzed further on. Transportation costs are the following:

- Each vehicle h has costs f
- Each vehicle h has minimum transportation costs per distance unit b.
- Stop costs s for unloading at depot and loading at client.

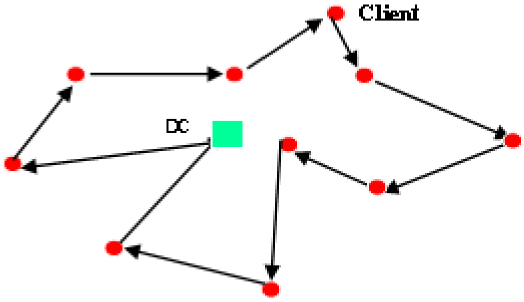

Fig. 7.1. Backload route

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Transportation costs are minimized according the following formula (7.1):

$$T(q) = s \cdot n + \sum_{j=1}^{q} b_j \cdot d_j \tag{7.1}$$

herein: $T(q)$ is Transportation costs, o – current client, j – next client, q – the number of clients, b – minimal transportation costs per distance unit, s – stop costs per client, x, u, y, v – pick-up points, d_j – the shortest distance (7.2):

$$d_j = \sqrt{(x_0 - u_j)^2 + (y_0 - v_j)^2} \tag{7.2}$$

d_j is the straight distance between points or value from distance matrix which reflects route network (such is used to replace the straight distances).

The route is the sum L_i of the distances which are computed as follows (7.3):

$$L_i = \sum_{j=1}^{n} d_j \tag{7.3}$$

Among it, d_j is the shortest distance from current client *o* to the next client j.

In the final stage ranking is applied. The greater the value of L_i, the lower place priority is. According rank results truck should be allocated to the next client j, which appeared in the first place.

The FRP can be described as follows: given the number of clients n, a set of distances d_j, a depot w, and the set of routes with minimal length, starting and ending at w, such that each customer *o* is visited by single vehicle h.

List of constraints

The following constraints are incorporated in the algorithm.

Route constraints

Maximum Stops: Number of maximum stops per route;

Kilometres between stops: Next task is allocated based on the shortest distance calculation.

Route Scheduling

It is implemented for the selection of routes for trucks at the minimum costs. The algorithm can be applied for such option: it is an option to plan sequence of stops based on the shortest distance between stops. Over wise the task to visit clients located far away is postponed in one week time horizon and stays in pre-generated routes. If new orders are coming, new clients are inserted into pre-generated routes. If the improvement is found the new route is fixed. Such is used to get better costs with focus to visit the client exactly once.

Truck allocation

The truck allocation suggests optimal routes in order to minimize the number of vehicles. The most important parameter of the truck allocation algorithm is maximum number of stops per day planned for a truck.

Fulfilment constraints

Kilometres: Driven kilometres (share of extra kilometres);

Time window: to pick-up parcels the number of available days is pre-described (T=1, 2, 3, 4 or 5).

Loading time (backload) specifications: Time is taken to pick-up parcel and load it to the truck at the client;

Unloading time specifications: The time taken to unload truck at depot w (distribution centre DC).

The pseudo code for scheduling clients

```
Algorithm:
Let start the calculation, number of clients q=0; $L_i$=0; route $L_i$ starts at position x,y; i=1
for open cluster client j {1,..,n} search; $Max_j$ : = average value from distance matrix
    Distance $d_j < Max_j$ or T=5 (the open number of workdays for the client)
    start assign distance $d_j$ for route $L_i$
        If q<=25 then
            take client position u,v into the route $L_i$
                change x:=u, y:=v; q:=q+1; $L_i:=L_i+d_j$
            If q=25 then Assign truck i to the workday route $L_i$
                change i:=i+1; $L_i$:=0
            end if
        end if
    else
        client j="open", take client position u,v into the route P, recalculate $d_j$
    end
end
return to DC, finish at position x,y
```

Getting started

This describes very briefly. The data required for a route scheduling is:

- Client information (geographic data)
- Vehicle fleet characteristics (the number of vehicles *h*, costs per route T_i)
- Geographic data (the travel distance L_i between any two points, Distance Matrix).

The client information is entered together with client order into entry system.

After the order is accepted, the incoming client q is allocated to a cluster client j. So, the current planners must maintain that information.

Other problem could be the geographic information, to find an accurate post code data accepted by couriers.

The application can also be used for answering strategic questions, e.g. the "difference" between scenarios (Fig. 7.2). It makes the comparison of schedules not difficult. The term "selection" means the choice among couple or multiple alternatives.

Finally, for the selection of clients the method three general steps are used:

- First step, from all incoming clients q have to select whose clients j, which are positioned with the shortest distance parameter;
- Second step, clients, which are positioned with intermediate distance parameter, are allocated to the pre-defined route P. At the last day of agreed pick-up time window (when T =5) they are executed by having distance L_i;
- Last step, last clients, which positions have the longest distance parameter. These clients could be postponed for next days (based on agreement when for visit one-week pick-up time window (T=5) is given).

The route P typically starts from empty solution q=0 and L_i=0 when more and more clients are inserted until all of them are routed inside clusters.

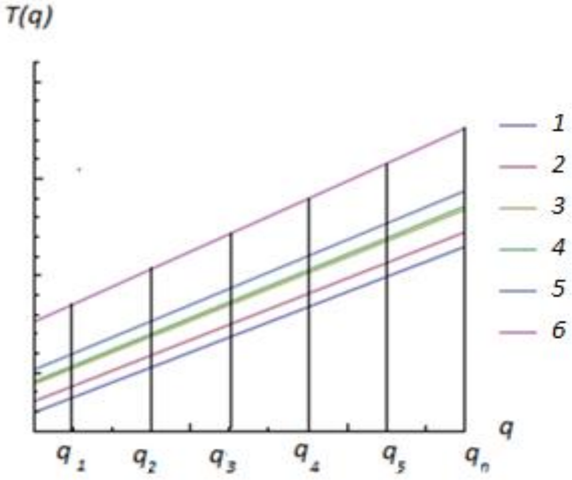

Fig. 7.2. Scenario analysis

Results show that first clients are selected, which have the closest neighbor places.

Clustering option

The cluster solution was selected as based on simulation results such gives 12 % of transportation costs. Client is allocated to a territory cluster based on neighbourhood logic. The vehicle routing is done within a cluster. For example, clusters can be used to plan pick-up at clients. If the large variety of neighbourhoods is available more routes are generated.

Process Flow Diagram

Main steps that are handled during the process (Fig. 7.3).

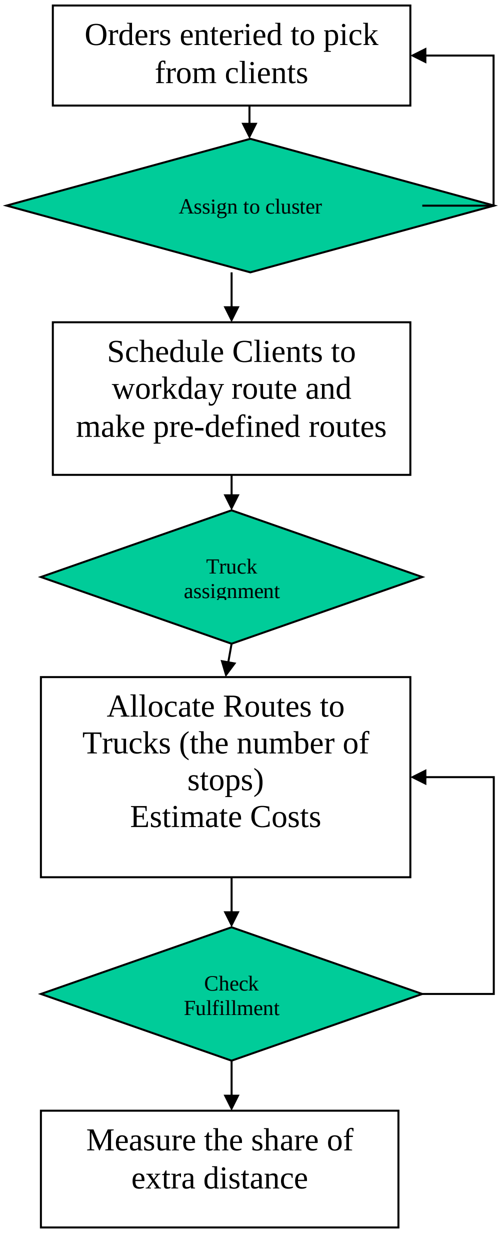

Fig. 7.3 Process Flow Diagram

7.7 CONCLUSION

The aim of the most algorithms is to offers the lowest possible transportation costs. Large variety of FRP solutions is available. There are a lot of algorithms used for constructing routes, make clustering and sequential routing, improving routes, dividing gigantic route into smaller ones, also routes are used in combination with travelling salesman problem or inventory routing problem.

In the most of the cases planning is static, especially in primary transportation cases. In backload cases the dynamic algorithms could be implemented if monitoring of client availability is taken, then pre-defined routes could be corrected based on up-to-the date information.

The suggested algorithm is formulated based on logic from route construction and route improvement methods. The route typically starts from empty solution when more and more clients are inserted until all of them are routed. The implemented logic falls under parallel method subdivision as for each cluster routes are assigned. The algorithm has two phases: in the first phase, all feasible clients are revised; in the second phase, some clients are selected to form workday route. Other clients stays in pre-defined routes. When new orders are coming, new clients are inserted and the improved routes are constructed.

The most of methods suggested for solving Fleet routing problem consider primary transportation by using capacity restrictions or distance restrictions or full truck loads, time windows, multiple periods, multiple products, multiple tasks, the multiple use of truck or other parameters.

In the paper author suggested transport routing solution for picking small parcels for backload cases. Author hope this research will stimulate further surveys in the area of fleet routing problem for backload.

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Chapter 8

LCA of a belt conveyor and its application

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Abstract

As transportation machines, belt conveyors are part of intralogistics. Intralogistics is branch of logistics which is a much broader concept. In the field of bulk material handling belt conveyors are the most common means of transportation of goods. This research is dealing with the life cycle assessment (LCA) of a bucket wheel excavator (BWE) belt conveyor. It should establish methodology for LCA analyses of such short and similar types of belt conveyors and their possible eco and energy efficiency improvements. Generally, this methodology could be applied on any type of belt conveyors for bulk material handling as well as for solids transportation. Belt conveyor components were analysed separately within series of simplified LCAs which are presented in scientific papers. The first analysed component of the belt conveyor was the belt conveyor idler. The next component of belt conveyor subjected to analysis was the drive pulley. Further research was focused on analysis of the belt conveyor belting. The most recent analysed component is belt conveyor electric motor. Previously published paper related to conveyor design optimization can serve as source of definitions for such terms as sustainability, energy efficiency and energy savings. Latest research is dealing with summarized results from previous papers and with simplified LCA of a complete belt conveyor as well. It also contains recommendations, guidelines and possible solutions for eco and energy efficiency improvements of such type of belt conveyors. This series of simplified LCAs should provide a basis for further analysis and more comprehensive complete LCA of the belt conveyor with more powerful software tools, such as GaBi and SimaPro.

Keywords: life cycle assessment, belt conveyor, energy efficiency, sustainability.

8.1 INTRODUCTION

Bucket wheel excavators (BWEs), belt conveyors and spreaders as well as bucket wheel or bucket chain reclaimers belong to the class of high performance machines (HPMs) and present the backbone of surface mining and conveying systems (Bošnjak & Zrnić, 2012).

Surface mining and conveying systems are usually consisted of:

- excavator-conveyor-spreader (ECS),
- excavator-conveyor-crusher (ECC),
- excavator-conveyor-transfer point (ECTP) (Pantelić et al., 2011).

Since HPMs are large-scale energy consumers, any improvement in energy efficiency or energy saving is considered to be significant contribution to sustainability (Đorđević et al., 2013). Following chapters will provide insight in terms related to sustainable development and LCA.

Advancements in energy and resource use, as well as climate change and environmental impacts are some of megatrends that are likely to be of particular relevance to intralogistics (Kartnig et al., 2012). This research is focused on investigation of environmental properties of belt conveyors on BWEs and similar types. It is based on simplified LCA of SRs 1201 BWE's belt conveyor and its components, which is a part of an ECS system. Each one of simplified LCAs, presented in scientific papers (Đorđević et al., 2013; Đorđević et al. (a), 2014; Đorđević et al. (b), 2014; Đorđević et al. (c), 2014) was conducted with Ecodesign Assistant (EA) and Ecodesign PILOT (EP) software tools (Austrian Ecodesign Platform, 2006; Wimmer, 2007).

There are published scientific papers that implement LCA into intralogistics as a tool for solving environmental issues. Such implementation can be illustrated with (Vujičić et al., 2013).

In addition to the conducted simplified analyses of the complete belt conveyor and its main components, three more simplified analyses were conducted in order to verify previously obtained results. These analyses included simplified LCA of ball bearing 6310 C3, belt conveyor gearbox BKF 320 and conveyor belting. Analysis of belting is conducted for the second time with more accurate data, obtained from the manufacturer. However, this analysis has shown the same result as the one previously obtained and published in (Đorđević et al. (b), 2014). These analyses will be presented in further chapters alongside suggestions for possible improvements.

Purpose of this study is to establish approach and methodology for LCA analyses and improvement of environmental properties of short type belt conveyors.

8.2 SUSTAINABILITY AND RELATED TERMS

From the environmental point of view, **sustainability** represents the system’s capacity (in this case the Earth) to support anthropogenic activities’ impact on the environment without putting the future of human race under risk. From the designer point of view, **sustainable development** is about designing objects that use limited resources; it is also about social responsibility and ethics, see Figure 8.1. According to the United Nations Brundtland Commission, **sustainable development** is "development that meets the needs of the present without compromising the ability of future generations to meet their needs" (Bârsan & Bârsan, 2007; Zrnić & Đorđević, 2012).

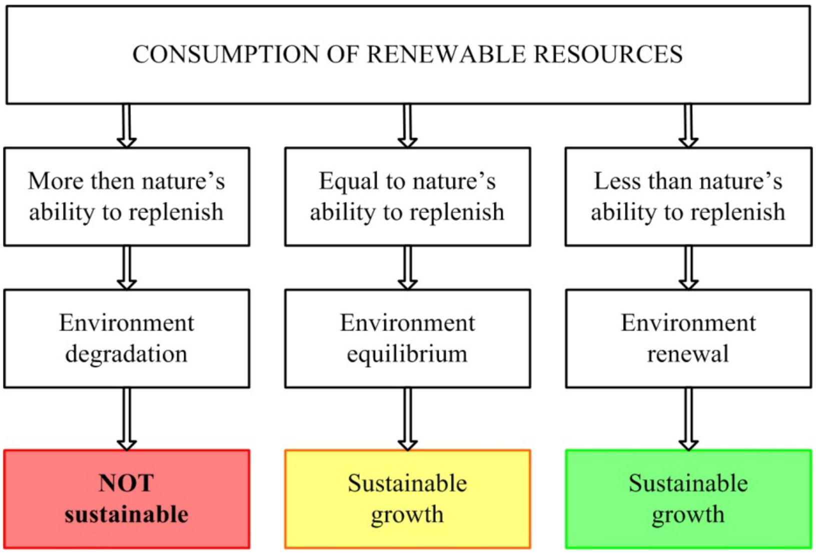


Fig. 8.1 The human choice on development strategies (Bârsan & Bârsan, 2007)

Environmental degradation is damage to a local ecosystem or the biosphere as a whole due to human activity. Environmental degradation occurs when nature's resources (such as vegetation, habitat, earth, water and air) are being consumed faster than nature can replenish them (Bârsan & Bârsan, 2007).

Energy efficiency means using less energy inputs while maintaining an equivalent level of economic activity or service (Langerholc et al., 2013; Humpl & Starkl, 2010).

Energy saving is a broader concept that also includes consumption reduction through behaviour change or decreased economic activity (Langerholc et al., 2013; Humpl & Starkl, 2010).

8.3 LCA AND RELATED TERMS

Life cycle assessment (LCA) presents the analysis of environmental impacts (refer to Chapter 8.3.3) of a product during its entire life cycle. LCA is an iterative technique. In accordance with EN ISO 14040: 2006, life cycle of a product consists of five consecutive and interlinked stages. Therefore **life cycle** includes:

1. raw material stage,
2. manufacturing stage (design and production),
3. distribution stage (packaging and transportation),
4. use stage, and
5. end of life stage (EoL).

In accordance with the same standard EN ISO 14040: 2006, the formal **structure of an LCA** contains four phases:

- goal and scope definition,
- life cycle inventory analysis (LCI),
- life cycle impact analysis (LCIA),
- life cycle interpretation.

These phases are consecutive and interlinked, as life cycle stages, see Figure 8.2.

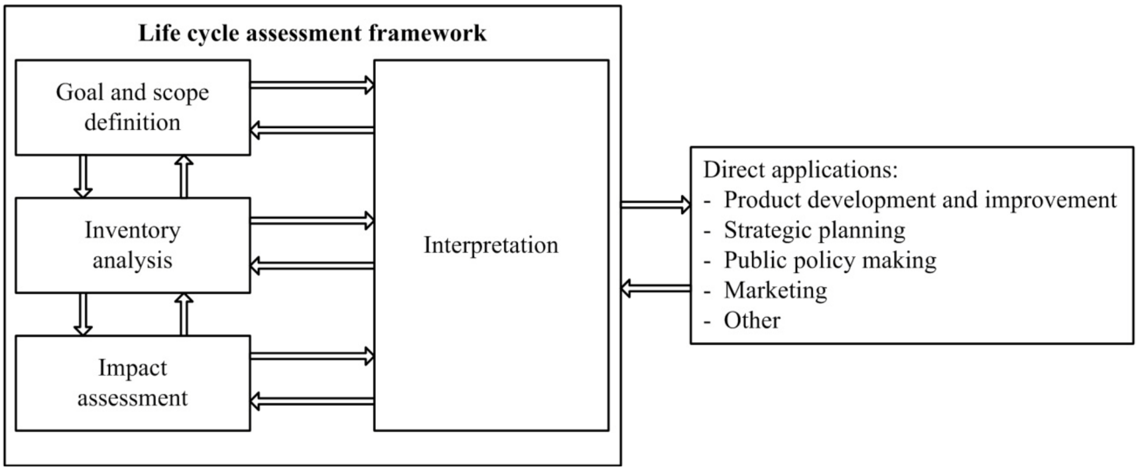


Fig. 8.2 Phases of an LCA (EN ISO 14040: 2006)

8.3.1 Goal and scope definition

At first the scope, level of comprehensiveness, depth and detail of the analysis, target audience, the intended application and the reason why the study is to be carried out needs to be identified. The scope of the study defines temporal, geographical and technological coverage of the study in relation to its goal. The goal and scope definition determines the working plan of the entire LCA. The most important is to set boundaries to the product system properly and to define the functional unit (Morris, 2007; Wimmer, 2007).

A **function** is what the product provides to the user. It is an abstract, viewpoint and user expectance dependant term.

Therefore a **functional unit** is required since it quantifies the function and makes it measurable. Functional unit is a reference that is used throughout the whole LCA and it describes the primary function(s) fulfilled by a product system, and indicates how much of this function is to be considered in the intended LCA study. It enables different systems to be treated as functionally equivalent. Selection of appropriate functional units is important under any circumstance. It is crucial for comparative studies. If two products are to be compared, the functional unit should be the same (Morris, 2007; ISO/TR 14049: 2000 (E), p. 7).

The **lifetime of a product** is the span of time during which the product fulfils its function properly.

Different boundaries set for the same product system consequently give different LCA results as well.

Setting excessive **system boundaries** requires too much information needed to obtain an environmental profile of a product and result in more time consuming and more expensive LCA. On the other hand, too small system boundaries may lead to a wrong and insufficient description of the environmental profile of a product. In both cases the real weak points of the product may be overlooked. Therefore, defining proper **system boundaries** remains an important task. It is important to identify the most important parts and components. Significant processes should be included within the system boundary, while other can be neglected.

For the evaluation of the significance of processes and activities **"cut-off"** rule, based on mass inclusion, can be used. If fractional weight of the process/activity to the product is less than a certain percentage, they are excluded from consideration. Decision rules based on energy flows can also be used. It is of great importance to take into account those materials which have a high environmental impact when used in small quantities. These materials are not subject to the **"cut-off"** rule, and they have to be taken into consideration (Wimmer, 2007).

8.3.2 Life cycle inventory analysis (LCI)

“This LCA phase involves the intensive data collection and compilation and often it is the most time-consuming step in LCA. Energy and material input and outputs for the entire life cycle are measured as well as embedded resources in resulting products and by-products. With information gathered about each unit process, it is possible to compile a **life cycle inventory** of all the environmental inputs and outputs associated with the product. Each impact is expressed as a particular quantity of a substance, although from this alone we cannot tell which parts of the process are necessarily more environmentally damaging than others, it is simply a table of collected data.” (Morris, 2007).

The main processes with the biggest impact should be considered first. Collected data should then be verified and validated. This can be done by simple mass and energy balances to ensure that 100% of the processes within the system boundary have been accounted for (Morris, 2007).

8.3.3 Life cycle impact assessment (LCIA)

The goal of the **Life Cycle Impact Assessment** (LCIA) phase is to convert the results determined in the LCI into understandable impacts on the environment (Morris, 2007).
Environmental impacts (of human activities) are reflected in air and water pollution, greenhouse effect and global warming, ozone layer depletion, soil contamination, land degradation and desertification, acidification, resources depletion and reducing biodiversity (Bârsan & Bârsan, 2007).
All substances that contribute to the specific impact category have different harmful potentials. Therefore, to compare harmful potentials of the respective substances with each other **characterisation factor** and **unit of equivalence** (characterisation factor unit) (see Table 8.1) have to be established.

Table 8.1 Commonly used impact categories with respective characterization factor units

Impact category	Abbreviation	Unit of equivalence
Global warming potential	GWP	g CO_2 eq/g
Ozone depletion potential	ODP	g CFC11 eq/g
Acidification potential	AP	g SO_2 eq/g
Eutrophication potential	EP	g PO_4^{3-} eq/g
Photochemical oxidant creation potential	POCP	g C_2H_4 eq/g
Depletion of abiotic resources potential	ADP	1/yr

8.3.4 LCA interpretation

In the Life Cycle Interpretation, the results of the LCI and LCIA are used to derive perspectives on the system, or recommendations to minimise the detrimental environmental attributes of the system under study. The life cycle interpretation phase consists of three elements:

- identification of the significant issues based on the results of the LCI and LCIA.
- evaluation which considers completeness, sensitivity and consistency checks.
- conclusions, recommendations and reporting (Morris, 2007).

8.4 ECODESIGN AND LIFE CYCLE THINKING

The European Environment Agency defines **Ecodesign** as "the integration of environmental aspects into the product development process, by balancing ecological and economic requirements. Ecodesign considers environmental aspects at all stages of the product development process, striving for products which make the lowest possible environmental impact throughout the product life cycle." (EEA, 2006).
Ecodesign integrates the idea of sustainability as well as environmental considerations into the product development. It considers the contribution of the product to environmental impact through all of its life cycle stages. Speaking of Ecodesign and environmental friendly product development it is important to bring together environmental requirements from stakeholders, as well as legal frameworks. For the purpose of product improvement, Ecodesign process integrates stakeholder and environmental point of view, see Figure 8.3 (Wimmer, 2007).

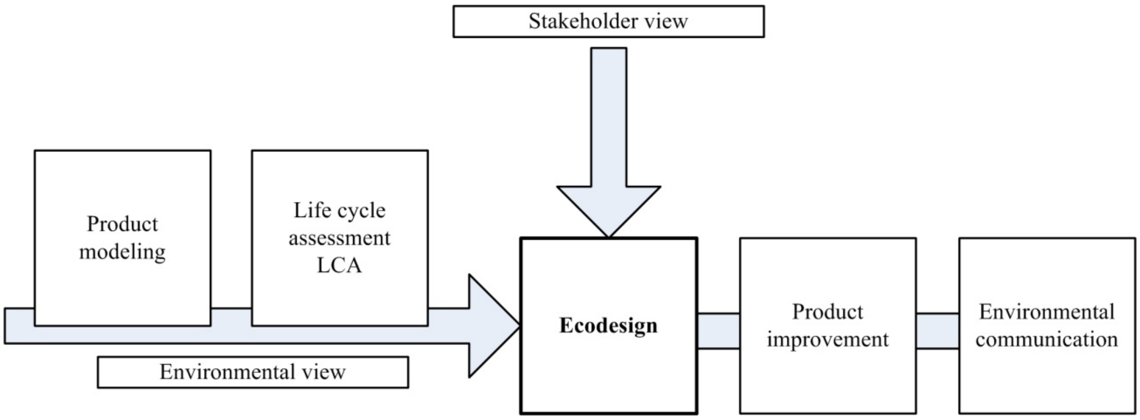


Fig. 8.3 Inputs to the Ecodesign process (Wimmer, 2007)

Implementation of Ecodesign assumes **Life Cycle Thinking** (LCT) approach, which is the holistic consideration of environmental impacts of a product caused throughout its life cycle stages (Wimmer, 2007). For achieving higher level of sustainability life cycle thinking should be applied whenever designing or analysing a product.

8.5 ECODESIGN ASSISTANT AND ECODESIGN PILOT

Unlike formal LCA with energy values where absolute numbers are derived, the **Ecodesign Assistant** (EA) and **Ecodesign PILOT** (EP) only calculate relative environmental impacts by comparing the occurring impacts of the different life cycle stages of the product (Wimmer, 2007). In that way EA and EP define basic type of a product which is determined with the most significant stage of its life cycle. Relative to life cycle stages, there are 5 **basic types** of the product:

- basic type A - raw material intensive product,
- basic type B - manufacture intensive product,
- basic type C - transportation intensive product,
- basic type D - use intensive product and
- basic type E - disposal intensive product.

In addition, Ecodesign measures with greatest potential for improving the product are provided by EP in accordance with the identified product type (Đorđević et al., 2013).

The EA contains a sequence of six forms which are used for entering data that describe the product and its life cycle stages. Based on these data, the EA gives detailed guidelines for product improvement by proposing **strategies** which are directly linked to the EP, see Table 8.2. The improvement strategies are divided into main strategies with a high priority, secondary strategies and additional strategies with lowest priority. For each improvement strategy the EP offers checklists and product improvement tasks. Priority of each particular improvement task is determined in accordance with its relevance and fulfilment. Ecodesign tasks showing a high priority should be chosen for product improvement. Before realizing any improvement strategy or improvement task legal requirements must be investigated and put into action. Voluntary stakeholder requirements from **eco-labelling** programs might be considered as well. Taking part in an environmental labelling program helps decrease the environmental impact of the product through its life cycle and raises the value of the product on the market (Wimmer, 2007).

Table 8.2 Strategies defined in the EA and EP to the different product types (Wimmer, 2007)

No.	Strategy	Type A	Type B	Type C	Type D	Type E
S1	Selecting the right materials	x				x
S2	Reducing material inputs	x				
S3	Reducing energy consumption in production processes		x			
S4	Optimizing type and amount of process materials		x			
S5	Avoiding waste in the production process		x			
S6	Ecological procurement of external parts		x			
S7	Reduction of packaging			x		
S8	Reduction of transportation			x		
S9	Optimizing product use	x	x			
S10	Optimizing product functionality	x	x		x	
S11	Increasing product durability	x	x			x
S12	Ensuring environmentally safe performance				x	
S13	Reducing consumption at use stage				x	
S14	Avoidance of waste at use stage				x	
S15	Improving maintenance	x	x		x	
S16	Improving reparability	x	x			x
S17	Improving disassembly	x	x			x
S18	Reuse of product parts	x	x			x
S19	Recycling of materials	x				x

For the purpose of evaluation of environmental properties of constituent materials used in a product in raw material stage, the EA has a built-in **material class table** with their respective environmental impact determined by class. Deficiency of this table is a lack of certain types of material such as water and lubricants.

During the manufacture stage, a product requires variety of different process materials and energy inputs for its production. It usually requires thermal and/or electric energy. Another kind of energy which has to be taken into account is the so called "**overhead energy**". The overhead energy of a factory includes, for example, the energy needed to warm or cool the manufacturing halls or for their lightening. This kind of energy consumption should not be neglected since experience shows that this energy consumption may rise up to 200% of the energy needed for the manufacturing of the product itself. It is clear that the overhead energy must be allocated to the total energy consumption of the product for manufacture (Wimmer, 2007).

Transportation distance for the final product as well as for its external parts has significant influence on overall environmental impact of a product. Therefore, relative transportation distance diagram was made, see Figure 8.4. The length of the Equator is about 40 000 km (40 075 km). Having this in mind, the longest one-way distance should be about half of equator length, which is approximately 20 000 km.

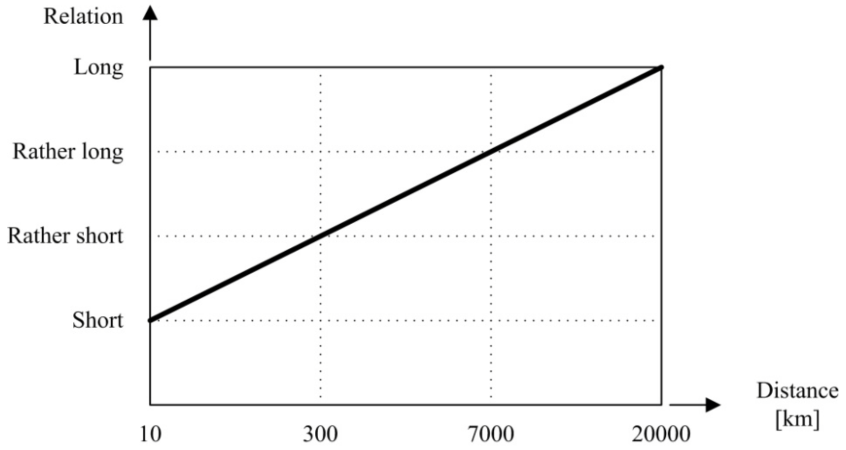


Fig. 8.4 Relative transportation distances diagram

Different means of transportation require different kinds and amounts of energy. Energy values in MJ normalised per tonne per km are presented in Table 8.3.

Table 8.3 Energy values for different means of transport (Morris, 2007; Wimmer, 2007)

Means of transport	**Energy value [MJ/tkm] (Morris, 2007)**	**Energy value [MJ/tkm] (Wimmer, 2007)**
Air, Freight	8.3 ÷ 15	33 (in Europe)
Truck	0.9 ÷ 1.5	2.7
Freight train (Rail freight)	0.86	0.8
Barge (River)	0.83	-
Transoceanic freight ship (Sea freight)	0.11	0.17

Use intensive products may need a lot of additional materials for proper operating (e.g. lubricants) which may cause harm to the environment. For the same reason they could also need some kind or many different kinds of energy and could release emissions to the environment (Wimmer, 2007).

There are several options available for dealing with the product when it reaches the end of its life cycle. **Integrated solid waste management** (ISWM) proposes **pyramid of priority** shown in Figure 8.5.

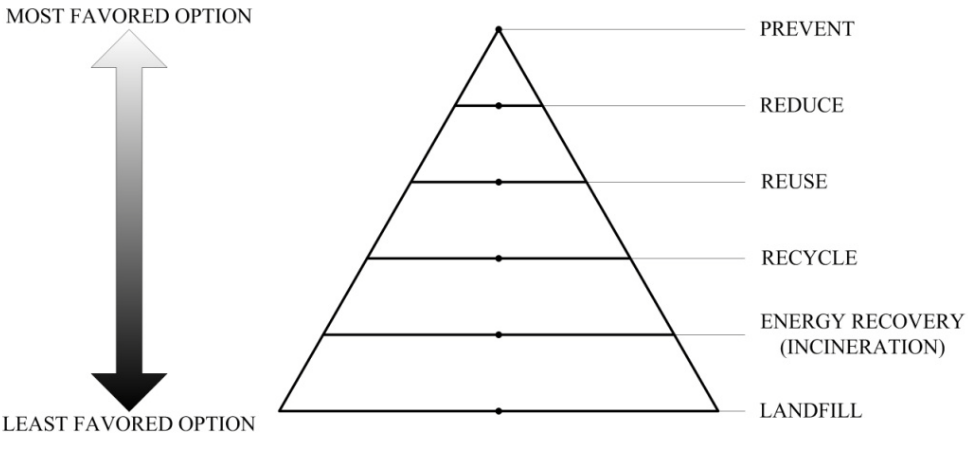


Fig. 8.5 EoL options: Pyramid of priority
(Morris, 2007; Paralika, 2007; Zrnić & Đorđević, 2012)

Prevention/reduction of waste is the most favored option in the ISWM hierarchy.

By **reusing** parts and components, the amount of manufactured parts and components, hence the processed materials and the energies used can be reduced as well. Reduced energy demand means reduced environmental impact (Wimmer, 2007).

Recycling often uses less energy, causes less pollution than using raw materials and also results in fewer emissions (Paralika, 2007). In general, recycling processes are able to reduce the total environmental impact of a product by recovering material or energy (Wimmer, 2007).

Incineration is the process of destroying waste material by burning it at very high temperatures. Incineration of waste allows to recover the useful energy content of the disposed materials (Paralika, 2007).

Disposing of waste material in a **landfill** can cause environmental impact in case of toxic or otherwise hazardous material. Hazardous materials require special care. On the other hand no energy can be recovered by disposing of waste in a landfill.

Life cycle stages of a product are not just a linear sequence but contain different **cycles** and **loops**.

Besides the end of life options presented with pyramid of priority, there are few more options such as repair, upgrade and reverse manufacturing (Wimmer, 2007).

A **repair** cycle delays the arrival of the EoL stage of a product. Parts and components of a product can be repaired several times and be used again (Wimmer, 2007).

Upgrading requires special product designs which allow changing and substituting parts and components of the product. Products which have a modular structure are easy to enter into such an upgrading cycle (Wimmer, 2007).

Reverse manufacturing assume disassembly of the product, followed by inspection, repair and/or replacement of defective parts and reassembly of the product. This way the EoL stage of the product is delayed and raised its value as well as environmental impact is reduced.

EA offers several EoL options, presented in Table 8.4.

Table 8.4 EoL options defined in the EA (Austrian Ecodesign Platform, 2006)

Selection	Disposal method
Reuse	Reuse parts and components
Recycling	Reuse of parts and components
Incineration	Generation of (thermal) energy
Landfill	Dumping
Hazardous waste	Special treatment of hazardous substances Also select in the following cases: - Dumping of hazardous substances without special treatment - Incineration of PVC or glass - Etc…

8.6 ANALYSIS OF A BWE BELT CONVEYOR WITH THE EA & EP

8.6.1 Description of the product

Analysis of the BWE's belt conveyor, which is 8.3 m long, with 1.6 m wide belting and throughput of 3465 m^3/h of brown coal is presented here.

In accordance with its throughput the **functional unit** of the belt conveyor is determined as: "Transportation of 3465 m^3/h of brown coal".

As previously explained in Chapter 8.3.1, a functional unit is used for normalization of total energy, materials and emissions. This way different conveyors with the same throughput of brown coal can be compared. Moreover, results of such comparison can lead to improvement of design of short conveyors from the environmental point of view or choosing adequate type of conveyor for required purpose (perhaps change in concept or some other changes).

Minimum **service life** of a belt conveyor is expected to be 5 years. It is calculated in accordance with l10 bearing service life. Actual life span of a belt conveyor is considerably longer and it equals 25 to 30 years. Therefore, ball bearings are to be replaced at least 5 to 6 times during the conveyor lifetime. Gearbox oil is changed on a yearly basis.

Most of the data are taken from previous partial analyses and implemented into the analysis presented in (Đorđević et al., 2015).

For the purpose of the analysis, the belt conveyor is divided into five main groups of parts as presented in (Đorđević et al., 2015), see Figure 8.6:

1. idlers/rollers,
2. pulleys,
3. belting,
4. electric motor (EM),
5. other.

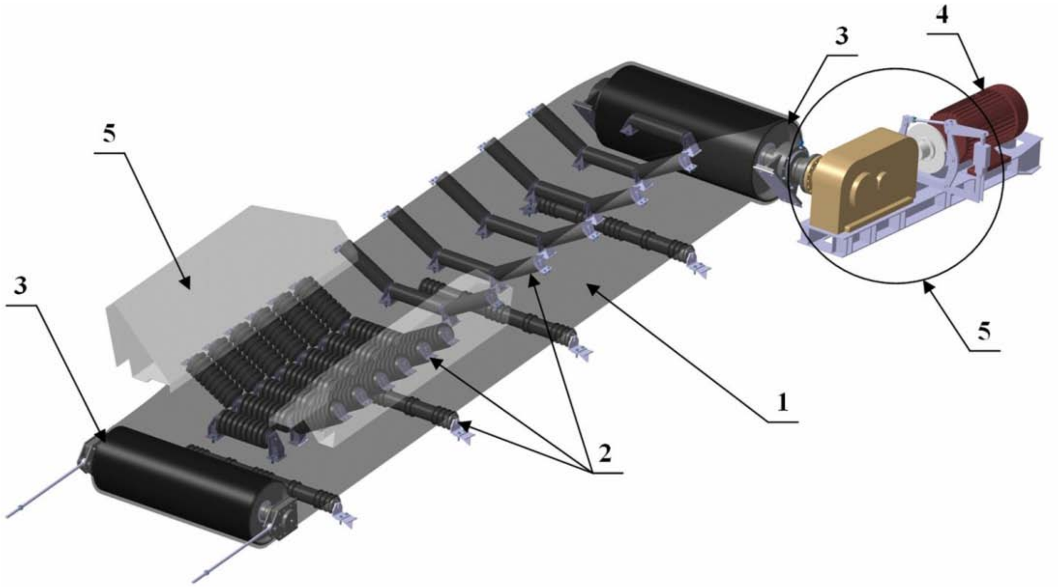


Fig. 8.6 Main components of a conveyor: 1. belting, 2. idlers/rollers, 3. pulleys, 4. electric motor, 5. other

Group of parts named "other" consists of belt conveyor drive components (without EM), take up device and accessories. Drive components considered here are gearbox unit, coupling and drum brake, see Figure 8.7.

Take-up device is not considered within the analysis because of the lack of data. Normally, take-up device could be considered as component that:

1. consumes electric or other kind of energy,
2. does not consume energy.

In case that take-up device consumes energy, the type and amount of consumed energy per use should be calculated and added to the total energy consumed by the belt conveyor in its use stage. In the second case, take-up device is considered a part predominantly made of steel which is produced by machining. Generated waste during the production stage of take-up device is assumed to be 10% of its mass. The second case will be used as a pattern for modelling parts and components predominantly made of single material and do not consume energy.

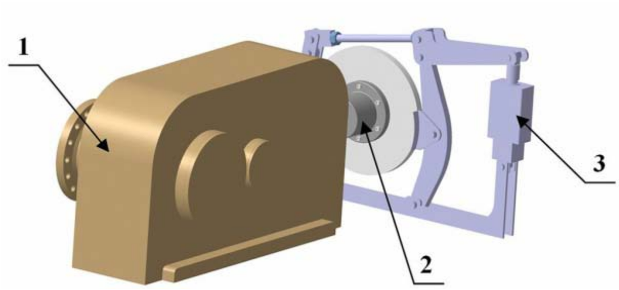


Fig. 8.7 Belt conveyor drive components: 1. gearbox, 2. coupling, 3. drum brake

Parts and components which belong to the accessories are analysed the same way as the take-up device. The only component from this group of parts considered here is chute.

8.6.2 Assumptions and simplifications used for modelling the belt conveyor

This belt conveyor consists of three types of idlers: impact idlers, carrying idlers and return idlers. There are 6 impact idlers, 5 carrying idlers, 4 return idlers and 2 transition (terminal) idlers, see Figure 8.8. Impact and carrying idlers are troughed with side rollers inclined at 30°. They are consisted of three Ø159 x 600 mm rollers, wherein carrying idlers have smooth rollers and impact idlers are equipped with rubber disc and rings. Exceptions are two terminal idlers which are consisted of single roller - centre roller. One of them is impact idler and the other one is carrying idler. Return rollers are consisted of single roller Ø159 x 1800 mm equipped with rubber discs and rings.

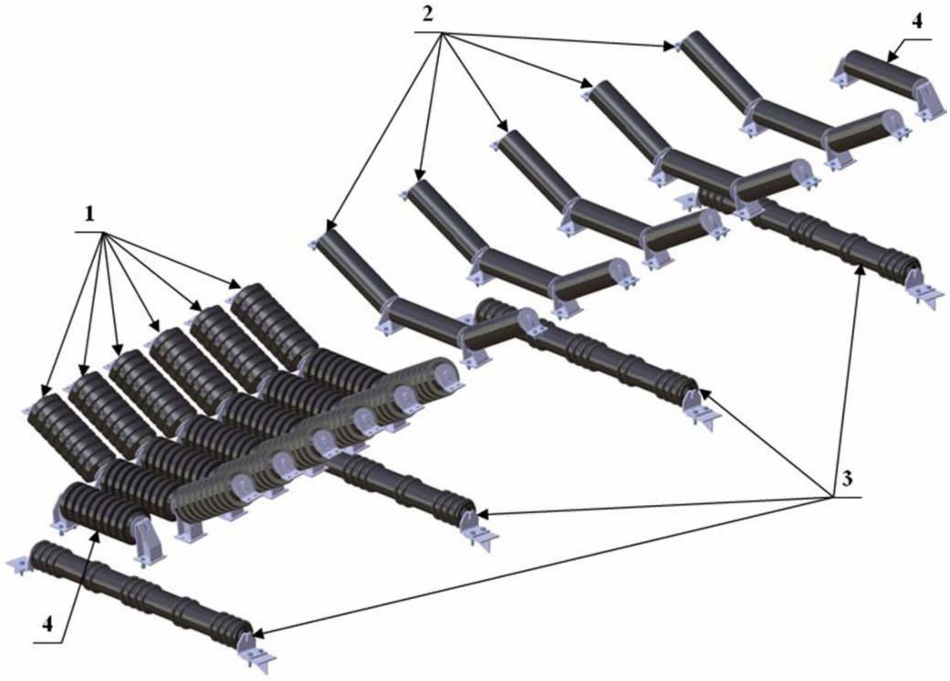


Fig. 8.8 Idler types: 1. impact idler, 2. carrying idler, 3. return idler, 4. transition idler.

For the purpose of simplification of the analysis following assumptions are made:

- return idlers are presented with three rollers, see Figure 8.9,
- return and impact idlers are presented with Ø159 x 600 mm smooth rollers equipped with rubber discs and rings, see Figure 8.9,
- all idler ball bearings are presumed to be 6310 C3 type,
- ball bearings are predominantly made of steel.

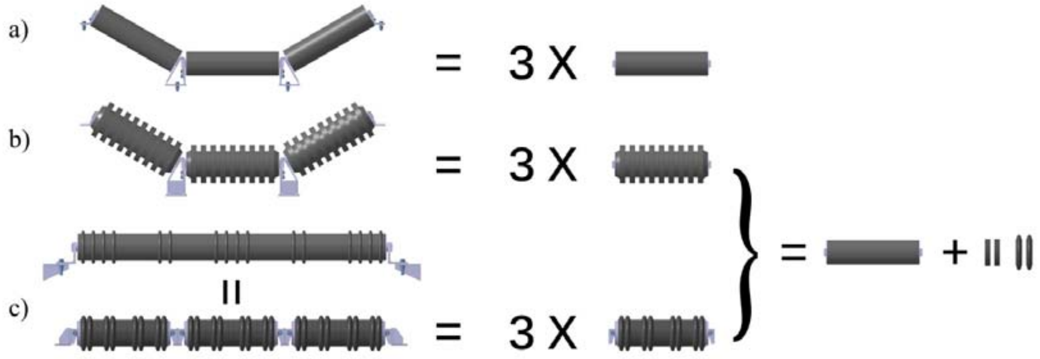


Fig. 8.9 Simplified models of idler types: a) carrying idler, b) impact idler, c) return idler

In accordance with these simplifications all idlers are presented with 47 smooth rollers Ø159 x 600 mm, 392 rubber discs, 196 rubber rings and 94 ball bearings. This way 16 ball bearings more than in actual case is considered within calculations. A more precise situation could be achieved with their exclusion from the analysis. However, this fluctuation does not affect the final result.

The conveyor has two pulleys: drive pulley and take-up pulley. Since they are of similar construction, they are both presented with drive pulley 1.5 times heavier than the original drive pulley.

The belting is 16 m long and 1.6 m wide 3-layer flat composite. Top and bottom covers and interlayers are made of rubber. The carcass is consisted of 3 reinforcing plies made of polyester and polyamide.

The data for EM are completely taken from analysis done in paper (Đorđević et al. (c), 2014).

The rest of the belt conveyor components analysed here are gearbox unit, coupling, drum brake and chute. These components do not consume energy during their use stage and they are analysed as presented in Chapter 8.6.1.

These types of simplifications and assumptions could be used to model any kind of short belt conveyor.

8.6.3 LCI and LCIA

Since this study is so far based only on simplified analyses conducted with the EA & EP software tools, which calculate only relative environmental impacts, LCI and LCIA parts of a formal LCA are not covered with the study.

8.6.4 Analysis

During the analysis, the belt conveyor is divided into 5 groups of parts. These 5 groups are further classified in accordance with their constituent materials. This classification is presented in Table 8.5 and summarized in Figure 8.10 (Đorđević et al., 2015).

Table 8.5 Classification of groups of parts relative to the material they are made off and their appropriate waste per unit for manufacturing stage (Đorđević et al., 2015)

Group of parts	Pieces	Weight/piece [kg]	Weight [kg]	Material	Class	Scrap [kg]
1. Rollers						
Steel parts	47 rollers	27.8	1307.0	Steel	III	10% = 130.7
Rubber parts	31 rollers	6.2	192.0	Rubber	IV	10% = 19.2
Lubricating grease: considered in raw material stage considered in use stage			7.52 0.023 kg/use	Li-based oil	V V	
2. Pulleys						
Steel parts	1.5	1252.0	1878.0	Steel	III	10% = 187.8
Alloyed steel parts	1.5	751.3	1127.0	Alloyed steel	VI	10% = 112.7
Rubber parts	1.5	157.37	236.0	Rubber	IV	10% = 23.6
Lubricating grease: considered in raw material stage considered in use stage			4.095 0.013 kg/use	Li-based oil	V V	
3. Belting						
Carcass	1	112.64	112.64	EP & PA	V	10% = 11.3
Covers	1	450.56	450.56	Rubber	IV	10% = 45.1
4. Electric motor						
Windings and bars	1	176.0	176.0	Copper	V	10% = 17.6
Housing	1	264.0	264.0	Cast iron	IV	10% = 26.4
Steel parts	1	440.0	440.0	Steel	III	10% = 44.0
5. Other						
5.1 Gearbox	1		900.0			
Casing	1	450.0	450.0	Cast iron	IV	10% = 45.0
Flange	1	74.0	74.0	Alloyed steel	VI	10% = 7.4
Steel parts	1	376.0	376.0	Steel	III	10% = 37.6
Lubricating oil: considered in raw material stage considered in use stage			50 l ≈ 45 kg 0.144 kg/use	Mineral oil	V V	
5.2 Coupling	1	20.0	20.0	Steel	III	≈50% = 10.0
5.3 Drum brake	1	120.0	120.0	Steel	III	10% = 12.0
5.4 Chute	1	1950.0	1950.0	Steel sheet	IV	10% = 195.0

In accordance with the "cut-off" rule, parts with mass inclusion lower than 5% of total mass of the product have been neglected. In this case, since there were partial analyses conducted, "the product" stands for components of the belt conveyor presented in papers (Đorđević et al., 2013; Đorđević et al. (a), 2014; Đorđević et al. (b), 2014; Đorđević et al. (c), 2014) and summarized in paper (Đorđević et al., 2015). "Cut-off" rule based on energy inclusion gives similar results.

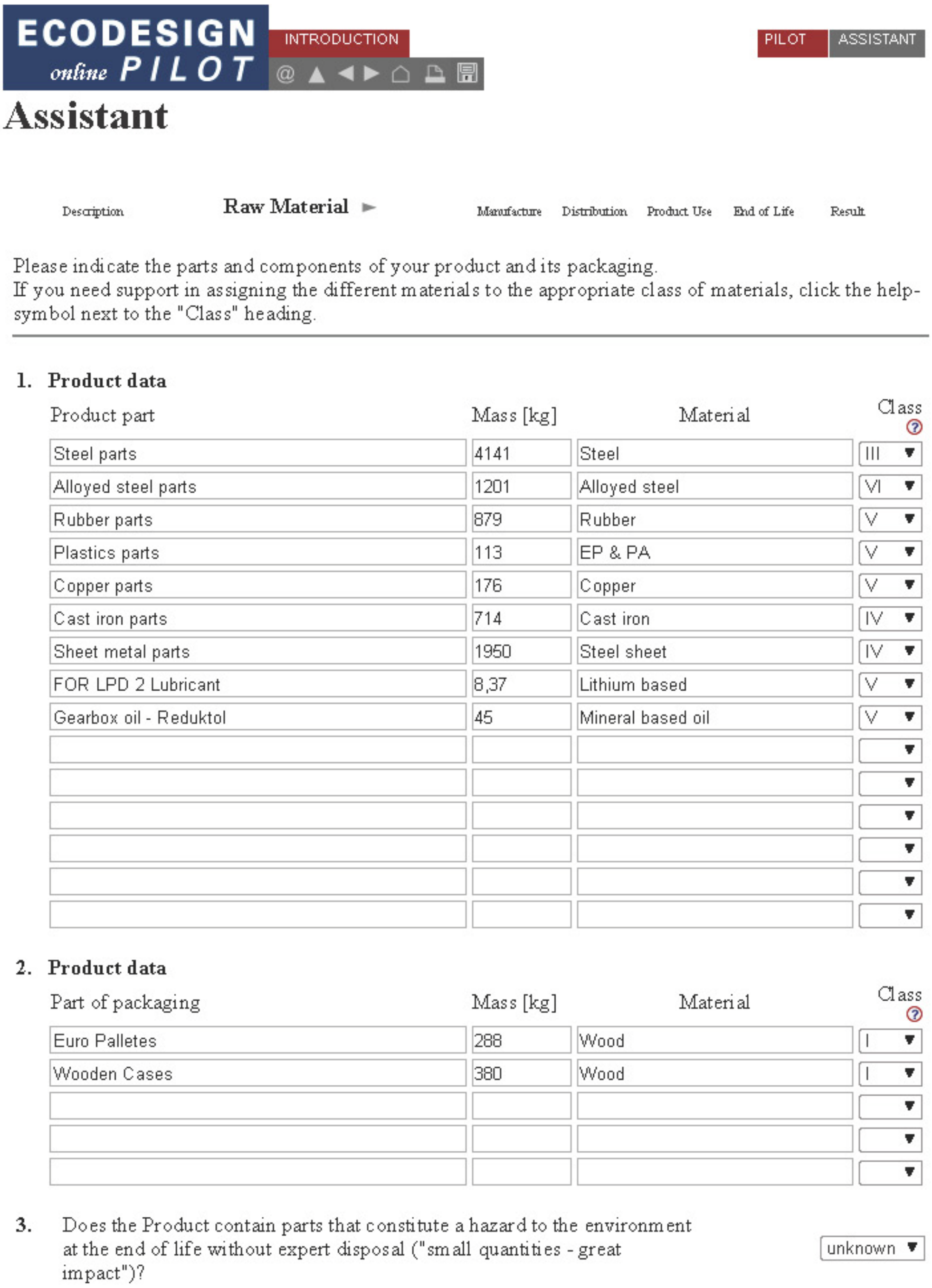
Lubricants can be considered either within raw material stage or within use stage. Regardless of which of these two options are chosen, the result remains the same.

Besides the belt conveyor parts, packaging and packaging material are taken into account as presented in (Đorđević et al., 2015).

Total energy input and generated waste during the manufacturing of the belt conveyor are obtained from (Đorđević et al., 2015) and shown in Figure 8.11.

Data from the manufacturing stage form for initial iteration are shown in Figure 8.11. The initial iteration presents the worst case scenario and basis for further optimization of environmental properties of the belt conveyor.

The belt conveyor, as a part of BWE, is utilized at the open pit mine near Lazarevac. Most of the belt conveyor components are supplied from the manufacturer in the proximity to the open pit mine. Calculated hauling distance for transportation of external parts by truck was 1865 km. In accordance with Figure 8.4, this distance can be classified as "rather short". The drum brake is transported from the greatest distance (approximately 1500 km) and it is considerably affecting total transportation distance (Đorđević et al., 2015).



Assistant

Description | **Raw Material ►** | Manufacture | Distribution | Product Use | End of Life | Result

Please indicate the parts and components of your product and its packaging.
If you need support in assigning the different materials to the appropriate class of materials, click the help-symbol next to the "Class" heading.

1. Product data

Product part	Mass [kg]	Material	Class ?
Steel parts	4141	Steel	III ▼
Alloyed steel parts	1201	Alloyed steel	VI ▼
Rubber parts	879	Rubber	V ▼
Plastics parts	113	EP & PA	V ▼
Copper parts	176	Copper	V ▼
Cast iron parts	714	Cast iron	IV ▼
Sheet metal parts	1950	Steel sheet	IV ▼
FOR LPD 2 Lubricant	8,37	Lithium based	V ▼
Gearbox oil - Reduktol	45	Mineral based oil	V ▼
			▼
			▼
			▼
			▼
			▼
			▼

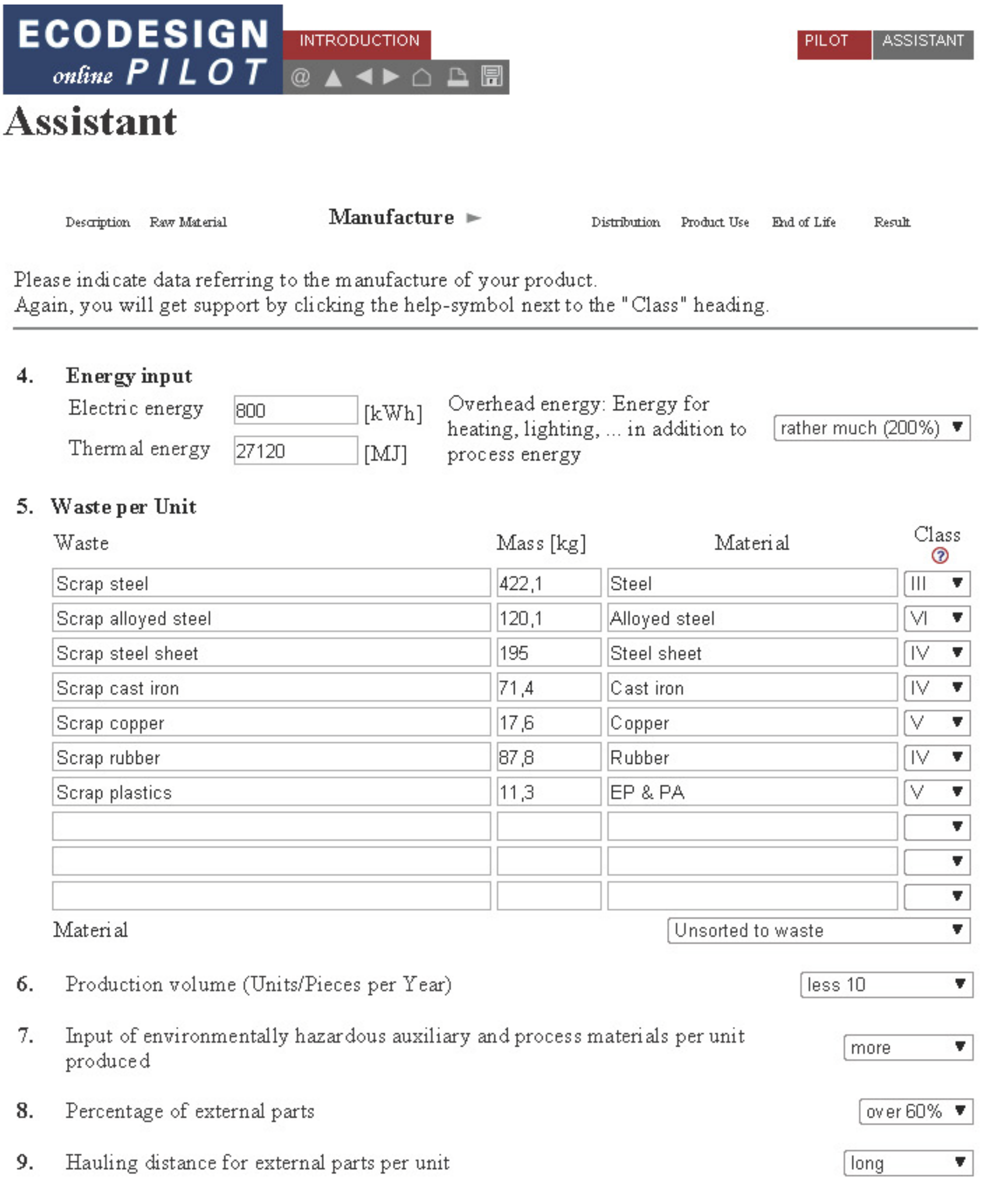
2. Product data

Part of packaging	Mass [kg]	Material	Class ?
Euro Palletes	288	Wood	I ▼
Wooden Cases	380	Wood	I ▼
			▼
			▼
			▼

3. Does the Product contain parts that constitute a hazard to the environment at the end of life without expert disposal ("small quantities - great impact")? unknown ▼

Fig. 8.10 Raw material stage form with lubricants considered within it (Đorđević et al., 2015)

The use stage is determined with the number of operating hours per day and consumption of electricity and auxiliary material. The belt conveyor operates 20 hours per day 325 days a year. It is assumed that one use equals one working day. The belt conveyor consumes 2.64 MWh/use, but due to software limitations this value is set to 1.0 MWh/use. However, this fact does not affect the result. Besides the electricity consumption, the belt conveyor needs lubrication for its proper operation. Lubrication could be considered either in this stage or in raw material stage. In case of lubricating the belt conveyor in use stage there is a need for 0.036 kg/use of FOR LPD 2 lubricating oil for ball bearings and 0.144 kg/use of Reduktol oil for gearbox unit. As previously stated, both options give the same result (Đorđević et al., 2015).



Please indicate data referring to the manufacture of your product.
Again, you will get support by clicking the help-symbol next to the "Class" heading.

4. Energy input

Electric energy 800 [kWh]

Thermal energy 27120 [MJ]

Overhead energy: Energy for heating, lighting, ... in addition to process energy: rather much (200%)

5. Waste per Unit

Waste	Mass [kg]	Material	Class
Scrap steel	422,1	Steel	III
Scrap alloyed steel	120,1	Alloyed steel	VI
Scrap steel sheet	195	Steel sheet	IV
Scrap cast iron	71,4	Cast iron	IV
Scrap copper	17,6	Copper	V
Scrap rubber	87,8	Rubber	IV
Scrap plastics	11,3	EP & PA	V

Material: Unsorted to waste

6. Production volume (Units/Pieces per Year): less 10

7. Input of environmentally hazardous auxiliary and process materials per unit produced: more

8. Percentage of external parts: over 60%

9. Hauling distance for external parts per unit: long

Fig. 8.11 Manufacturing stage form for initial iteration (Đorđević et al., 2015)

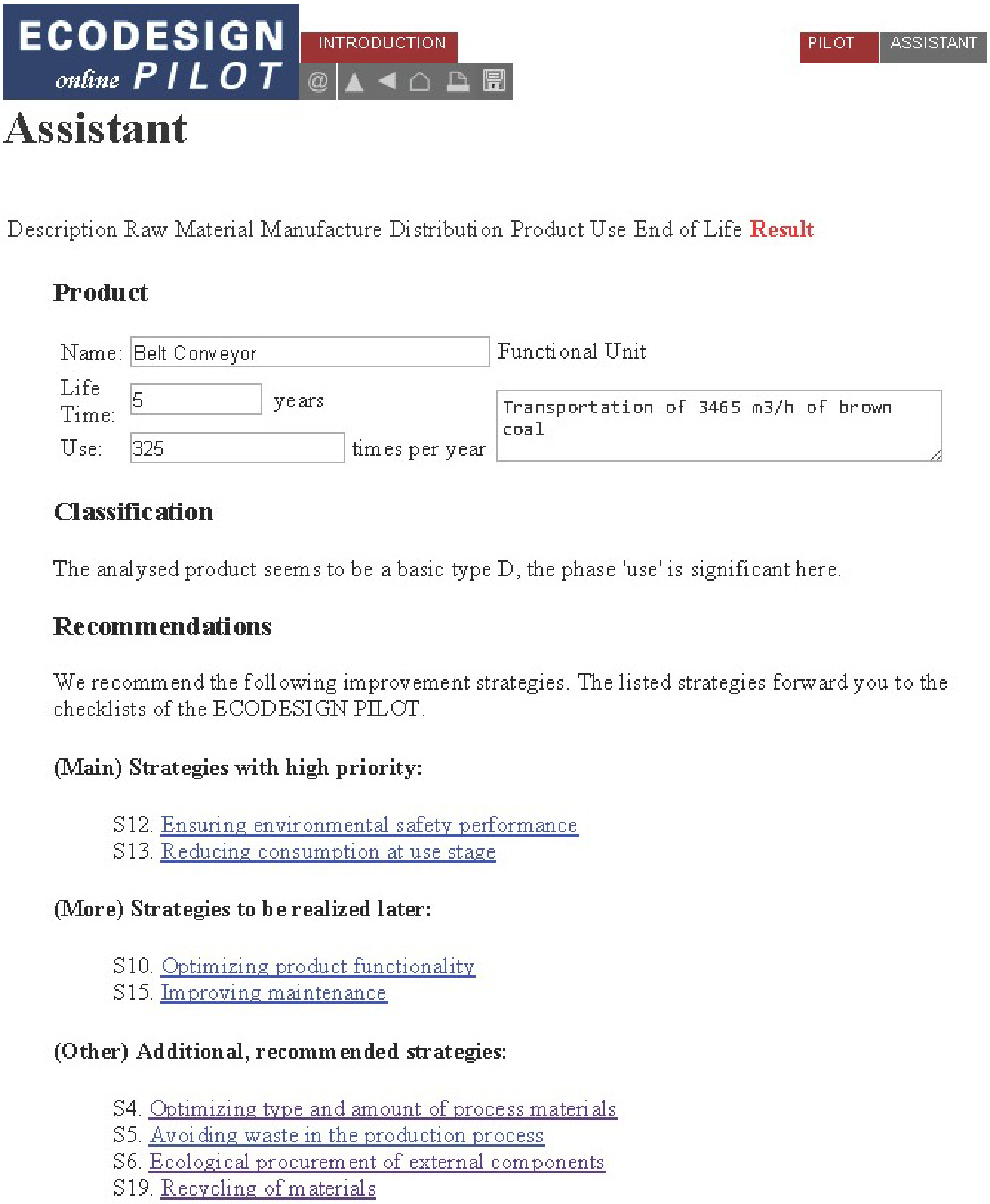
Spare parts and their consumption were not considered during the analysis presented in (Đorđević et al., 2015). This fact will certainly affect the increasing consumption of auxiliary material in the use stage. However, this will not change the result since use stage already has the greatest impact to the environment in accordance with (Đorđević et al., 2015). Spare parts and their consumption affect more the maintenance strategy and service intervals.

The first iteration assumed the worst case scenario for EoL options also. All of the belt conveyor components are disposed of in a landfill.

When lubricants are considered as a parts in raw material stage, at the EoL stage there has to be chosen the way of their disposal.

8.6.5 Result

The belt conveyor is a D-type product. Initial iteration is conducted in a way that results in maximum environmental load. Result of initial iteration is initial result, and it serves as a basis for further environmental improvements of the belt conveyor, refer to Figure 8.12. Further optimization of environmental properties of the belt conveyor are described in (Đorđević et al., 2015). Regardless of variations in input parameter values through iterations the belt conveyor remained use intensive product. Strategy S13 remained the strategy with the highest priority (main), while strategies S10, S12 and S15 had been assigned to the strategies that are to be realized latter (more) and all other strategies disappeared from recommendations due to proper optimization of input parameters that already involved their implementation.



Assistant

Product

Name: Belt Conveyor

Functional Unit: Transportation of 3465 m3/h of brown coal

Life Time: 5 years

Use: 325 times per year

Classification

The analysed product seems to be a basic type D, the phase 'use' is significant here.

Recommendations

We recommend the following improvement strategies. The listed strategies forward you to the checklists of the ECODESIGN PILOT.

(Main) Strategies with high priority:

S12. Ensuring environmental safety performance
S13. Reducing consumption at use stage

(More) Strategies to be realized later:

S10. Optimizing product functionality
S15. Improving maintenance

(Other) Additional, recommended strategies:

S4. Optimizing type and amount of process materials
S5. Avoiding waste in the production process
S6. Ecological procurement of external components
S19. Recycling of materials

Fig. 8.12 The result of the first iteration - initial result (Đorđević et al., 2015)

8.7 ADDITIONAL SIMPLIFIED ANALYSES

8.7.1 Ball Bearing

A simplified LCA of the ball bearing 6310 C3 type has shown that it is a B-type product. Four iterations are conducted during the analysis. These iterations were dealing with different cage materials and considered lubrication in two different life cycle stages. Regardless of input changes throughout iterations, the result form remained the same. Too many production processes such as machining, multiple stages grinding, polishing, washing, cutting, die punching and furnace hardening alongside with use of water-based and oil-based lubricants, kerosene and other process materials result in a manufacturing-intensive product, see Table 8.6.

Table 8.6 Ball bearing parts and most of their production processes and process materials

Product part	Manufacturing process	Process material
Raceways	Machining	
	Grinding	Water-based lubricant
	Polishing	Oil-based lubricant
	Washing	Oil and kerosene
Balls	Steel wire cutting	Oil-based lubricant
	Die-punching	
	Grinding (3÷4 stages)	Water-based lubricant
	Hardening (furnace)	Oil (for quenching)
	Washing	Oil and kerosene
Cage	Die-punching	
	Machining	
Automatic assembly machine	Testing	
	Quality control	
	Laser marking	

Ecodesign PILOT’s improvement strategies are also the same for each iteration.

All of the improvement strategies are primarily focused on the manufacturing stage and thus on reduction of energy consumption in production process and optimizing type and amount of process materials followed by reducing waste and ecological procurement of external components.

Concerning process and auxiliary materials, lubricating oils and greases can be replaced with more environmental friendly lubricants. For example: lubricating grease FOR LPD 2 can be replaced with some sort of environmentally friendly lubricant such as SKF biodegradable, low-toxicity, synthetic ester-based greases using a lithium-calcium thickener. Lubricants with better environmental characteristics will be further explained in Chapter 8.9.

Although the ball bearing belongs to B type products, its production energy, multiplied by the number of ball bearings installed in the belt conveyor, is negligible in comparison with energy consumption of the belt conveyor in use stage. Therefore, this fact will not change the outcome of the conducted analysis described in previous Chapter.

8.7.2 Gearbox

Simplified LCA of the belt conveyor gearbox BKF 320 has shown that it is a raw material intensive product. It is assumed that gearbox oil is changed once a year.

Depending on maintenance and servicing intervals, namely frequency of oil changes, gearbox may become AD hybrid type product. By shortening service intervals (changing oil several times a year) gearbox becomes more use intensive product. The most important improvement strategy is reduction of material inputs. Other recommendations are related to selecting the right materials, reducing consumption and avoidance of waste at use stage, optimizing product use and functionality, etc.

Maintenance and service intervals will be further considered in Chapter 8.9.

The result of this analysis is in compliance with assumptions made in (Đorđević et al., 2015). Even if gearbox becomes D type product it would still be in compliance with analysis of the belt conveyor, which has shown that it is D type product. This way gearbox would contribute in a way that the belt conveyor would be even more use intensive product.

8.7.3 Belting

The second simplified LCA of the belting has shown that it is a raw material intensive product. Difference between the first analysis, presented in paper (Đorđević et al. (b), 2014) and the second analysis was in manufacturing energy input. For the second, more accurate analysis, calculated energy input was 800 kWh of electric energy and 2140 MJ of thermal energy in comparison with energy input of 568 kWh of electric energy and 10700 MJ of thermal energy for the first analysis. Regarding A-type products main improvement strategy is addressed to reducing material inputs. It is followed by several lower priority strategies such as selecting the right materials, optimizing product use and functionality and so on.

This analysis confirmed previously obtained results published in (Đorđević et al. (b), 2014) as well as assumptions made in (Đorđević et al., 2015).

8.8 DISCUSSION

In compliance with current research and published papers it can be said that:

- since EM is a belt conveyor component that contributes most to electricity consumption, just increase in its energy efficiency delivers the greatest reduction of environmental impact,
- adequate maintenance strategy and similar service intervals for different components of the belt conveyor ensure reduction of overhauling time,
- reliability of the belt conveyor is largely dependent on selected maintenance strategy,
- improving functional quality increases reliability, improves maintenance and reduces consumption,
- replacement of process and auxiliary materials, especially lubricants, with renewables contributes to reduction of environmental impact of the product,
- lubricants are marked as hazardous waste and they have to be treated in a proper manner at the EoL; possible improvements related to lubricant characteristics will be considered later,
- in-house recycling eliminates transportation needed in case of external recycling or disposal,
- regionally available parts and materials reduce need for transportation,
- production volume does not affect the result,
- number of external components has greater impact than their hauling distance,
- steel parts are recycled (this applies particularly to the rollers),

- any EoL option for packaging does not affect the result, but it is likely that the euro pallets are reused and the wooden cases are disposed of in a landfill.

These issues will be further elaborated in the next Chapter.

8.9 RECOMENDATIONS

Improvement of environmental properties of the belt conveyor could be achieved through implementation of following recommendations.

Main improvement strategy recommends improving energy efficiency with the goal of lowering operating costs. Energy efficient products lower total primary energy consumption and decrease the life cycle emissions to the environment due to lowered demand on electricity and thus lowered emissions from electricity production. Having that in mind, it is obvious that the most significant component of the BWE belt conveyor is its EM. Therefore, special attention should be paid on improving energy efficiency and environmental performance of EM. Energy efficiency of EM, as a sole electricity consumer, can be increased by properly selecting its class of efficiency and service factor. It is identified that the EM life cycle costs are in about 95% related to energy consumption during its use stage (Langerholc et al., 2013). Therefore, it is reasonable to invest in acquisition of electric motor with efficiency class as high as possible.

Another way to improve energy efficiency is to reduce friction and other resistances to motion, to improve alignment of rotating parts, or by using energy-efficient ball bearings. Higher bearings quality lowers resistances to motion and increases energy efficiency. Reduction of resistances to motion and improvement of functional quality can be achieved through usage of self-adjusted equipment, such as pressure self-regulating plows and cleaners, self-aligning idlers etc.

Maintenance costs of an ECS system are directly related to the selected maintenance concept. Majority of life cycle costs of an ECS include low functional quality, (which is addressed to the low reliability), lost throughput capacity (approximately 50%), environmental impacts, safety risks (ECS failure occurrence), waste material etc. (Pantelić et al., 2011).

Maintenance and reliability of the belt conveyor can be improved by use of protective devices against overload, non-destructive inspection, constant temperature and vibrations monitoring, belt cleaning and belt training devices.

Research conducted on BWE SRs 1201 has shown that its most unreliable subsystem is material handling/conveying system with following failure occurrence rate (Pantelić et al., 2011):

- rollers,
- drive pulley,
- conveyor gearbox,
- EM
- belt cleaning and training devices.

Most of the failures are caused by harsh working conditions and excessive wear and tear.

Rollers are being refurbished in accordance with determined service intervals. In this case refurbishing of rollers assumes an in-house recycling process. About 20% of the annual production of the rollers are refurbished rollers.

Ball bearings are parts that are most often changed as spare parts. They are becoming worn-out mostly because of inadequate lubrication, harsh working condition and improper installation.

When considering selection of lubricant it should be kept in mind that the purpose of lubrication is:

- wear/friction reduction,
- heat dissipation and
- protection against corrosion and environmental influences.

Since lubricants are marked as hazardous waste they have to be treated in a proper manner at the EoL. Replacement of process and auxiliary materials, especially lubricants, with renewables contributes to reduction of environmental impact of the product. In this case conventional lubricants can be replaced with environmentally adapted lubricants (EALs).

EALs are based on biodegradable base fluids with a high degree of renewable content. Lubricants that reduce the environmental impact are generally technically as good as regular ones and fulfil the same requirements. A 60% biodegradation within 10 days is the requirement for readily biodegradable lubricants. Renewability is becoming increasingly important due to worldwide oil depletion. A source is considered renewable if it can be renewed within approximately 100 years. Vegetable oils and synthetic esters are more readily biodegradable than base oils originating from crude oil. Vegetable oils have excellent lubricating properties, are biodegradable and renewable, and are in general low toxic. However, the oxidation stability is low and they have limited cold flow properties (Torbacke et al., 2014).

Lubricants age when being used. This implies that additives are being used and that base oils degrade. In addition, a lubricant may have become contaminated with water, dissolved contaminants or particles. After a while, the lubricant is not suitable in the application and needs to be replaced. However, used lubricant can be re-refined by purification, removal of water, particles and soluble contaminants. Any mineral-based lubricant or industrial oil that is not suitable to be used should be re-refined rather than burned (Torbacke et al., 2014).

Wear and tear of the belting could be reduced by improving belt surface quality grade or investigating new materials with better dirt-repellent and anti-friction properties. This way the belting life is prolonged. Since belting participates with approximately 60% of acquisition costs of complete belt conveyor, this is a good way to achieve costs saving.

Although the belting is being refurbished, its recycling rate depends on detritions of its components. It could be increased by reusing worn rubber parts for production of parts that require lower grade quality rubber. Recycling rate could be increased even more by recycling of belting intended for disposal in a landfill and reusing its ingredient material for less intense use. Finally, if belting carcass could not be otherwise used, it could rather be incinerated for energy recovery, than disposed of in a landfill.

Producers should use component and material coding standards, in concert with material and equipment manufacturers, in particular to facilitate the identification of those components and materials which are suitable for reuse and recovery (Wimmer, 2007). This concept is widely implemented in motor vehicles industry. Most of the belt conveyor parts are made of steel, but there are some exceptions. Belt cleaners are usually equipped with rubber or polymer blades. Special types of rollers could also be predominantly made of some kind of polymer. In such cases material coding standards could be applied.

Energy intensive materials have high energy values (e.g. PA, PU…) and contribute significantly to the environmental impact when used already in small amounts (Wimmer, 2007). In order to improve the product, this kind of materials should be identified and considered for replacement with alternative materials whenever it is possible. In case that product consists of toxic or otherwise problematic substances, they should be clearly labelled and hence adequately handled.

Since the belt conveyor consumes a lot of electric energy, originate of the consumed energy should be considered. There are different kind of energies and they all originate either from fossil fuels or from renewable sources of energy. Most of the electricity produced in the Republic of Serbia is obtained by burning fossil fuels. According to the "Annual report on the environmental situation in the Republic of Serbia for the year 2014" share of fossil fuels in primary energy production was almost 88%. Any change towards more sustainable electricity production is worth an effort. Good example for utilization of renewable sources of energy is Port of Rotterdam. Electricity generated by its own windmill farm reduces its demand on electricity from the grid. Likewise, there could be established local electricity production based on renewable energy sources for the purpose of powering the belt conveyor or complete ECS system.

Although belt conveyor realizes greatest environmental impact in its use stage, following improvements related to production and distribution stages could also be implemented:

- reduction of production facility overall energy consumption can be achieved upon analysis of energy flows and concomitant costs,
- avoiding/reducing waste in production stage and closing loops by in-house recycling or sorting and collecting waste lowers demand on resources, reduces amount and costs of virgin raw material, reduces/eliminates cost of disposal and consequently reduce overall environmental impact,
- recycling of process materials, particularly coolants, lubricants and process water,
- environmental impact in distribution stage, as well as environmental impact of transportation of external parts and components, can be reduced by using alternative fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG), hydrogen fuels, methanol, bio-ethanol, bio-diesel, bio-gas, biomass or use of electric vehicles. Some of these alternative fuels could be used in production stage for some processes in which their utilisation is possible (i.e. using biomass as fuel for heating steam needed for calendering process in belting production),
- etc.

8.10 CONCLUSION

Intralogistics is closely related to conveying technologies. Therefore, investigations and research of potential improvements of environmental properties of belt conveyors, especially energy efficiency, has great impact on future trends in intralogistics. Recently conducted analysis of a complete belt conveyor has shown that the most significant stage of a BWE belt conveyor life cycle is its use stage. Besides EM, consumption of the belt conveyor is determined with different kind of resistances to motion. Improving EM efficiency together with reduction of these resistances contributes to minimization of electricity consumption, reduction of wear of moving parts such as belting surface, prolonging of belt conveyor's life and consequently to sustainable development in general.

Most of the possible improvements of environmental properties of the belt conveyor have been processed in previous Chapter. In accordance with that, conclusion will be focused on review of future research. So far the research involved analyses of idler, drive pulley, belting, EM and summarized simplified analysis of the SRs 1201 BWE's belt conveyor.

Further research should consider generalization which should include:

- most common types of idlers/rollers, normalized by their length and diameter;
- pulleys with different kinds of coatings, normalized by their length and diameter;
- steel cord beltings and beltings with textile reinforcing plies, normalized by their unit of length, belt width and reinforcing plies (in case of beltings with textile reinforcing plies, normalization should be done in accordance with number of reinforcing plies and in case of steel cord beltings, normalization should be done in accordance with steel cord diameter),
- establishment of relation between power and weight of EM and normalization of EM in accordance with its power.

The idea is to implement these generalizations into formal LCA, which will be conducted with SimaPro software. Afterwards, this formal LCA will be used to establish a methodology for analysing and improving environmental properties of short type belt conveyors.

8.11 ACKNOWLEDGMENT

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Chapter 9

Dynamics of transportation machinery

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Abstract

This chapter contribution is oriented toward investigation of horizontal inertial forces imparted to crane load carrying structure during acceleration and deceleration of movable crane parts as well as of the payload and its pendulum motion. In the first part the case of linear motion of the load suspension point is studied and the results are compared toward the standard approach. In the second part the study is executed of the circular motion of the pivot where the spatial swinging of the load appears. A new coefficient for the fast determination of the radial horizontal forces imparted by the payload during rotation of the crane slewing platform is introduced.

Keywords: transport machinery, non-linear dynamic systems, linear and slewing motion, load sway, dynamic loading.

9.1 INTRODUCTION

9.1.1 Outline

Faster, cheaper, more efficient, more green and sustainable are all actual issues in the field of transportation. It is important to point out that economical and green policies have a lot of common goals and can therefore be supportive each to other. To follow these goals the optimization of the transportation chains regarding logistic systems and transportation machinery involved is necessary.

Transport is, namely, one of the human activities which have considerable ecological effects, many of them detrimental to environmental sustainability. It can be divided into transportation of goods by land, sea and air (supply-chain logistics, comprising of inbound and outbound logistics), and internal transportation of goods inside of the factories and warehouses (intralogistics). Both parts are increasing exponentially to fulfil the larger needs due to the rise of population, due to the rise of production, and due to the globalization.

When optimization of the transport machinery regarding the sustainability and carbon footprint is in question the optimization of their transportation cycles, driving means and mass optimization of their mechanisms and overall construction must be considered. Thankfully, the optimization of the machinery regarding the energy efficiency and environmental issues has the same or similar goals - generally the mass of the machine must be reduced. The optimized mass of the structure has commonly direct positive influences on production costs as well as on the energy consumption regarding the production and transportation of raw materials, production of the machinery itself, and exploitation of the machinery, and by all this on the improved sustainability and cost-efficiency.

When considering the transportation machinery in intralogistics, cranes are, because of their complex composition, and large and heavy structure, movable in different ways, one of the most interesting machines. Optimization of their load carrying structure is of a great importance. Besides other the fatigue design and optimization are vital. For this reason the dynamic loading must be predicted in advance.

9.1.2 Literature overview

Cranes and other lifting devices are indispensable links in the transport chain (Vähä & Voutilainen 1988, Feng & Yoo 2005) intended for safe transport of goods from a starting position to a desired position in as short time interval as possible (Vähä & Voutilainen 1988). Dynamic loads are induced to the crane's moving parts, caused by the accelerations, decelerations and rotations. These loads represent an important part of the loading of the crane's steel structure (Abdel-Rahman et al. 2003). The swinging of the payload is the most important contributor to these dynamic loads, making investigations of this phenomenon, which is probably one of the oldest scientific topics (Brzeski et al. 2012), increasingly relevant. Once these dynamic forces are known, however, it is then possible to predict a load spectrum that is the basis for modern fatigue and reliability design.

Published research papers and conference contributions on payload dynamics can be divided into two groups, depending on the nature of the motion investigated. The first group consists of studies dealing with the linear motion of the suspension point (typically for overhead travelling cranes), which produces planar payload swinging (Jerman & Hribar 2013, Zrnić et al. 2009, Zrnić et al. 2010, Zrnić et al. 2011, Gašić et al. 2011, Vladić et al. 2011, Abdel-Rahman et al. 2003, Lee 2004, Oguamanam & Hansen 2001, Bartolini et al. 2002, Yavin & Kemp 2000, Cheng & Chen 1996, Moustafa 1993, Suzuki et al. 1993, Razdol'skii 1989, Lu 1989, Strip 1989, Moustafa & Ebeid 1988, Louda 1998, Louda 1998, Cartmell et al. 1996, Cartmell et al. 1994 and many others: see Abdel-Rahman et al. 2003). The second group deals with the curved motion of the suspension point (typically for slewing cranes performing a slewing motion) and therefore with spatial load swinging (Jerman et al. 2004, Abdel-Rahman et al. 2003, Spathopoulos & Fragopoulos 2004, Glossiotis & Antoniadis 2003, Abdel-Rahman & Nayfeh 2002, Ghigliazza & Holmes 2002, Sawodny 2002, Vähä & Voutilainen 1988, Towarek 1998, Al-Garni et al. 1995, Lau & Low 1994, Wei et al. 1993, Hara et al. 1990, Posiadała et al. 1990, Yoshimoto & Sakawa 1989, Sato & Sakawa 1988, Matthias & Kirsten 1984 a, Matthias & Kirsten 1984 b, Schaufuss 1983, Zareckij 1968, Sedelmayer 1965 a, Sedelmayer 1965 b, Peeken 1964 and others: see Abdel-Rahman et al. 2003).

A division can also be made based on the purpose of the investigation. The majority of contributions deal with control strategies and techniques for load-swing suppression (most of them for linear motion of the load suspension point (Abdel-Rahman et al. 2003, Lee 2004, Oguamanam & Hansen 2001, Bartolini et al. 2002, Yavin & Kemp 2000, Cheng & Chen 1996, Moustafa 1993, Strip 1989, Sawodny 2002, Abdel-Rahman & Nayfeh 2002, Onishi et al. 1982, Lu 1989, Hwang & Shabana 1992, Beliveau et al.

1993, Al-Garni et al. 1995), and fewer for curved motion (Abdel-Rahman et al. 2003, Glossiotis & Antoniadis 2003, Spathopoulos & Fragopoulos 2004, Hara et al. 1990, Vähä & Voutilainen 1988, Moustafa & Ebeid 1988, Sato & Sakawa 1988). The mathematical models, introduced for this purpose, are usually very simplified.

Payload swinging, or its influence on the loading of a crane's steel structure, has not been investigated to the same extent (some papers are Gašić et al. 2012, Jerman et al. 2004, Jerman 2006, Jerman & Kramar 2008, Ghigliazza & Holmes 2002, Wu 2000, Vähä & Voutilainen 1988, Lau & Low 1994, Towarek 1998, Wei et al. 1993, Posiadała et al. 1990, Matthias & Kirsten 1984 a, Matthias & Kirsten 1984 b, Schaufuss 1983, Zareckij 1968, Sedelmayer 1965 a, Sedelmayer 1965 b, Huilgol et al. 1995). The majority of the proposed models are simplified by the introduction of all or some of the following assumptions: small swinging angles, a non-deformable structure for the crane and the load-carrying rope, and the neglecting of non-linear and dissipative effects.

For instance, in the slewing-crane model proposed by Wei et al. (Wei et al. 1993), the following assumptions are made: the crane's steel structure is completely neglected, as are the friction and the material damping; the effects of wind and air resistance are only considered for the payload; the motion of the load's suspension point is predefined and independent of the swinging of the payload; and the zero-mass load-carrying rope is non-extendible. The very same assumptions can be found in the model of the mobile-boom crane proposed by Lau and Low (Lau & Low 1994). Sato and Sakawa (Sato & Sakawa 1988) and Yoshimoto and Sakawa (Yoshimoto & Sakawa 1989) proposed models of a boom crane with an auxiliary jib. Here, the assumptions include the following: only the deformability between the main boom and the auxiliary jib is considered; both jibs are represented by their masses and the inertial moments of the masses; all dissipative effects are neglected, as is the rope's deformability; small angles are assumed for the swinging of the payload as well as for the relative auxiliary jib movement. Similar simplifications can be found in the models of an overhead travelling crane proposed by Moustafa (Moustafa 1993, Moustafa & Ebeid 1988). In both models, the deformability of the crane's structure is neglected and small angles are assumed for the payload swinging angles. In the older model, viscous damping of the motion in both directions in the horizontal plane is considered as well as the spatial nature of the payload pendulation. In the newer model, these two effects are neglected, but the elasticity of the load-carrying rope is introduced.

Simplified models are appropriate for an investigation of the basic facts of the phenomena considered (Ghigliazza & Holmes 2002, Posiadała et al. 1990) and for control purposes, especially if closed-loop techniques are used. On the other hand, a determination of the dynamic loads using a model that is too simple is not reliable enough, and so more complex models must be used.

9.1.3 Contents overview

In this chapter, firstly the horizontal inertial forces imparted by the crane payload in the case of the linear motion of the pivot, typical for gantry cranes and overhead traveling cranes are studied by means of an appropriate mathematical model. The diagram of coefficient of the horizontal inertial forces of a swinging payload mass for different conditions of operation is determined. The developed curves are compared with standard curves and corresponding conclusions and recommendations are drawn. It is find out that in some of the cases the standard curves are not conservative. This topic is introduced in more details in the paper (Jerman & Hribar 2013).

In the second part of the chapter the horizontal inertial forces imparted by the crane payload in the case of the circular motion of the pivot, which is typical for tower cranes and other slewing cranes are studied. Circular motion of the pivot is a result of a slewing motion of the jib around the crane vertical axis. In order to conduct the investigation, a complex non-linear mathematical model of the load sway during the slewing motion was formulated. The dynamic forces acting on the steel structure of the crane during payload transport were obtained. In order to confirm the mathematical model, an actual model of a crane was built and used as the basis for measurements. A comparison of the results shows good agreement between the predicted and the measured values. This topic is introduced also in the paper (Jerman et al. 2004).

When designing a crane’s load-carrying structures, a static analysis is still central to a preliminary determination of the dimensions required. However, to bring the results of these calculations closer to those needed for insurance of an appropriate fatigue life too, different quasi-static procedures are introduced. These procedures take account of various dynamic effects by means of suitable coefficients.

In the third part of this chapter, a new procedure is proposed for determining the maximum horizontal inertial forces in a radial direction that are acting on a load suspended from the jib during a crane’s slewing motion. By means of the previously discussed mathematical model of a general-type slewing crane it was verified that the horizontal inertial forces in the radial direction shouldn’t be regarded with less care than those in tangential direction. Based on these results a new coefficient of radial horizontal inertial force was introduced, and a diagram for the rapid determination of this coefficient was calculated. This topic is discussed also in the paper (Jerman & Kramar 2008).

9.2 THE HORIZONTAL INERTIAL FORCES IMPARTED BY THE CRANE PAYLOAD IN THE CASE OF THE LINEAR MOTION OF THE PIVOT

9.2.1 Overview

In the next paragraph the horizontal inertial forces imparted on the suspended payload during linear motion of the load suspension point are briefly introduced as they are treated in the standard (F.E.M 1.001 1998). Than the mathematical model of a crane payload on the load carrying rope - the pendulum suspended from a moving mass - is introduced and its structure is explained. Further the results of extensive simulations with different crane parameters and different types of deceleration of load suspension point - the pivot - are used for determination of the diagram of coefficient of the horizontal inertial forces of a swinging payload mass. The developed curves are compared with curves from the standard. Finally the findings are discussed. See also (Jerman & Hribar 2013).

9.2.2 The horizontal inertial forces acting on a payload mass

9.2.2.1 *The standard consideration of the horizontal inertial forces*

For covering the horizontal effects of the payload dynamics during linear motion of the pivot the coefficient of horizontal inertial forces ψ_h is introduced in the standard (F.E.M 1.001 1998). Its purpose is fast determination of the maximal horizontal inertial force $F_{h,\max}$ acting due to the load acceleration or deceleration:

$$F_{h,\max} = \psi_h \cdot \overline{F} = \psi_h \cdot m_Q \cdot \overline{a}\,, \tag{9.1}$$

where $\overline{F}$ is the average inertial force, developed during an acceleration or deceleration, and m_Q and $\overline{a}$ are payload mass and the average acceleration/deceleration respectively. For determination of the horizontal inertial effects of masses, which are rigidly connected to the moving crab or crane the equation similar to Eq. 9.1 is used. Instead of coefficient ψ_h the value 2 is used, assuming that maximal acceleration cannot exceed double the value of the average acceleration. Therefore, if the coefficient of horizontal inertial forces of the payload receives the value of $\psi_h = 2$ the maximal expected horizontal inertial force of the suspended load is equal to the force of the rigidly connected mass. If its value is greater or smaller than 2 the influence of the swinging payload is larger or smaller respectively.

For determination of the diagram of the coefficient ψ_h in the standard (F.E.M 1.001 1998) a relatively simple mathematical model of an overhead-travelling crane is used (Fig. 9.1) where the entirely non-deformable crane's structure is assumed, including the non-extendible load carrying rope. The dissipative effects are neglected and small angles φ of the swinging of the payload are assumed. The linear motion of a load suspension point (pivot) is assumed and the breaking phase from a constant velocity of a pivot to the standstill is observed. The system of two second-order differential equations is solved analytically for the case of breaking with the constant breaking force F and the results are introduced in the corresponding diagram where ψ_h is plotted against the coefficient β for different values of coefficient μ. The coefficient β is defined as the ratio between the acceleration time t_1 and the period of oscillation t_Q of the load suspended on the rope looked at as a mathematical pendulum:

$$\beta = \frac{t_1}{t_Q}\,. \tag{9.2}$$

The coefficient μ is defined as the ratio between the payload mass m_Q and the mass m, which is defined as the sum of masses of all the parts that moves together with the pivot (including the inertia effects of the rotating parts of the corresponding driving mechanism):

$$\mu = \frac{m_Q}{m}\,. \tag{9.3}$$

It refers to the influence of the payload sway on the pivot movement. The coefficient μ has (e.g. for overhead travelling cranes) values from almost 0 to around 5. As it can be

seen from the equation (9.3) the zero value is reached when there is almost no load suspended from the rope, which automatically guarantee zero influence. On the other hand the zero influence can also be assumed in the cases where the velocity of the pivot maintains (almost) unchanged regardless of the payload sway.
For the analytically solved system of equations the following rules apply. For the value of $\mu \le 1$, the factor ψ_h can't go beyond the value of 2. This value is reached only in the case when the coefficient β reaches or goes beyond the critical value ($\beta \ge \beta_{crit}(\mu)$). If $\beta \ge \beta_{crit}$ the value of ψ_H should stay constant and equal to 2. For the value of the $\mu > 1$ the value of ψ_h can be greater than 2, if $\beta \ge \beta_{crit}$ and can reach the maximum value, defined with the equation:

$$\psi_h = \sqrt{2 + \mu + \frac{1}{\mu}} \, . \tag{9.4}$$

With increasing value of β the value of ψ_h varies and reaches the maximum repetitively. In the diagram for determination of ψ_H in standard (F.E.M 1.001 1998) the maximum value is kept for all $\beta \ge \beta_{crit}$ (see the dashed curve in Fig. 9.6).

9.2.2.2 *The mathematical model*

For the purpose of consideration of different types of breaking of a pivot (not just breaking with constant force) a new mathematical model of an overhead travelling crane (Fig. 9.1) is developed and the system of two differential equations with two independent coordinates $q_1 = x$ and $q_2 = \varphi$ is solved numerically. In the Fig. 9.1, x represents the horizontal position of the pivot and φ represents the deviation angle of the load carrying rope from the static equilibrium.

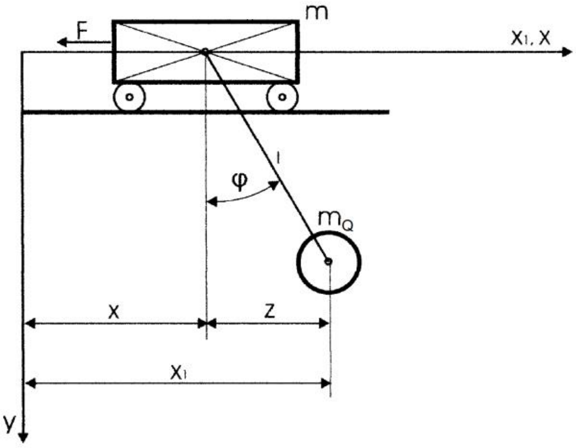


Fig. 9.1 The basic mathematical model (Jerman & Hribar 2013)

To enable the comparison of the results the new model is based on the standard model (F.E.M 1.001 1998) but the assumption of small angles of load sway is withdrawn. The motion of the pivot can be initiated or changed by means of the active force F acting on the movable structure. The model allows for arbitrary definition of the force F, which doesn't have to be constant trough the acceleration or deceleration period. The motion of the pivot can also be predefined as arbitrary time-velocity profile. In this case the coordinate $x = x(t)$ of the pivot is known and is therefore no longer the independent coordinate.

The mathematical model in Fig. 9.1 consists of the point mass m of the movable structure (crab or crane), of the point mass m_Q of the payload and of the non-extendible load carrying rope of the length l. Second-order Lagrange equations (Eq. 9.5) were used for deriving the differential equations of motion:

$$\frac{d}{dt}\left[\frac{\partial T}{\partial \dot{q}_j}\right] - \frac{\partial T}{\partial q_j} + \frac{\partial V}{\partial q_j} = Q_j^n \qquad j = 1, 2\ , \tag{9.5}$$

where j represents the index of generalised independent co-ordinates, T the kinetic energy of the system, V the potential energy of the system, and Q_j^n the (non-conservative) generalized forces. The total kinetic energy T is the sum of the individual contributions of the masses m and m_Q:

$$T = \frac{m \cdot \dot{x}^2}{2} + \frac{m_Q \cdot v_Q^2}{2}, \tag{9.6}$$

where v_Q is the velocity of the mass m_Q ($v_Q = \sqrt{\dot{x}^2 + l^2 \cdot \dot{\varphi}^2 + 2 \cdot l \cdot \dot{x} \cdot \dot{\varphi} \cdot \cos\varphi}$). The potential energy of the system is expressed as follows:

$$V = V_Q = m_Q \cdot g \cdot h, \tag{9.8}$$

where h is the height of the mass m_Q relative to its equilibrium position ($h = l \cdot (1 - \cos\varphi)$). The generalized force of non-conservative active force F is:

$$Q_{x,F} = F\ . \tag{9.10}$$

Following a common procedure and taking Eq. 9.5 into account, the system of two second-order differential equations is derived:

$$(m + m_Q) \cdot \ddot{x} + m_Q \cdot l \cdot \ddot{\varphi} = F\ , \tag{9.11}$$

$$m_Q\ l\ \ddot{x} + m_Q \cdot l^2 \cdot \ddot{\varphi} + m_Q\ l\ g\ \varphi = 0\ . \tag{9.12}$$

For the numerical integration a commercial software package Mathematica was used. Because of in the standard (F.E.M 1.001 1998) only the breaking phase is used for determination of the ψ_H also in this case only the deceleration of the pivot from constant velocity ($\dot{x}$) back to a standstill was simulated, together with observation of the pendulum motion after the pivot was brought to a standstill. The system of equations was solved separately for each of these two phases and the values of the parameters at the end of the preceding phase were used as the initial conditions for the next phase.

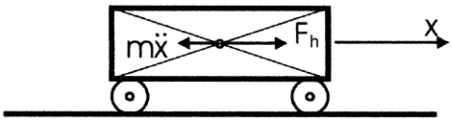


Fig. 9.2 The horizontal force $F_h = F_h(t)$ acts in the pivot point (Jerman & Hribar 2013)

The influence of the swinging payload on the moving pivot (crab or crane) is introduced by means of the force $F_h = F_h(t)$, which is the horizontal component of the force in the load carrying rope. It is defined in Eq. 9.13 and shown in Fig. 9.2.

$$F_h(t) = m_Q(g\cos\varphi(t) + l\dot{\varphi}(t)^2)\sin\varphi(t)\,. \tag{9.13}$$

9.2.2.3 *Determination of the coefficient of horizontal inertial forces*

From the Eq. 9.1, the coefficient of horizontal inertial forces ψ_h can be defined as:

$$\psi_h = \frac{F_{h,\max}}{\overline{F}_h}, \tag{9.14}$$

where $F_{h,\max}$ is the maximal horizontal force of the payload acting on the pivot and where the average horizontal force is defined as $\overline{F}_h = m_1 \cdot a_{av}$. These forces are defined for different deceleration types, using the developed mathematical model. On the other hand these forces are in standard (F.E.M 1.001 1998) defined as:

$$\overline{F}_h = F \cdot \frac{m_Q}{m + m_Q}, \tag{9.15}$$

$$F_{h,\max} = \overline{F}_h \cdot \sqrt{(1 - \cos(\omega_r\, t_d))^2 + \frac{\omega_r^2}{\omega_1^2} \cdot \sin^2(\omega_r\, t_d)}\,, \tag{9.16}$$

where the following transcendent equation is solved:

$$(\omega_r\, t_d) + \mu \cdot \sin(\omega_r\, t_d) - 2\pi\beta\sqrt{1+\mu} = 0\,, \tag{9.17}$$

to determine the product $(\omega_r\, t_d)$. When $(\omega_r\, t_d) \geq \pi$, the maximal horizontal force $F_{h,\max}$ appears during the deceleration and on the other hand, it appears after that, when the pivot is in the standstill.

9.2.2.4 *Determination of the coefficient of horizontal inertial forces*

First of all the case of breaking with the constant force ($F = F_m = const$) which is presumed in the standard was considered (Fig 9.3a) and was used for verification of the proposed mathematical model. This case represents the real world breaking with breaks, producing constant breaking moment.

Besides that also the following cases were considered which all have their real world application. The case with constant acceleration and deceleration ("a=const") of the load suspension point (Fig. 9.3b), the case with the linearly increasing/decreasing acceleration/deceleration ("a=linear") (Fig. 9.4a), and the case with the linearly increasing/decreasing driving/breaking force ("F=linear") (Fig. 9.4b).

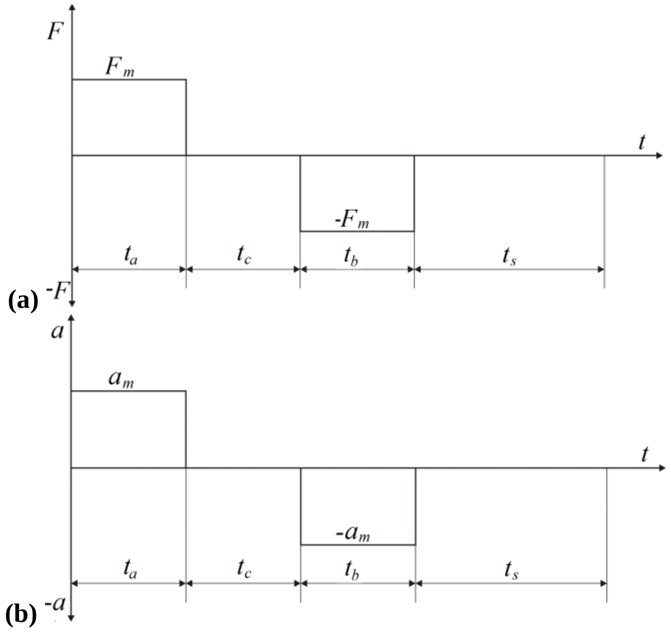


Fig. 9.3 Acceleration and breaking with (a) constant force (“F=const”) and (b) constant acceleration (“a=const”), (Jerman & Hribar 2013)

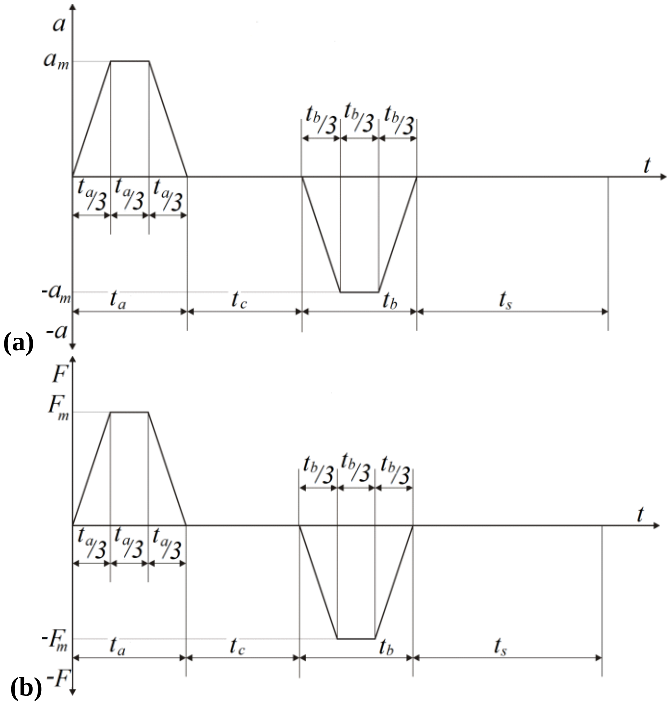


Fig. 9.4 Acceleration and breaking with (a) linearly variable acceleration (“a=linear”) and (b) linearly variable force (“F=linear”), (Jerman & Hribar 2013)

9.2.2.5 T*he coefficient of horizontal inertial forces*

Using results of the numerical simulations for different acceleration types (defined in 2.2.4) and different operating conditions, and the Eq. 9.14., the diagrams of the coefficient of horizontal inertial forces ψ_h were constructed (see Figs. 9.5, 9.6 and 9.7).

In Fig. 9.5 the curves of different types of breaking are shown, all for $\mu = 0$ to enable the comparison. The curve for "F=const" is close to the solution from the standard (F.E.M 1.001 1998). It is obvious that the course of the curve for the acceleration scheme with constant acceleration (a=const) is more favourable than the standard one whereas the cases with linearly changeable acceleration and force (a=linear, F=linear) give a higher values for ψ_H than they can be predicted from the standard. The standard prediction is exceeded for up to 28 %.

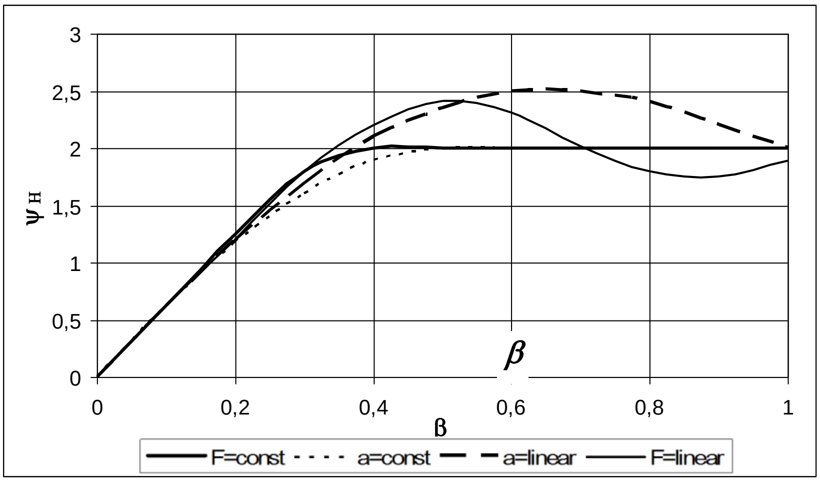


Fig. 9.5 The coefficient ψ_H for $\mu = 0$ and of different types of breaking (Jerman & Hribar 2013)

In Fig. 9.6 the curves for "F=const" and for different ratios $\mu \neq 0$ are shown. It is determined that for this type of accelerations and decelerations the standard values are covering all the studied variants. Exact matching of the standard and simulated curves in the first part of the diagram as well as the matching of the calculated peeks with the standard constant values in the other part of the diagram is the basis for verification of the mathematical model.

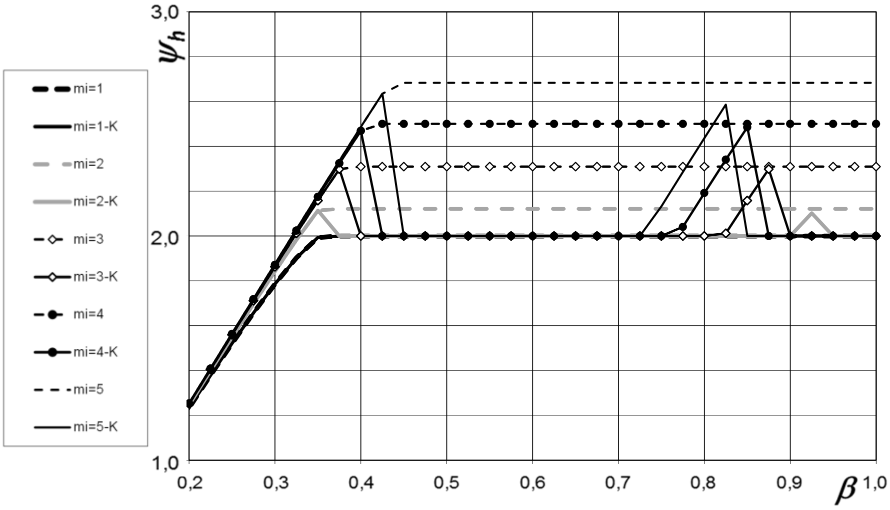


Fig. 9.6 The coefficient ψ_H for breaking with constant force F for different values of μ (in the legend, μ is denoted as "mi"). The standard curves are dashed (Jerman & Hribar 2013)

In Fig. 9.7 the curves for “F=linear” and for different ratios $\mu \neq 0$ are shown. It is clear that for this type of accelerations and decelerations the standard values for ψ_H (dashed lines) can be exceeded for ratios $\mu \leq 2$, whereas for ratios $\mu \geq 3$ the standard curves are on the safe side. The standard prediction is exceeded for up to 21 %.

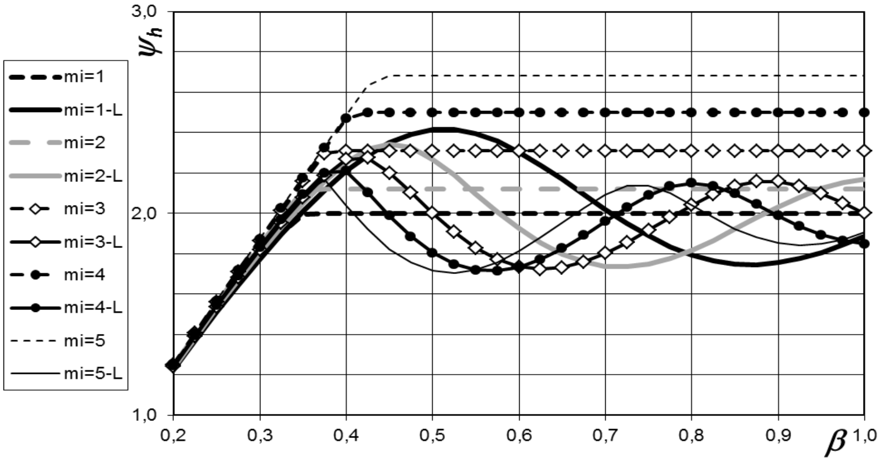


Fig. 9.7 The coefficient ψ_H for breaking with linearly changeable force F for different values of μ (in the legend, μ is denoted as “mi”). The standard curves are dashed (Jerman & Hribar 2013)

9.2.3 Conclusion

An investigation of the horizontal inertial forces imparted to the payload during deceleration of the linear motion of the moving mass with suspended load is conducted for different deceleration types and the results are compared with the standard approach. The mathematical model of a moving mass with the suspended load was derived based on the standard model but without limitations regarding small angles of the load sway. The standard deceleration type and three additional types of breaking were considered. The results show that the course of the deceleration has strong influence on the horizontal inertial force imposed by the suspended payload. For the purpose of the verification of the derived mathematical model the breaking with the constant force was simulated for ratios $\mu = 0$ and $\mu > 0$. Numerically determined curves of the coefficient of horizontal inertial forces ψ_h are matching the standard curves where this is appropriate. In this way the derived mathematical model was verified and used for the further study. In the case of constant deceleration the values of ψ_h are equal to or smaller than the values from standard. In other two investigated cases the coefficient of horizontal inertial forces ψ_H is, for some intervals of ratios β and μ, higher than corresponding standard values. The standard prediction is exceeded for up to 28 %. This implies that the horizontal inertial loads produced by the sway of the payload can be bigger than those predicted by standard. Consequently, the more careful consideration of these loads in engineering practice is suggested.

9.3 THE HORIZONTAL INERTIAL FORCES IMPARTED BY THE CRANE PAYLOAD IN THE CASE OF THE CIRCULAR MOTION OF THE PIVOT

9.3.1 Overview

Slewing cranes are widely used in ports and on big ships for the transfer of containers and bulk materials (Vähä & Voutilainen 1988); they are also common in civil engineering for the transport of building materials and in some other applications. For this reason, a study of these types of cranes and possible improvements to their performance is a study with a real-life application. A particularly important are slewing cranes with longer jibs, where there are major problems associated with the control of the swinging payload during the slewing motion (Lau & Low 1994). For the crane operator, it is especially hard to estimate the amount of payload swinging in the direction of the jib, in the vertical plane containing the jib (Sawodny 2002).

The operation of slewing cranes involves three main motions: the slewing motion of the jib around the vertical axis, the radial movement of the load suspension point (crab movement or luffing of the jib) and hoisting of the load (lifting or lowering). One form of motion that has received little attention so far has been the slewing motion of a crane during which the spatial motion of the suspended load is introduced (Onishi et al. 1982). In this chapter we have looked in more detail at this motion. See also paper (Jerman et al. 2004).

Because of for the determination of the dynamic loads a more complex model must be used, a new mathematical model is proposed, that takes into account the elasticity and material damping in the crane's structure and in the load-carrying rope. The air resistances on the rotating jib and on the payload are also considered, as is the non-linearity of the slewing motion's power transmission, including the friction in the main slewing bearing. The proposed mathematical model has no restriction with regard to small angles of load sway therefore allows us to study the crane's behaviour under both normal and extreme conditions, and the influence of these different conditions on the loading of the steel structure can be obtained. The latest reports suggest that more complex non-linear crane models will also be used for control purposes (Abdel-Rahman et al. 2003). Finally, the influence of a particular property of the crane can be excluded by choosing the appropriate input data. By doing so, the influence of that particular property on the results of the simulation can be estimated.

The velocity time profile of the rotating velocity $\dot{\varphi}_1$ of a driving shaft was used as an input to the model. This is suitable for the simulation of cases where the velocity of the driving motor during acceleration and deceleration is controlled (for instance, by a frequency controller) and for investigating the influence of different (also extreme) inputs (acceleration and braking) on the system's output. The model does not, however, consider external disturbances like the wind or flexible foundation effects.

In the following subsection, the proposed mathematical model is described and the equations of motion are derived. In next subsection, the physical model is introduced. Further, the results acquired by means of the simulation and by making measurements on the physical model are reported, and a comparison of these results in the time domain is introduced. The last section lists the major conclusions.

9.3.2 The mathematical model

9.3.2.1 *Assumptions*

For the slewing cranes considered, a non-linear mathematical model of the load sway during the slewing motion was set up (Fig. 9.8), based on the following assumptions:

a) masses: the moment of inertia of the rotating platform and/or tower together with the crane mechanisms attached to it (including the counterweight and a part of the jib) are represented by the moment of inertia J_1; the corresponding part of the mass of the jib and the mass of the crab (or sheave) are represented by the point mass m_2. Because of the load carrying rope in the model is mass-less, the influence of rope's mass on the overall dynamics is approximated in such a way that the mass of the upper half of the free length of the payload-carrying rope ($L_0/2$) is also added to the mass m_2; the net payload mass and the mass of the load-handling device are represented by the point mass m_3. The mass of the lower half of the free length of the payload-carrying rope ($L_0/2$) is also added to the mass m_3, for the reason explained above;

b) the elements connecting the masses are weightless. Their stiffness and damping (Lazan 1968) are represented as follows: the properties of the connecting elements between the motor shaft and the rotating platform in terms of torsion (around the z-axis) are represented by the stiffness characteristics k_1 and damping characteristics d_1. Both of them are non-linear; the torsion stiffness of the rotating platform (or tower) and the bending stiffness of the jib, both around the *z* axis, are represented by the stiffness coefficient k_2. These influences are combined together because both of them contribute to the shift of the mass m_2 in *y* direction of the local co-ordinate system *xyz*. The damping characteristic of the considered elements are represented with damping coefficient d_2 ; the stiffness of the rotating platform (or tower) in terms of bending around the *y* axis and the stiffness of the jib in terms of the tensile deformation in *x* direction are represented by the stiffness coefficient k_x. These influences are combined together because both of them contribute to the shift of the mass m_2 in *x* direction of the local co-ordinate system *xyz*. The damping characteristic of the discussed parts are represented with damping coefficient d_x; the stiffness of the rotating platform (or tower) in terms of the tensile deformation in the *z* direction and the stiffness of the jib in terms of the bending around the *y* axis are represented by the stiffness coefficient k_z. These influences are combined together because both of them contribute to the shift of the mass m_2 in *z* direction of the local co-ordinate system *xyz*. The damping characteristic of the discussed parts are represented with damping coefficient d_z; the stiffness of the payload-carrying rope in terms of the tensile deformation along the rope length is represented by the stiffness coefficient k_L and it's damping characteristic by the coefficient d_L;

c) the velocity time profile of the rotating velocity $\dot{\varphi}_1$ of the driving shaft is used as a system input;

d) the friction in the slewing ring is represented by the moment of friction M_{SL};

e) the air resistance is represented by the forces acting on the point masses m_2 and m_3.

For an easier mathematical description, three co-ordinate systems are introduced (Fig. 9.8):

a) the global inertial co-ordinate system *XYZ*;

b) the local co-ordinate system *xyz*, which rotates together with the jib. The vertical axis *z* coincides with the vertical axis *Z* of the global *XYZ* co-ordinate system;

c) the origin of the local co-ordinate system $\xi\eta\zeta$ is placed into the mass suspension point. The co-ordinates ξ, η and ζ are parallel to the corresponding co-ordinates *x*, *y* and *z*.

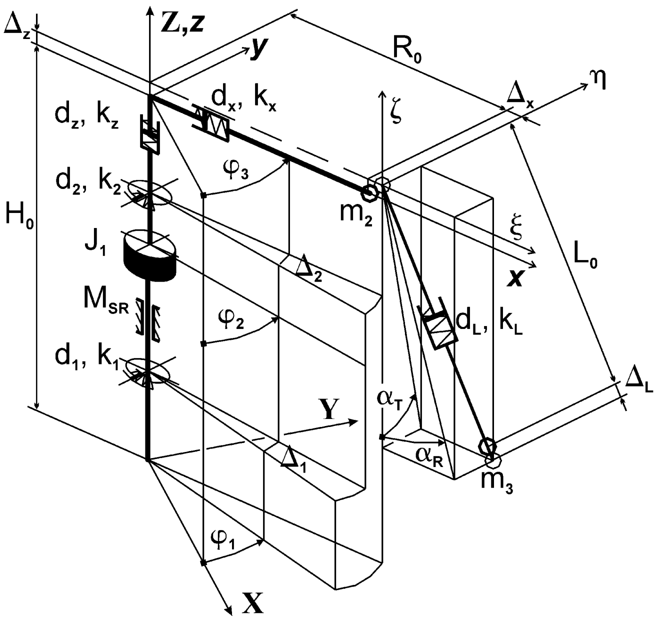


Fig. 9.8 The mathematical model of the slewing crane ($m_3 \equiv m_Q$), (Jerman et al. 2004)

9.3.2.2 *Equations of motion*

Second-order Lagrange equations were used for deriving the differential equations of motion. The generalized forces Q_j can be divided into the forces Q_j^k , originated form the conservative forces, and the forces Q_j' , originated from the non-conservative forces. The influence of the conservative forces can be expressed by means of the system's potential energy *V*. By using these possibilities, the following form of the Lagrange equations can be written:

$$\frac{d}{dt}\left[\frac{\partial T}{\partial \dot{q}_j}\right] - \frac{\partial T}{\partial q_j} + \frac{\partial V}{\partial q_j} = Q'_j \qquad j = 1, \ldots, s. \tag{9.18}$$

In Eq. (9.18), *s* represents the number of generalised independent co-ordinates. For the successful use of Lagrange's equations the correct generalised independent co-ordinates must be chosen:

$$q_1 = \varphi_2 = (\varphi_1 + \Delta_1), \tag{9.19}$$

$$q_2 = \varphi_3 = (\varphi_2 + \Delta_2), \tag{9.20}$$

$$q_3 = R = (R_0 + \Delta_x), \tag{9.21}$$

$$q_4 = H = (H_0 + \Delta_z), \tag{9.22}$$

$$q_5 = \xi = L \cdot \sin\alpha_R = (L_0 + \Delta_L) \cdot \sin\alpha_R, \tag{9.23}$$

$$q_6 = \eta = L \cdot \cos\alpha_R \cdot \sin\alpha_T = (L_0 + \Delta_L) \cdot \cos\alpha_R \cdot \sin\alpha_T, \tag{9.24}$$

$$q_7 = \zeta = -L \cdot \cos\alpha_R \cdot \cos\alpha_T = -(L_0 + \Delta_L) \cdot \cos\alpha_R \cdot \cos\alpha_T. \tag{9.25}$$

The next step is the definition of the velocities of all the masses by means of selected independent coordinates. The moment of inertia J_1 is rotating with angular velocity $\dot\varphi_2$. The velocities of the point masses m_2 and m_3 must be represented in the global *XYZ* frame. First, the positions for these two points must be determined:

$$X_2=R\cdot\cos\varphi_3, \tag{9.26}$$

$$Y_2=R\cdot\sin\varphi_3, \tag{9.27}$$

$$Z_2=H, \tag{9.28}$$

$$X_3=(R+\xi)\cdot\cos\varphi_3-\eta\cdot\sin\varphi_3\ , \tag{9.29}$$

$$Y_3=(R+\xi)\cdot\sin\varphi_3+\eta\cdot\cos\varphi_3\ , \tag{9.30}$$

$$Z_3=H+\zeta\ . \tag{9.31}$$

The associated velocities are the time derivatives of the positions:

$$\dot X_2=\dot R\cdot\cos\varphi_3-R\cdot\dot\varphi_3\cdot\sin\varphi_3, \tag{9.32}$$

$$\dot Y_2=\dot R\cdot\sin\varphi_3+R\cdot\dot\varphi_3\cdot\cos\varphi_3, \tag{9.33}$$

$$\dot Z_2=\dot H, \tag{9.34}$$

$$\dot X_3=(\dot R+\dot\xi)\cdot\cos\varphi_3-\dot\varphi_3\cdot[(R+\xi)\cdot\sin\varphi_3+\eta\cdot\cos\varphi_3]-\dot\eta\cdot\sin\varphi_3, \tag{9.35}$$

$$\dot{\mathrm{Y}}_3=(\dot{\mathrm{R}}+\dot\xi)\cdot\sin\varphi_3+\dot\varphi_3\cdot[(\mathrm{R}+\xi)\cdot\cos\varphi_3-\eta\cdot\sin\varphi_3]+\dot\eta\cdot\cos\varphi_3\ , \tag{9.36}$$

$$\dot Z_3=\dot H+\dot\zeta\ . \tag{9.37}$$

The absolute velocity is the vector sum of the components:

$$v_2^2=\dot X_2^2+\dot Y_2^2+\dot Z_2^2, \tag{9.38}$$

$$v_2^2=\dot R^2+R^2\dot\varphi_3^2+\dot H^2, \tag{9.39}$$

$$v_3^2=\dot X_3^2+\dot Y_3^2+\dot Z_3^2, \tag{9.40}$$

$$\begin{aligned}v_3^2=&(\dot R+\dot\xi)^2+\left[(R+\xi)^2+\eta^2\right]\dot\varphi_3^2+\dot\eta^2-\\&-2\eta(\dot R+\dot\xi)\dot\varphi_3+2\dot\eta(R+\xi)\dot\varphi_3+(\dot H+\dot\zeta)^2\end{aligned} \tag{9.41}$$

As can be seen from Eq. (9.18), the total kinetic energy *T* must be defined. This is the sum of the individual contributions of the masses J_1, m_2 and m_3:

$$T=\sum_{i=1}^{3}T_i=T_1+T_2+T_3\ . \tag{9.42}$$

The components are defined as follows:

$$T_1=\tfrac{1}{2}J_1\dot\varphi_2^2, \tag{9.43}$$

$$T_2=\tfrac{1}{2}m_2v_2^2=\tfrac{1}{2}m_2(\dot R^2+\dot\varphi_3^2R^2+\dot H^2), \tag{9.44}$$

$$\begin{aligned}T_3=\tfrac{1}{2}m_3v_3^2=\ &\tfrac{1}{2}m_3\Big\{\dot\varphi_3^2\cdot\left[(R+\xi)^2+\eta^2\right]+\dot R^2+\dot H^2+\dot\xi^2+\dot\eta^2+\dot\zeta^2+\\&+\dot\varphi_3\dot R\cdot[-2\eta]+\dot\varphi_3\dot\xi\cdot[-2\eta]+\dot\varphi_3\dot\eta\cdot[2(R+\xi)]+2\dot R\dot\xi+2\dot H\dot\zeta\Big\}\end{aligned}\ . \tag{9.45}$$

The potential energy of the system is also required. This is the sum of the contributions of the potential terms:

$$V=V^{m2}+V^{m3}+V^{k1}+V^{k2}+V^{kx}+V^{kz}+V^{kL}\ . \tag{9.46}$$

The potential energy is expressed by means of generalised independent co-ordinates, as follows:

$$\begin{aligned} V=g[m_2 H+m_3(H+\zeta)]+\tfrac{1}{2}[k_1(\varphi_2-\varphi_1)^2+k_2(\varphi_3-\varphi_2)^2+ \\ +k_x(R-R_0)^2+k_z(H-H_0)^2+k_L\{\xi^2+\eta^2+\zeta^2-2L_0(\xi^2+\eta^2+\zeta^2)^{\frac{1}{2}}+L_0^2\}] \end{aligned} \tag{9.47}$$

The generalized, non-conservative, dissipative and possible active forces (Q_j') are defined through their virtual work δA:

$$\delta A=\delta A^{fr}+\delta A^{d}+\delta A^{ar}\ , \tag{9.48}$$

where the individual components represent the influence of friction forces, the damping of members and the air resistance. The dissipative effects of friction in the bearings are encountered via the friction in the slewing ring. The components of virtual work are defined as below:

$$\delta A^{fr}\ =\ -M_{SR}\cdot\delta_{\varphi 2}\,, \tag{9.49}$$

$$\delta A^{d}=-\{d_1\dot{\Delta}_1\delta_{\Delta 1}+d_2\dot{\Delta}_2\delta_{\Delta 2}+d_x\dot{\Delta}_x\delta_{\Delta x}+d_z\dot{\Delta}_z\delta_{\Delta z}+d_L\dot{\Delta}_L\delta_{\Delta L}\}\,, \tag{9.50}$$

$$\delta A^{ar}=\ \delta A^{ar2}\ +\ \delta A^{ar3}\,, \tag{9.51}$$

$$\delta A^{ar2}=-\left[d^{x}_{ar2}v_2\dot{R}\right]\delta_R-\left[d^{y}_{ar2}v_2\dot{\varphi}_3R^2\right]\delta_{\varphi 3}-\left[d^{z}_{ar2}v_2\dot{H}\right]\delta_H\,, \tag{9.52}$$

$$\delta A^{ar3}\ =-d_{ar3}v_3\left[\dot{X}_3\delta_{X3}+\dot{Y}_3\delta_{Y3}+\dot{Z}_3\delta_{Z3}\right]. \tag{9.53}$$

On the right side of each of the Eqs. (9.49)-(9.53), there is a term representing the dissipative force (or moment) multiplied with a virtual displacement of an infinitesimal size. These equations must be rewritten in terms of the generalized coordinates and the generalized virtual displacements, where appropriate. From the equations arranged in this manner, individual non-zero components of the generalized forces can be obtained as the coefficients near the corresponding virtual displacements. For instance, the Eq. (9.54) is derived from the Eq. (9.49) where the coefficient near the virtual displacement $\delta_{\varphi 2}$ is the friction moment in the slewing ring M_{SR}. The same inference leads to the Eqs. (9.55)-(9.70).

$$Q_1^{fr}\ =-M_{SR}{}^{\text{a)}}\,, \tag{9.54}$$

a)… Q_1^{fr} *is always in the opposite direction to the motion of the rotating platform* ($\dot{\varphi}_2$).

$$Q_1^{d}\ =-d_1(\dot{\varphi}_2-\dot{\varphi}_1)\ +\ d_2(\dot{\varphi}_3-\dot{\varphi}_2)\}\,, \tag{9.55}$$

$$Q_2^{d}\ =-d_2(\dot{\varphi}_3-\dot{\varphi}_2)\,, \tag{9.56}$$

$$Q_3^{d}=-d_x\dot{R}\,, \tag{9.57}$$

$$Q_4^{d}=-d_z\dot{H}\ , \tag{9.58}$$

$$Q_5^{d}\ =-d_L\tfrac{1}{L^2}(\xi\dot{\xi}+\eta\dot{\eta}+\zeta\dot{\zeta})\xi\ , \tag{9.59}$$

$$Q_6^{d}\ =-d_L\tfrac{1}{L^2}(\xi\dot{\xi}+\eta\dot{\eta}+\zeta\dot{\zeta})\eta\}\,, \tag{9.60}$$

$$Q_7^{d}\ =-d_L\tfrac{1}{L^2}(\xi\dot{\xi}+\eta\dot{\eta}+\zeta\dot{\zeta})\zeta\ , \tag{9.61}$$

$$Q_2^{ar2}\ =-d^{y}_{ar2}v_2\dot{\varphi}_3R^2\,, \tag{9.62}$$

$$Q_3^{ar2}\ =\ -d^{x}_{ar2}v_2\dot{R}\,, \tag{9.63}$$

$$Q_4^{ar2} = -d_{ar2}^{z} v_2 \dot{H} \,, \tag{9.64}$$

$$Q_2^{\,ar3} = -d_{ar3} v_3 \{\dot{\varphi}_3[(R+\xi)^2+\eta^2]+\dot{\eta}(R+\xi)-\dot{R}\eta-\dot{\xi}\eta\} \,, \tag{9.65}$$

$$Q_3^{\,ar3} = -d_{ar3} v_3 \{\dot{R}+\dot{\xi}-\dot{\varphi}_3\eta\} \,, \tag{9.66}$$

$$Q_4^{\,ar3} = -d_{ar3} v_3 \{\dot{H}+\dot{\zeta}\} \,, \tag{9.67}$$

$$Q_5^{\,ar3} = -d_{ar3} v_3 \{\dot{R}+\dot{\xi}-\dot{\varphi}_3\eta\} \,, \tag{9.68}$$

$$Q_6^{\,ar3} = -d_{ar3} v_3 \{\dot{\varphi}_3(R+\xi)+\dot{\eta}\} \,, \tag{9.69}$$

$$Q_7^{\,ar3} = -d_{ar3} v_3 \{\dot{H}+\dot{\zeta}\} \,. \tag{9.70}$$

The generalized non-conservative forces (Q'_j) are defined as the sum of the contributions:

$$Q_j{}' = Q_j^{fr}+Q_j^{d}+Q_j^{ar2}+Q_j^{ar3} \qquad \text{for } j=1,\ ...,\ s \ . \tag{9.71}$$

They are representing the dissipative effects in the mathematical model. There is one generalised force for each degree of freedom of the model.

The components introduced above (by the Eqs. (9.42), (9.46) and (9.71)) must be adequately treated and the derivatives (where appropriate) must be calculated. Now the corresponding expressions can be substituted into Eq. (9.18). After rearranging the equation, the system of differential equations of motion of the studied mathematical model is derived. This system can be presented in the matrix form:

$$\begin{bmatrix} J_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & R^2 m_2 + R_3^2 m_3 & -\eta m_3 & 0 & -\eta m_3 & x m_3 & 0 \\ 0 & -\eta m_3 & m_2+m_3 & 0 & m_3 & 0 & 0 \\ 0 & 0 & 0 & m_2+m_3 & 0 & 0 & m_3 \\ 0 & -\eta m_3 & m_3 & 0 & m_3 & 0 & 0 \\ 0 & m_3 x & 0 & 0 & 0 & m_3 & 0 \\ 0 & 0 & 0 & m_3 & 0 & 0 & m_3 \end{bmatrix} \cdot \begin{bmatrix} \ddot{\varphi}_2 \\ \ddot{\varphi}_3 \\ \ddot{R} \\ \ddot{H} \\ \ddot{\xi} \\ \ddot{\eta} \\ \ddot{\zeta} \end{bmatrix} = \begin{bmatrix} A_{10} \\ A_{20} \\ A_{30} \\ A_{40} \\ A_{50} \\ A_{60} \\ A_{70} \end{bmatrix} , \tag{9.72}$$

where vector components A$_{j0}$ are defined as follows:

$$A_{10} = -d_1(\dot{\varphi}_2 - [\dot{\varphi}_1]) + d_2(\dot{\varphi}_3 - \dot{\varphi}_2) - k_1(\varphi_2 - [\varphi_1]) + k_2(\varphi_3 - \varphi_2) - M_{SR} \quad ^{a),\,b)} \tag{9.73}$$

$^{a)}$…sign for M_{SR} is minus for $\dot{\varphi}_2 \geq 0$ and plus for $\dot{\varphi}_2 \leq 0$.

$^{b)}$…[φ_1] is in brackets to indicate its predefinition (it is not an generalised independent co-ordinate).

$$\begin{aligned} A_{20} = & -d_2(\dot{\varphi}_3 - \dot{\varphi}_2) - d_{ar2}^{y} v_2 \dot{\varphi}_3 R^2 + d_{ar3} v_3 \{-\dot{\varphi}_3 R_3^2 - \dot{\eta} x + \dot{R}\eta + \dot{\xi}\eta\} - \\ & - 2m_2 R\dot{R}\dot{\varphi}_3 - 2m_3\dot{\varphi}_3(x\dot{x} + \eta\dot{\eta}) - k_2(\varphi_3 - \varphi_2) \end{aligned} \tag{9.74}$$

$$\begin{aligned} A_{30} = & -d_x \dot{R} - d_{ar2}^{x} v_2 \dot{R} - d_{ar3} v_3 \{\dot{x} - \dot{\varphi}_3\eta\} + m_3\dot{\eta}\dot{\varphi}_3 + \\ & + m_2 R\dot{\varphi}_3^2 + m_3[\dot{\varphi}_3^2 x + \dot{\varphi}_3\dot{\eta}] - k_x(R - R_0) \end{aligned} \tag{9.75}$$

$$A_{40} = -d_z\dot{H} - d_{ar2}^{z} v_2 \dot{H} - d_{ar3} v_3 \{\dot{H} + \dot{\zeta}\} - g[m_2 + m_3] - k_z(H - H_0) \tag{9.76}$$

$$A_{50}=-\frac{d_L}{L^2}\xi\chi-d_{ar3}v_3\{\dot{x}-\dot{\varphi}_3\eta\}+m_3[\dot{\varphi}_3^2x+2\dot{\varphi}_3\dot{\eta}]-k_L\xi\left[1-\frac{L_0}{L}\right] \tag{9.77}$$

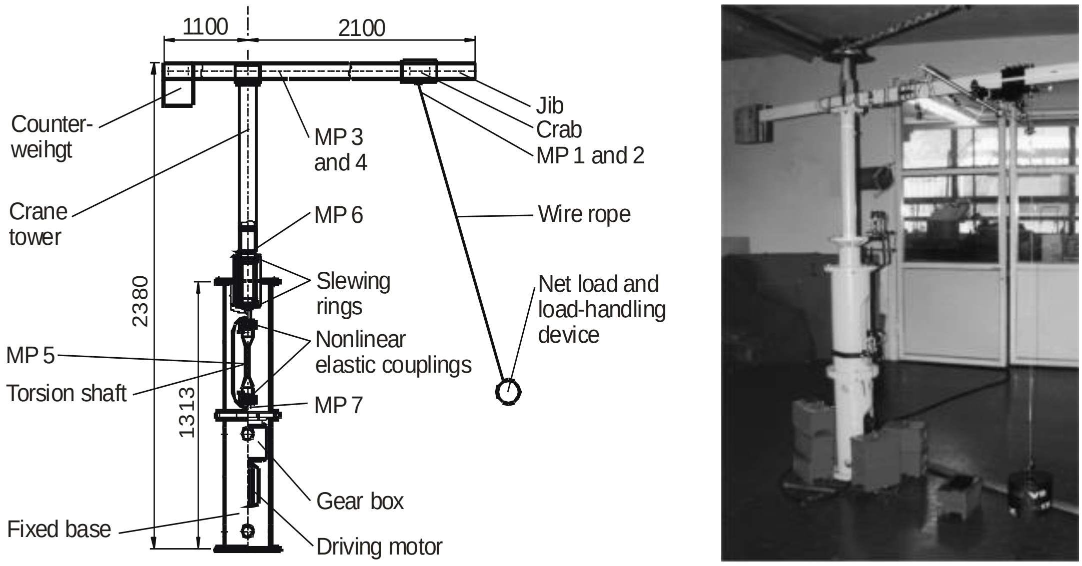
$$A_{60}=-\frac{d_L}{L^2}\eta\chi-d_{ar3}v_3\{\dot{\varphi}_3x+\dot{\eta}\}+m_3[\dot{\varphi}_3^2\eta-2\dot{\varphi}_3\dot{R}-2\dot{\varphi}_3\dot{\xi}]-k_L\eta\left[1-\frac{L_0}{L}\right] \tag{9.78}$$

$$A_{70}=-\frac{d_L}{L^2}\zeta\chi-d_{ar3}v_3\{\dot{H}+\dot{\zeta}\}-g\,m_3-k_L\zeta\left[1-\frac{L_0}{L}\right] \tag{9.79}$$

Eq. (9.72) represents a system of seven non-linear differential equations with non-constant coefficients. A system like this can be solved numerically by using the Runge-Kutta method. Software has been written in C++ to do the task in order to enable the future research of control algorithms based on this model.

9.3.3 The physical model

In order to confirm the mathematical model, a physical model of a crane was built (Fig. 9.9). A three-phase squirrel-cage electric motor was used as the driving motor, and a frequency controller was used to regulate the rotation velocity of the motor, to ensure the prescribed shape of the input (e.g. Fig. 9.10). The frequency controller was operated with a computer.



(a) (b)

Fig. 9.9 A sketch (a) and a photograph (b) of the physical model of a general-type slewing crane. The points where the measurements were carried out are marked with MP (Jerman et al. 2004)

The seven different quantities were measured during the model operation. The radial and tangential angle (α_R and α_T in Fig. 9.8) of the pendulum motion were measured using two inductive transducers (LVDT), with one end mounted on the wire rope and the other on the crab (MP 1 and 2 in Fig. 9.9a). The bending moments on the jib, around the *y*-axis (in the vertical plane *xz*) and around the *z*-axis (in the horizontal *xy* plane) were measured using strain gauges placed on the jib (MP 3 and 4). In addition, the torsion moment on the torsion shaft was measured with strain gauges (MP 5 on the torsion shaft). The angles of rotation of the driving shaft (MP 7) and of the slewing platform (MP 6) were measured with incremental rotary encoders. The measured quantities were amplified, digitised and recorded with a computer. The data were processed with the LabView program.

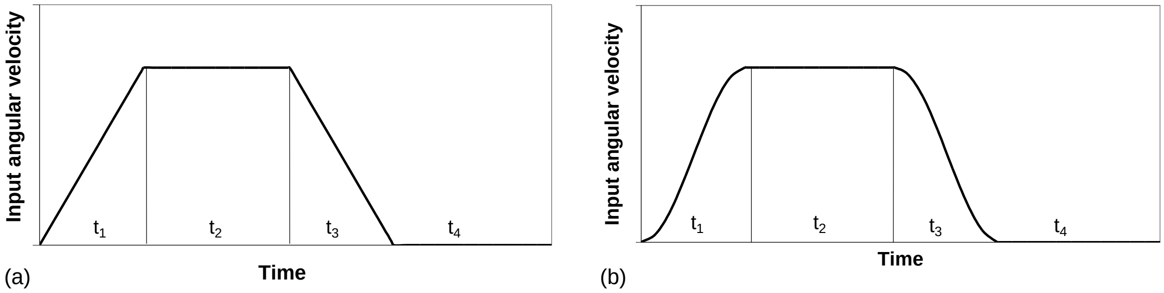


Fig. 9.10 Two profiles of the input angular velocity of the driving shaft. In case (a), the changes of the input velocity are linear (constant acceleration), and in the second case the changes are sinusoidal (co-sinusoidal acceleration shape), (Jerman et al. 2004)

9.3.4 Results

For the simulations, the mathematical model (Fig. 9.8) introduced in section 3.2 was used, and for the measurements, the physical model (Fig. 9.9) from section 3.3 was used. To allow a comparison between these two models, the input data from the physical model were employed for the simulation.

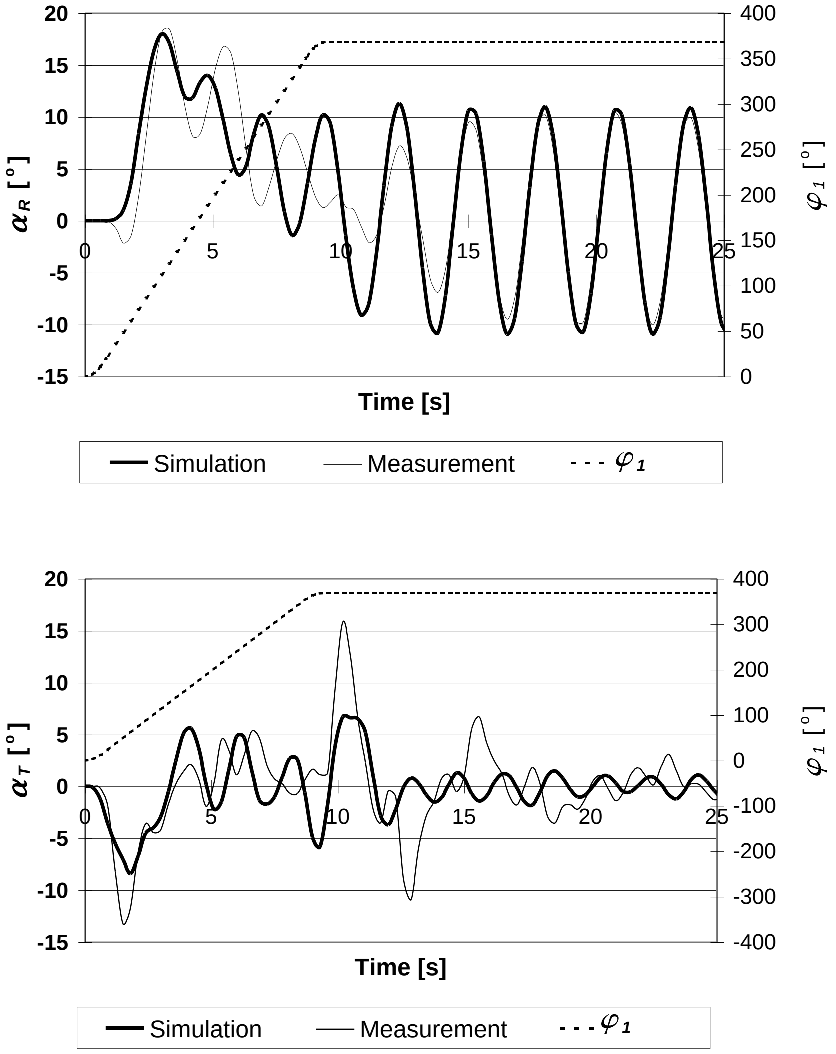
The simulations and the measurements were carried out with a range of load masses (m_Q = 20 to 50 *kg*), different radii of the suspension point (R_0 = 1 to 2 *m*), and different lengths of the load-carrying rope (L_0 = 0.5 to 2 *m*). The effects of various types of acceleration and deceleration on the trajectory of the suspended load were also studied (Fig. 9.10), including the changes to the acceleration time and average acceleration. 44 different combinations of input data were investigated.

A printout of the simulation includes the data relating to the rotation of the jib and about the oscillation of the suspended load. The dynamic forces acting on the steel structure of the crane during the transport of a load were also obtained. The results from the physical model were obtained from the measurements of seven different quantities, as described in section 3.3 (see also Fig. 9.9). The sample results of the simulation and the measurements are shown in Figs. 9.11 - 9.16.

9.3.5 Comparison of the simulated and measured results

Simulations and measurements for many different combinations of parameters and types of acceleration were carried out. In this section results are shown for the following cycle, denoted as Example 1: a constant acceleration of 1.039 rad/s^2 from zero to a maximum rotating velocity of 0.738 *rad/s,* constant rotation with this velocity for 8 *s*, and then a constant deceleration back to zero. An acceleration time can be calculated from this data: t_1 = 0.7103 *s*. Some of the additional data used in the simulation are as follows: load mass, m_Q = 50 *kg*; height of the considered part of the crane's tower, H_0 = 1.14 *m*; radius of the suspension point, R_0 = 2 *m;* and length of the load-carrying rope, L_0 = 2 *m*. The period of oscillation of the suspended payload, looked at as a mathematical pendulum, can be calculated, t_Q = 2.837 *s*.

The pendulum motion of a suspended load can be seen from the graphs in Fig. 9.11, where $\boldsymbol{\alpha_R}$ is the radial angle and $\boldsymbol{\alpha_T}$ is the tangential angle of the swinging pendulum. The graph representing the angle of rotation of the driving shaft φ_1 is also shown. From this graph, the phases of the input angular velocity $\dot{\varphi}_1(t)$ can be seen (acceleration, deceleration, etc., see Fig. 9.10). This is plotted on the subsequent graphs too, allowing the reader to compare the values of the observed quantity with respect to the angular position of the driving shaft.



(a)

(b)

Fig. 9.11 Radial (α_R) and tangential (α_T) angles of the load sway with respect to time. The secondary scale has the values of the angle of rotation of the driving shaft (φ_1), (Jerman et al. 2004)

The load sway in the radial direction (Fig. 9.11a), denoted by the radial angle (α_R), is initiated by the centrifugal force, which is caused by the angular velocity. In the first moment, an apparent shift of the payload in the radial direction is encountered (negative values of α_R). This is the result of the movement (rotation) of the local co-ordinate system $\xi\eta\zeta$, the origin of which is located at the mass suspension point. This effect is more noticeable for the measured curve than for the simulated one. The reason is due to the acceleration of rotation of the slewing platform ($\ddot{\varphi}_2$) in the measured case: the start of the platform's rotation (see Fig. 9.12) involves more of a shock than is the case with the simulation, and the effect of the payload's lag is more apparent. The peak value of the radial angle (α_R) is achieved after the acceleration phase. The comparison shows that the simulated peak value of the radial angle is about 2.4 % lower than the measured one. The negative peak value turns up after the deceleration, when rotation stops. In this case, the difference is 9.2 %.

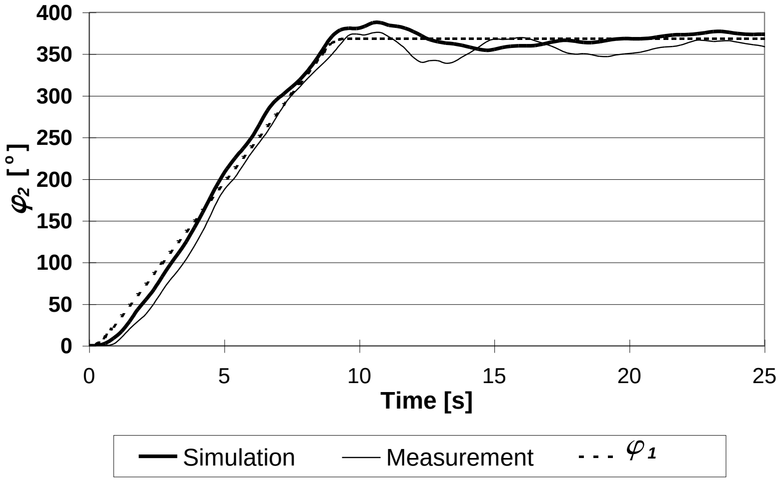


Fig. 9.12 Angle of rotation of the slewing platform (φ_2) with the jib. The values of the (simulated) angle of rotation of the driving shaft (φ_1) are also shown (Jerman et al. 2004)

The tangential angle (α_T) of the load sway (Fig. 9.11b) can be compared with the in-plane load sway under conditions of linear motion of the suspension point. In the acceleration phase, a degree of payload lag can be observed (negative values of α_T). The maximum lag is observed immediately after this phase. The simulated value of the lag is approximately 36.5 % smaller than the measured one. The phase of moving with a constant velocity is denoted by oscillations whose mean value is close to the static equilibrium. In the deceleration phase the payload is forestalling the suspension point, and finally, after the rotation stops, damped oscillations develop around the static equilibrium. The maximum positive peak value is encountered at that time. The simulated value of this peak is 57.7 % smaller than the measured one. From the graph, it is clear that the qualitative matching of the simulated and measured values is good. The quantitative differences are greater during and after the deceleration phase, because the initial values of the payload's swinging angles at the beginning of the deceleration phase are different for the mathematical and physical models. The time difference between the start of deceleration phase in the simulated and measured cases is noticeable in Fig. 9.12.

Fig. 9.13 shows plots of the simulated (theoretical) and measured (achieved in reality) angles of rotation of the driving shaft φ_1 with respect to time. The differences between the theoretical and the real curves are mainly the consequence of the characteristic of the electric motor with frequency controller, not being included in the model. The maximal difference is 4.2 %.

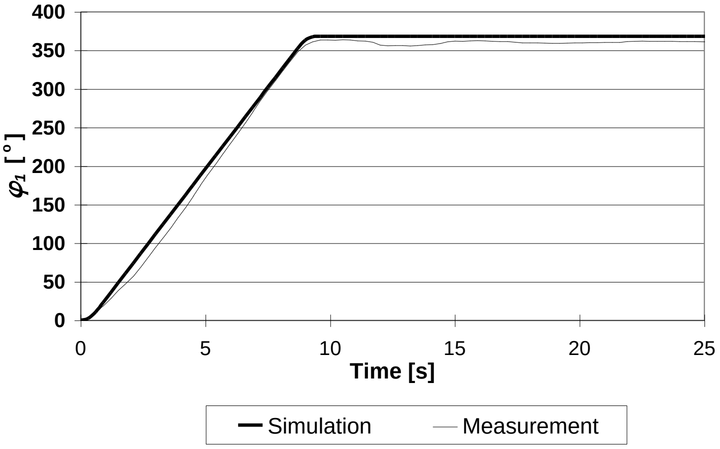


Fig. 9.13 Angle of rotation of the driving shaft (φ_1), (Jerman et al. 2004)

The bending moment in the jib around the z-axis (M_h) and the torsion moment in the driving shaft (M_t) are shown in Figs. 9.14 and 9.15. The values for both moments are, as expected, similar. A comparison of the simulated and measured curves shows good agreement. The deviation of the highest negative peak, immediately after the acceleration phase, is smaller than 5.3 % for both moments and the deviation of the highest positive peak, right after the deceleration phase is less than 17.2 % for both moments.

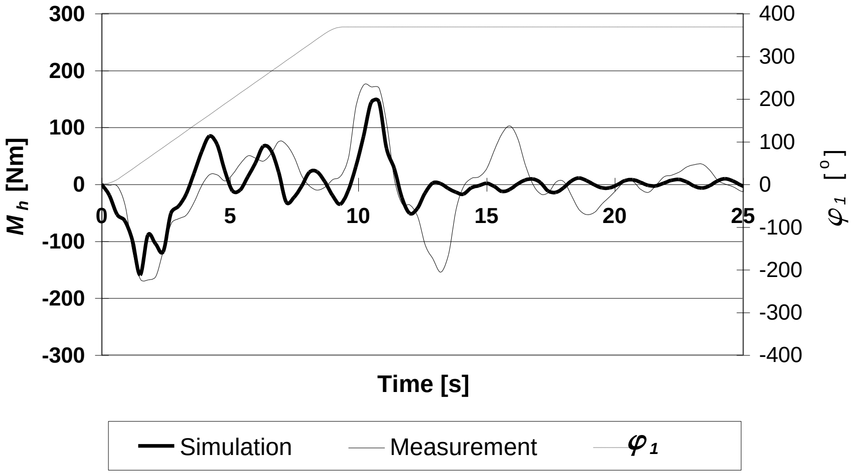


Fig. 9.14 Bending moment in the jib around the z-axis (M_h), (Jerman et al. 2004)

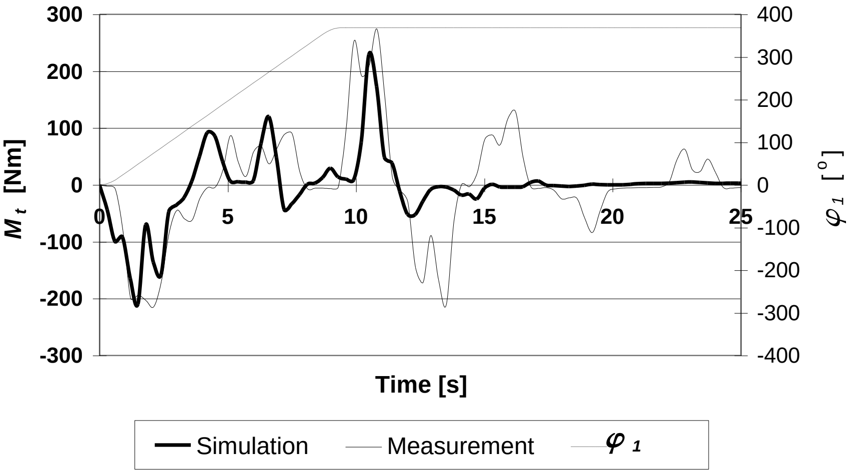


Fig. 9.15 Torsion moment in the driving shaft (M_t) (Jerman et al. 2004)

The bending moment in the jib around the y-axis (M_v) is shown in Fig. 9.16. This moment is a consequence of the payload's weight, and its time dependency is caused by the load's spatial swing (α_R and α_T). A comparison shows noticeable differences in the values of the moments only during the acceleration and deceleration phases. This is in accordance with the differences in the tangential angle of the load sway (α_T) at that particular time. However, the maximum difference is less than 9.3 %.

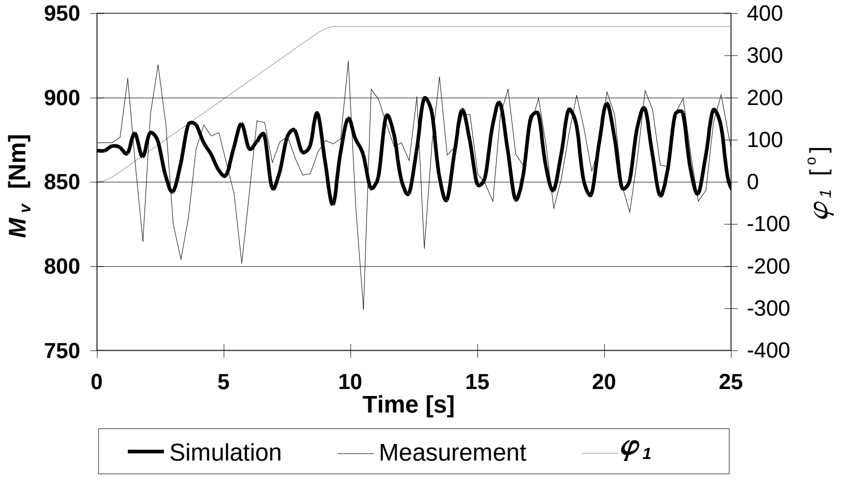


Fig. 9.16 Bending moment in the jib around the y-axis (M_v), (Jerman et al. 2004)

For a detailed comparison, the results were transferred to the frequency domain using the fast Fourier transformation (FFT). The obtained power spectra for the individual quantities were plotted in pairs (simulated and measured) on separate graphs. Because they are of most interest, the power spectra of the angles of load sway (α_R and α_T) were selected and corresponding graphs were plotted. The agreement of the compared power spectra for the radial angle (α_R) is very good. For the power spectra of the tangential angle (α_T) a qualitative matching shows good agreement, although the differences in the quantitative matching are more significant. The frequency domain comparison is introduced in more details in (Jerman et al. 2004).

9.3.6 Conclusion

A detailed study was carried out of the swinging of a load suspended from the jib of a general-type slewing crane because this form of swinging is an important source of dynamic forces in a slewing crane. Lagrange equations were used to derive the equations of motion, and a computer program was developed to solve these equations.

The derived mathematical model has no restriction in terms of small angles of load sway. This enables the study of the crane’s behaviour under extreme conditions, too. So the influence of such conditions on the loading of the steel structure can be obtained. In addition, the effect of different (extreme) inputs (acceleration and braking) on load sway can be tested.

The mathematical model was checked by means of measurements on the physical model. A comparison of the results in the time and frequency domains was carried out. The results were much closer in the time domain during acceleration than during deceleration. This is because the real and calculated initial conditions are equivalent for the acceleration, but just approximately equivalent for the deceleration. The comparison of the measured and simulated results in the frequency domain confirmed the good qualitative agreement of the results, and allows for a detailed study of the differences.

Important steps were executed by deriving and verifying the presented non-linear mathematical model. In the future, this mathematical model should be used for analysing the real-world cranes. Because the latest reports suggest that also for control purposes more complex non-linear crane models will be used, the proposed mathematical model also has potentials in this area.

9.4. THE COEFICIENT OF RADIAL HORIZONTAL INERTIAL FORCES

9.4.1 Overview

In the design of a crane's load-carrying structures, a static analysis is still of great importance. And it is especially convenient for a preliminary determination of a structure’s dimensions, which must then be tested for fatigue, buckling and other severe phenomena, including a check of the general stability. Because the basic static calculations do not include any of the effects of dynamic loading, the results of such an analysis are not practical enough. For this reason, so-called quasi-static calculations, which take into account the effects of dynamic loading, are used in actual standards (F.E.M 1.001 1998, SIST EN 13001-2 2005). Such an approach brings the results of calculations closer to reality.

These standards account for several dynamic effects. One of them is an increase in the force that appears in the rope during the lifting of a load. The effect of the “wheel skewing" of the crab or crane, where the horizontal forces normal to the rails are applied is also considered, as is the buffer effect in the event of a collision of the moving crane with an end buffer, and in the case of a collision of the payload with a fixed obstruction. Some of the effects of the inertial forces imparted to the moving parts, including the payload's dynamics, as one of the more important sources of the dynamic loading, are treated too. The case of linear motion of the load suspension point is treated in more detail, whereas the case of the slewing motion is not investigated to the same extent.

In this chapter, the horizontal inertial forces imparted to the load during a slewing motion are studied precisely. For the analysis, a previously described mathematical model of the general-type slewing crane was used (see chapter 3.2 and Jerman et al. 2004 b) and extensive simulations were performed. The results are introduced in sections 4.4 - 4.6. The main focus is on the forces acting in a radial direction, but some interesting results for the forces acting in a tangential direction are also described. A new coefficient for the radial horizontal inertial forces is introduced and the diagram for determining this coefficient is calculated (see also Jerman & Kramar 2008). Using the diagram a rapid prediction of the maximum radial forces is made possible.

9.4.2 Treatment of the horizontal inertial forces in accordance with the standard

The treatment of the horizontal inertial forces in accordance with the standard (F.E.M 1.001 1998) is briefly introduced in this section because some of the coefficients from the standard are used for the description of the newly developed procedures.

9.4.2.1 *The horizontal inertial forces acting in a tangential direction (standard)*

To cover the dynamics of the payload in (F.E.M 1.001 1998) the coefficient of the horizontal inertial forces ψ_h is introduced for a rapid determination of the maximum horizontal inertial force acting as a result of the load's acceleration or deceleration (Eq. 9.1).

In order to determine the coefficient ψ_h a simple mathematical model of an overhead-travelling crane is used, introduced in chapter 2.2.1. The model assumes a totally non-deformable crane structure. Dissipative effects are also excluded. The linear motion of the load's suspension point is observed, and the results are introduced in the corresponding diagram where ψ_h is plotted against the coefficient β for different values of the coefficient μ. The coefficient β is defined as the ratio between the acceleration time t_1 and the oscillating period t_Q of the load suspended on the rope (Eq. 9.2).

The coefficient μ is defined as the ratio between the load mass m_Q and the mass m, which moves together with the load's suspension point (the mass of the crab or the total mass of the overhead-travelling crane, including, where necessary, the mass equivalent of the rotary inertia of the driving motor's rotor and of the mechanisms). See (Eq. 9.3). It describes the influence of the sway of the payload on the movement of the suspension point, and with that on the movement of the whole crab or crane.

The coefficient μ normally has values from 0 to 5 for overhead-travelling cranes. As can be seen from equation (9.3), the zero value is reached when there is no load suspended from the rope, which automatically guarantees zero influence on the movement of the suspension point. On the other hand, the same zero influence is achieved within the so-called "systems with regulated acceleration", where the magnitudes of the accelerations and decelerations are kept constant, regardless of the external influences. Such conditions can be easily simulated with an appropriate mathematical model using input data that ensures the rigidity of the structure and prescribing, in advance, the time-velocity profile of the movement of the crane.

In the case of the model used in the standard, only the structure is assumed to be rigid, while a deceleration of the crab from a constant linear velocity to a standstill is caused by an applied force of constant magnitude. Because of that, with values of the load mass greater than zero, values of μ greater than zero can also be obtained.

In the case of a slewing motion of the slewing crane it is assumed in the standard (F.E.M 1.001 1998) that the same coefficient ψ_h can be used to determine the maximum horizontal inertial force acting in a tangential direction to the load suspension point's trajectory, as is used for the linear motion. In this chapter it will be for the case of slewing motion, denoted as ψ_{hT}:

$$F_{hT,\max} = \psi_{hT} \cdot \overline{F}_T = \psi_{hT} \cdot m_Q \cdot R_0 \cdot \overline{\alpha}\,, \tag{9.80}$$

where the average tangential force developed during an acceleration or deceleration is defined as $\overline{F}_T = m_Q \cdot R_0 \cdot \overline{\alpha}$. In the equation, R_0 represents the radius of the suspension point (see Fig. 9.8) and $\overline{\alpha}$ represents the average angular acceleration.

4.2.2 *The horizontal inertial forces acting in a radial direction (standard)*

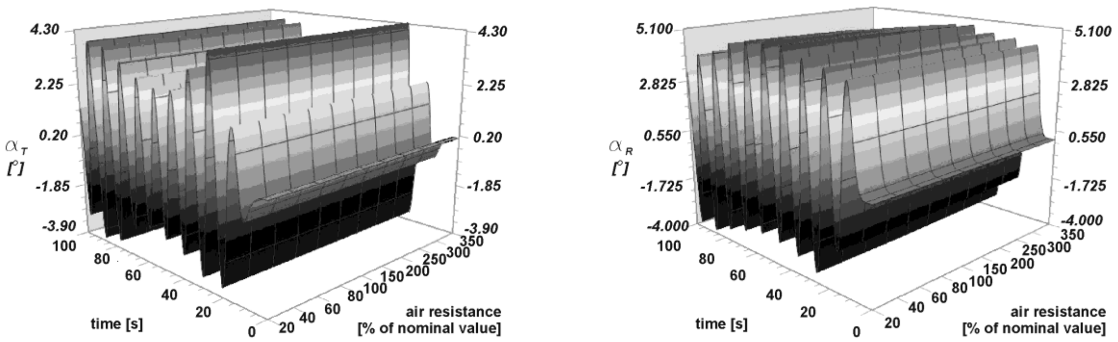
For the horizontal inertial force in the radial direction it is assumed that the part that should be combined with the established maximum tangential force is of the same magnitude as the nominal centrifugal force $F_{C.nom}$, which would be imparted in the case when the payload rotates with constant maximum angular velocity ω:

$$F_{C.nom} = m_Q \cdot R_0 \cdot \omega^2\,. \tag{9.81}$$

9.4.3 The assessment of the inertial forces acting on the suspended load

In this section the horizontal inertial forces imparted to the load in the case of the slewing motion are studied in more detail. For the analysis, a previously developed mathematical model of a general-type slewing crane (Jerman et al. 2004) is used (see section 3). The deformations of the crane’s structure were set close to zero and the dissipative effects were neglected with the application of the corresponding input data (the values of the stiffness coefficients were enlarged by a factor of 10000 and the damping and air resistance coefficients were set to zero). These assumptions were necessary because of the complexity of the investigated phenomena and on the other hand neglecting of these effects is presumed in standard procedure as well. In order to examine the influence of the deformability of the structure on the resulting inertial forces, additional analyses were performed with realistic input data (including the deformability), and the estimations are briefly introduced later in this section.

The dissipative effects are commonly the stabilizing factor which decreases the dynamic response of the structure. The influences of these effects on the motion of the suspended load were proven to be small for commonly used slewing cranes and their common performances by means of extensive simulations. The input data for the simulations were taken from a real world slewing cranes.



(a) Tangential (α_T) angle of the load sway with respect to time for different values of air resistance.

(b) Radial (α_R) angle of the load sway with respect to time for different values of air resistance.

Fig. 9.17 Angles of the load sway for an example of a real-world crane with respect to time and with to different values of air resistance (Jerman et al. 2008)

Sample graphs are shown in Fig. 9.17, where the angles of the load sway are shown with respect to time and with respect to 10 different values of air resistance in the span from 20 % to 350 % of the nominal value. The basic data used for this simulation are: the nominal velocity of the rotation is 0.8 revolutions in a minute, the position of the load suspension point R=30 m, the rope length is 24 m, the mass of the cylindrically shaped payload is 3300 kg and the area of the payload's silhouette is 3 m^2. The greatest difference in angles of the load sway with respect to the nominal curve is, for all the observed cases and for the described diapason of the air resistance, fewer than 8.5 % and for the example shown is fewer than 5 %.

Similar graphs could be shown for the simulations where the influence of the variation of the damping in the construction and in the driving mechanism (from 20 % to 350%) was observed. The clear influence on the vibration of the load suspension point (the centre of mass m_2 in Fig. 9.8) was estimated whereas the further influence on the swinging of the payload (m_3) was much less evident. In the considered cases the greatest difference in angles with respect to the nominal curve never exceeded 9.5 % and is for the introduced example fewer than 4 %.

The velocity-time profile of the rotation of the crane's platform (in the model from section 3) is prescribed in advance therefore no direct influence of the pendulum's motion of the load on the rotation is possible, and consequently the case with a zero value of μ can be assumed.

It is assumed that the values of the horizontal inertial forces F_{hR} and F_{hT} acting on the load suspended from a crane on the load-carrying rope in the radial and tangential directions are proportional to the angles of inclination of that rope from the vertical position in these directions, as presented in equations (9.82) and (9.83):

$$F_{hR} = (m_Q \cdot g) \cdot \tan(\alpha_R)\,, \tag{9.82}$$

$$F_{hT} = (m_Q \cdot g) \cdot \tan(\alpha_T)\,. \tag{9.83}$$

Because the maximum values of these forces that can appear during the crane's rotation are of the main interest, the following part of the crane's transport cycle was observed: the start of the rotation of the crane's arm from zero to the maximum angular velocity under constant acceleration, and then rotation with constant angular velocity for a time interval long enough to allow the maximum force to be detected.

The results of the simulations include the positions of all the masses in the model, the swinging angles of the load-carrying rope, and the forces and moments appearing in the spring and the damping elements of the model (see Jerman et al. 2004) with respect to time. Additional results include the maximum values of the radial and tangential inertial forces and the times associated with these maxima.

The results for the forces acting in the tangential direction are briefly introduced; however, the focus is on the forces acting in the radial direction. It is verified that the radial forces are of no less importance (no smaller in terms of their magnitude) than the tangential forces, and that their maximum values can easily be a few times greater than the nominal centrifugal force.

9.4.4 The horizontal inertial forces acting in a tangential direction (simulations)

When analysing the tangential horizontal inertial forces in the case of rotation, two different cases were taken into account. Firstly, the standard assumption (F.E.M 1.001 1998) of the equivalency of the tangential horizontal inertial forces in the case of rotation with horizontal inertial forces in the case of linear motion of the suspension point was verified in such a way that the non-deformable (rigid) crane structure was assumed and the obtained results were compared with the standard curve. As can be seen from the diagram in Fig. 9.18, the calculated points are very close to the standard curve.

Secondly, as a preliminary research only, the influence of the deformability of the crane's structure was taken into consideration, because the (standard) assumption of a rigid structure is much more realistic for overhead-travelling cranes and portal cranes than for slewing cranes (considered in this investigation). In this case, higher values of ψ_{hT} were obtained (see Fig. 9.18), which imply higher values of the maximum tangential horizontal inertial forces (in accordance with Eq. 9.1).

The following explanation was disclosed. When the deformability of the slewing crane's construction is considered, the pendulum motion of the load (m_3 on the Fig. 9.8) has a substantial influence on the motion of the mass m_2 located in the load suspension point. Because of that the assumption of a zero value of μ is no longer valid in spite of the fact that the velocity-time profile of the rotation of the motor (and the crane's tower) is prescribed. For higher values of μ also in standard (F.E.M 1.001 1998) a higher values of ψ_{hT} are defined and they reach the maximal value $\psi_{hT} = 2.68$ for the highest included coefficient $\mu = 5$.

This explanation covers only a part of a gap between the standard curves and calculated coefficient ψ_{hT} for the deformable crane's structure shown in Fig. 9.18. The reason for the other part of a gap can be searched in the non-consideration of the dissipative effects and in the particularities connected with the slewing motion. For this step an extensive simulations (with included dissipative effects) and measurements are necessary which is beyond the scope of this work.

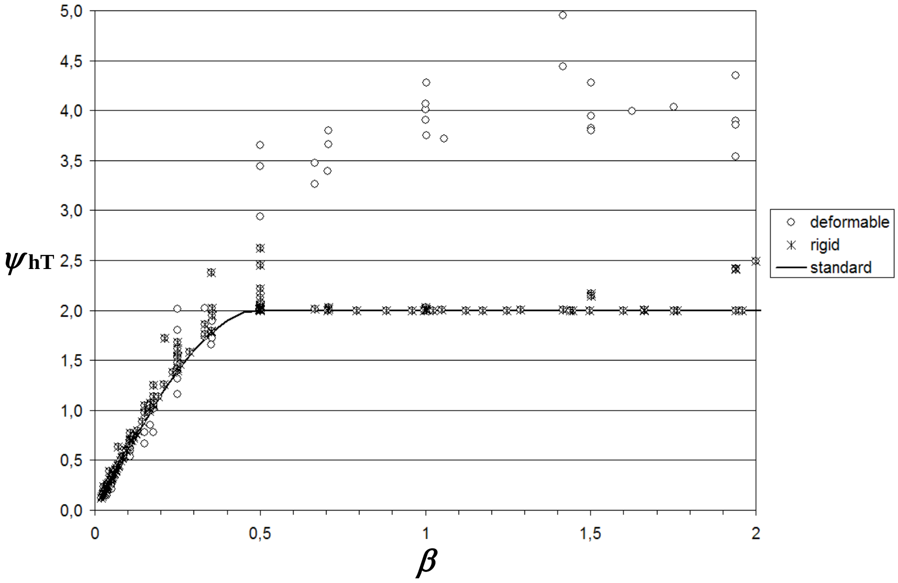


Fig. 9.18 The diagram of the coefficient ψ_{hT} of the tangential horizontal inertial forces for $\mu = 0$. The curve from the standard (F.E.M 1.001 1998) is shown (black line), together with the calculated points for the assumed rigid and for the realistic deformable crane structure (Jerman et al. 2008)

The obtained results show the possibility that the neglecting of the deformability of the slewing crane's structure can lead to non-conservative solutions. Therefore, a more careful consideration of the tangential inertial forces in the case of the slewing cranes would be appropriate.

9.4.5 The horizontal inertial forces acting in a radial direction (simulations)

For a rapid determination of the maximum radial horizontal force that can be expected to act on the suspended load during the rotation of the tower crane, the following equation is proposed:

$$F_{hR,\max} = \psi_{hR} \cdot F_{C.nom}. \tag{9.84}$$

In Eq. (9.84) $F_{C.nom}$ represents the nominal centrifugal force, as defined in Eq. (9.81), and ψ_{hR} represents the newly introduced coefficient of the radial horizontal inertial forces. This coefficient can be read out from the newly calculated diagram presented in Fig. 9.19, later in this section. For the determination of the individual points in the diagram the mathematical model introduced in section 3 was used. The deformations of the crane's structure were set close to zero and the dissipative effects were neglected with the application of the corresponding input data (the values of the stiffness coefficients were enlarged by a factor of 10000 and the damping and the air resistance coefficients were set to zero). These assumptions were necessary because of the complexity of the investigated phenomena. Because of the proven influence of the deformability of the structure on the resulting inertial forces, additional analyses were performed with realistic input data, and the estimations are briefly introduced later in this section.

In the diagram in Fig. 9.19 the coefficient of the radial horizontal inertial forces ψ_{hR} is plotted on the ordinate axis against the ratio:

$$\Phi = \frac{\Phi_0}{\beta} = t_Q \cdot \omega , \tag{9.85}$$

on the abscissa axis for different constant values of the coefficient β. In Eq. (9.85) a new, dimensionless coefficient is used:

$$\Phi_0 = \frac{F_{C.nom}}{\overline{F}_T} = \frac{\omega^2}{\overline{\alpha}} = t_1 \cdot \omega . \tag{9.86}$$

For each curve presented, several points were calculated and the corresponding regression curve was determined. The points were calculated for crane structures of different sizes, and it was verified that the overall size of the crane has no influence on the value of the coefficient ψ_{hR}, while the quotients Φ_0 and β remain unchanged.

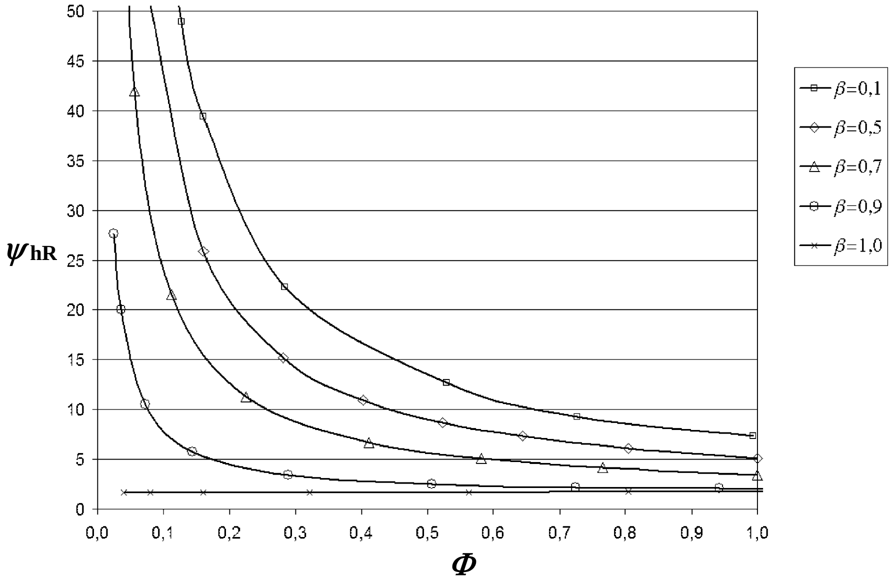


Fig. 9.19 The newly developed diagram of the coefficient of radial horizontal inertial forces ψ_{hR} (Jerman et al. 2008)

The diagram in Fig. 9.19 is shown for the range of the coefficient Φ from 0.04 to 1.0, which corresponds to the majority of existing slewing cranes, normally having Φ greater than 0,2. It shows the curves for the range of the coefficient β from 0.1 to 1.0. Higher values of the coefficient β are possible, and these will be discussed at the end of this section.

The first conclusion from the diagram is that the value of the nominal centrifugal force is exceeded by more than 65 % for all the cases shown, and in some cases by even more than 5000 % (values of ψ_{hR} from 1.65 to 50.0 and more). The conclusion can be drawn that for a better description of the loading a more careful consideration of the radial horizontal inertial forces is necessary than that stated in the standard (F.E.M 1.001 1998).

For smaller values of the coefficient Φ, the values of the coefficient ψ_{hR} increase rapidly. The reason for such behaviour is mainly that the small coefficient Φ correlates with a small maximum ω (see Eq. 9.85) and therefore with small nominal centrifugal forces. The smaller nominal force must then be multiplied by a higher coefficient ψ_{hR} to obtain the correct value of the maximum radial horizontal force, which depends on the behaviour of the pendulum's motion in the radial and tangential directions.

This can be explained more clearly by means of the diagram in Fig. 9.20, where the original curves (Fig. 9.19) are re-plotted in the following manner. On the ordinate, instead of the coefficient ψ_{hR}, a modified coefficient of the radial horizontal inertial forces, ψ'_{hR}, is plotted. This coefficient is defined by the following equation:

$$F_{hR,\max} = \psi'_{hR} \cdot \overline{F}_T \,. \tag{9.87}$$

The modified coefficient ψ'_{hR} is therefore the ratio between the maximum radial horizontal inertial force and the average tangential force developed during acceleration (instead of the nominal centrifugal force). Now the values of the coefficient ψ'_{hR} can be directly compared with the values of the standard coefficient of the maximum tangential horizontal inertial forces (F.E.M 1.001 1998), which is also based on the average tangential force. The curves for the range of coefficient β from 0.5 to 1.0 are shown. Lower and higher values of the coefficient β are possible, and will be discussed at the end of this section.

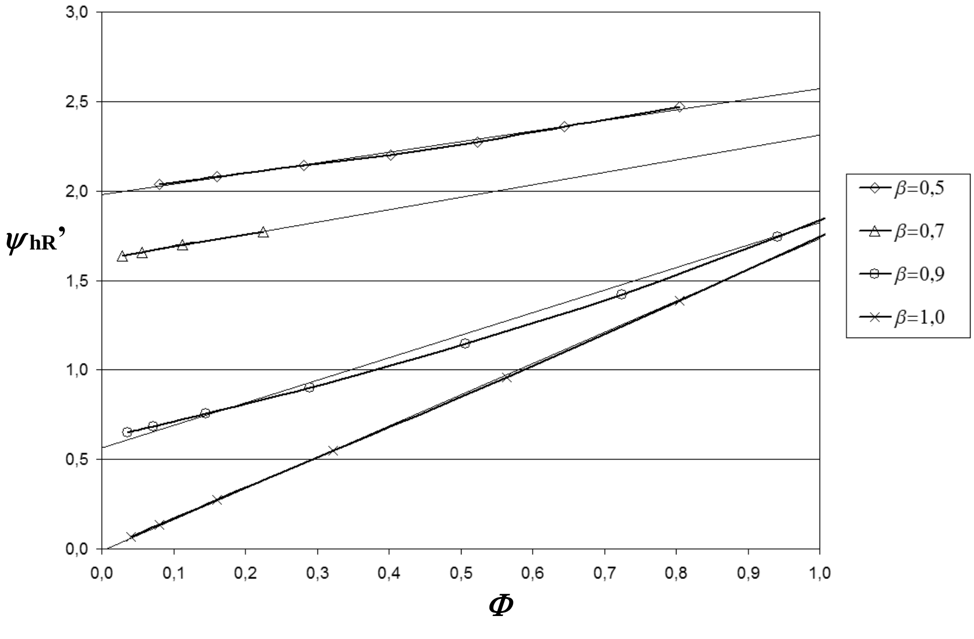


Fig. 9.20 The diagram of the modified coefficient of the radial horizontal inertial forces ψ'_{hR} (Jerman et al. 2008)

From the diagram in Fig. 9.20 is clear that the maximum horizontal inertial forces for the range of values of Φ smaller than 0.5 do not exceed the values of the average tangential horizontal inertial force by more than 2.3 times. Therefore, one assumption is confirmed: that the drastically increased values of ψ_{hR} do not imply extremely high values of the radial horizontal inertial forces. In fact these values even decrease slightly with a decrease of Φ (for constant β).

In Fig. 9.19 the curves for the range of the coefficient β from 0.1 to 1.0 are shown. In the real world, higher values of the coefficient β are possible and they need to be discussed. For this reason the diagram is re-plotted (see Fig. 9.21) in such a way that the values of ψ_{hR} are plotted against the values of β for different constant values of Φ. The values of ψ_{hR} decrease when the coefficient β goes from 0.1 to 1.0, and then increase to approximately $\beta = 1.5$, and again decrease until the value $\beta = 2.0$ is reached, resulting in a kind of wave-shaped curve. The shape of this wave is then repeated between each pair of neighbouring integer values of β. As a result of this, Fig. 9.19 would be hard to follow if the curves for values of β greater than one would be added.

The influence of the swinging of the load in the tangential direction on the swinging in the radial direction is also obvious. It is characteristic for integer values of the coefficient β that the pendulum motion in the tangential direction stops after the end of the acceleration. From the diagram in Fig. 9.21 it is clear that at the same points the values of ψ_{hR} also reach their local minimums. Furthermore, when the value of β goes towards infinity, the value of ψ_{hR} is limited to one. A large value of β implies a very small acceleration, which involves a very small amount of swinging in the tangential direction and therefore a very small influence on the swinging in the radial direction. When radial swinging is not influenced by the tangential, ψ_{hR} is limited to one and the maximum radial inertial force $F_{hR,\max}$ is limited to the nominal centrifugal force $F_{C.nom}$ (see Eq. 9.84).

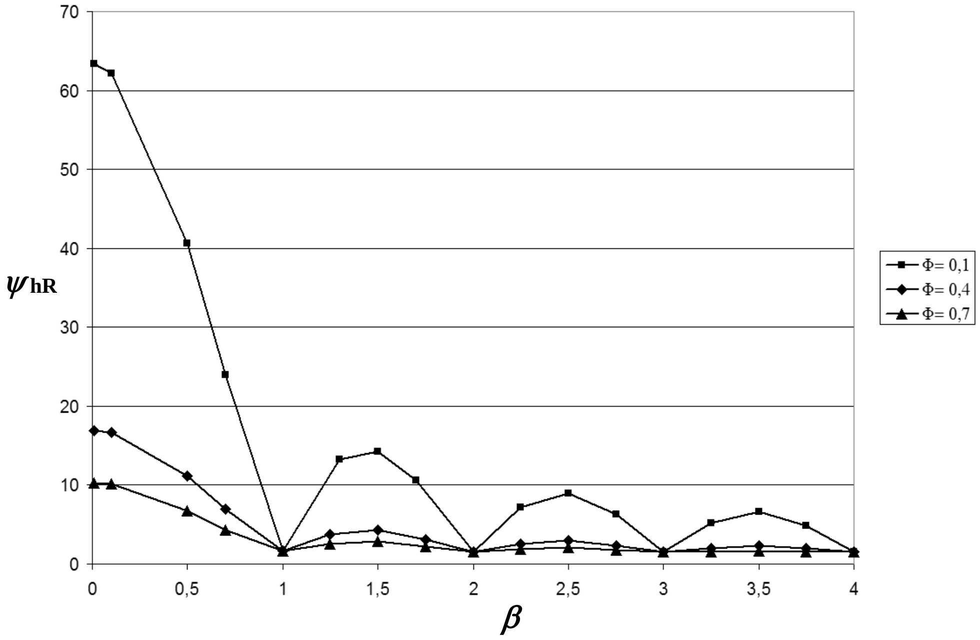


Fig. 9.21 The coefficient of the radial horizontal inertial forces ψ_{hR} for constant values of Φ (Jerman et al. 2008)

The same comments are also applicable for the diagram of ψ'_{hR} in Fig. 9.20, where the curves for the range of coefficient β from 0.5 to 1.0 are shown. From the diagram in Fig. 9.22 is clear that the curves for smaller and higher values of β would overlap with these for the range shown, and the diagram would become unclear. Additionally, the interdependence between the swinging in the radial and tangential directions is like that shown in Fig. 9.21.

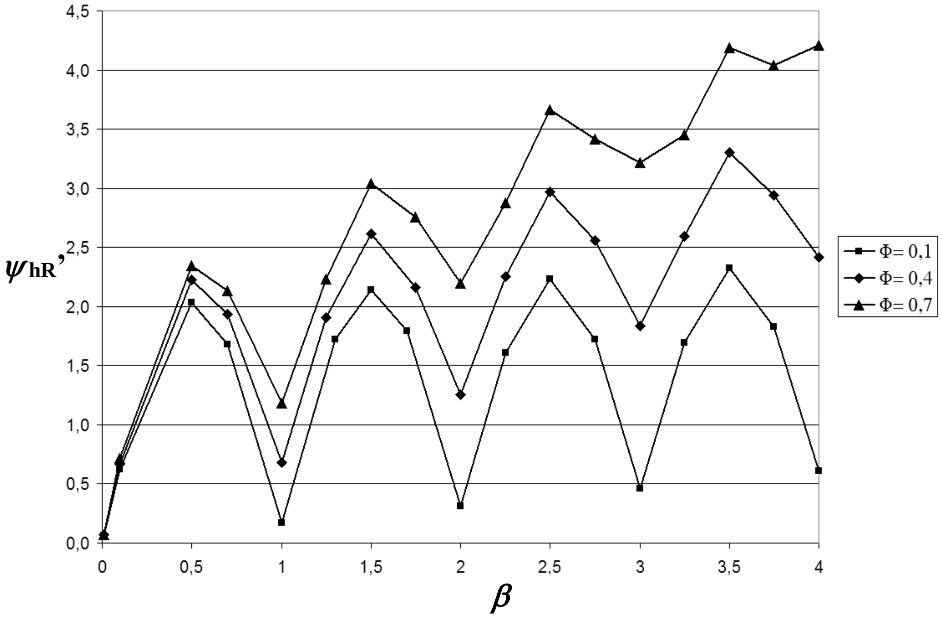


Fig. 9.22 The modified coefficient of the radial horizontal inertial forces ψ'_{hR} for constant values of Φ (Jerman et al. 2008)

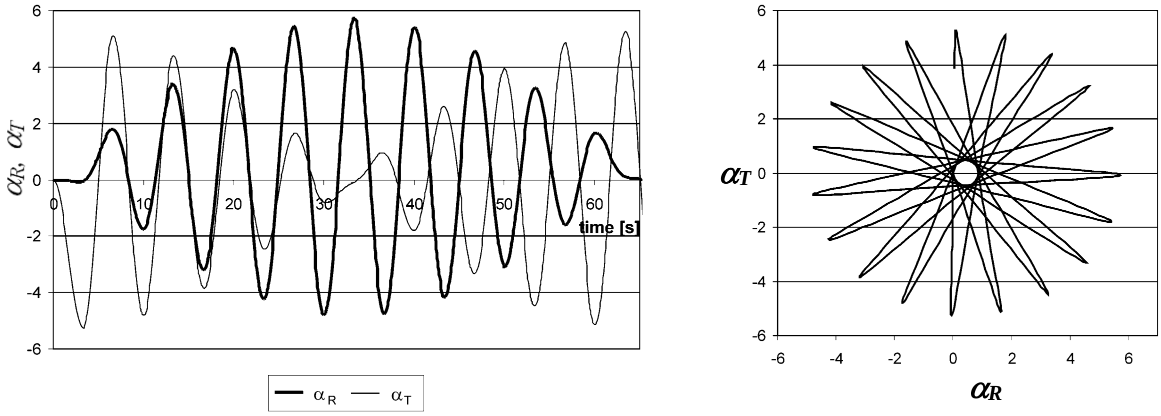
Because the deformability of the crane's structure was found to have a great influence when the tangential horizontal inertial forces were considered, this influence was observed in the case of the radial horizontal inertial forces too. The results show that for the different cases observed (involving different realistic stiffness coefficients and crane dimensions), for the same values of the coefficients β and Φ, higher and lower values of the coefficient ψ_{hR} than in the case of a non-deformable crane structure were determined. A study of these influences should be performed in the future.

9.4.6 The simultaneousness of the action of the horizontal inertial forces

When the load-carrying structure of a crane is designed, many load cases must be assessed. However, only the forces that can act simultaneously should be combined in each separate load case. For this reason the time dependence of the radial and tangential horizontal inertial forces is important, and the possibility of the concurrent acting of their maximums must be analysed.

In Figs. 9.23 and 9.24 the angles α_T and α_R for the two cases are presented. In Fig. 9.23, the results are for a non-deformable crane structure of height 32 m with the position of the load suspension point R=30 m and a rope length of 11 m. The maximum rotation velocity of 0.05 rad/s is reached by means of a constant angular acceleration of 0.015 rad/s^2 in 3.33 s. In Fig. 9.24, the results are for a real-world crane with a deformable structure of height 44.2 m with the position of the load suspension point R=30 m and a rope length of 14.4 m. The maximum rotation velocity of 0.055 rad/s is reached by means of a constant angular acceleration of 0.0103 rad/s^2 in 5.39 s. In Figs. 9.23 a) and 9.24 a) plots of the angles α_T and α_R against time are shown, whereas in Figs. 9.23 b) and 9.24 b) the state-space plots of angles α_T against α_R are presented.

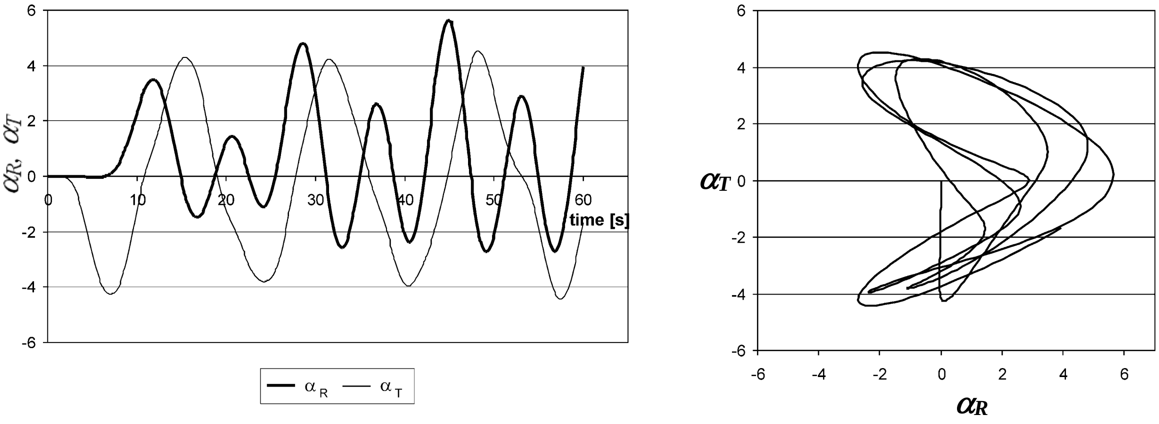
From the graph in Fig. 9.23 b) can be concluded that every time a peak value for the tangential force is reached the value of the radial force is close to zero, and vice versa. On the other hand, in Fig. 9.24 b) the situation is different. When one of the horizontal inertial forces reaches its maximum it is possible that the value of the other force is also close to its maximum.



a) Radial (α_R) and tangential (α_T) angle of the load sway with respect to time

b) Tangential (α_T) angle of the load sway with respect to the radial (α_R) angle.

Fig. 9.23 Angles of the load sway for an example of a real-world crane with a non-deformable construction (Jerman et al. 2008)



a) Radial (α_R) and tangential (α_T) angle of the load sway with respect to time.

b) Tangential (α_T) angle of the load sway with respect to the radial (α_R) angle.

Fig. 9.24 Angles of the load sway for an example of a real-world crane with a deformable construction (Jerman et al. 2008)

Attention must also be paid to the fact that most of the time the (non-maximal) forces in the radial and tangential directions do act concurrently, and it is therefore possible that the maximum values of the force in the tangential or radial directions combined with an appropriate value of the force in the other direction do not represent the worst load case for the crane’s structure. For this reason it is recommended that a careful and conservative approach to the definition of the load cases is used.

9.4.7 Conclusion

In chapter 4 the horizontal inertial forces acting on a suspended load during the crane’s slewing motion (including angular acceleration) are studied and the results are compared with the values obtained using actual standard for the design of hoisting appliances. A special attention is focussed on the forces acting in the radial direction.

For this research a previously developed and verified mathematical model of a slewing crane was used. The model includes several deformability and nonlinear effects. For the purpose of the presented research, a lot of these effects were made unactive by using appropriate values of the input parameters. By doing so, the model became more analogues to the mathematical model used in the standard for the linear crane’s motion, where the deformability and dissipative effects are neglected. In this manner the results became more comparable.

The results based on the introduced assumptions show that the maximum values of the horizontal inertial forces in the radial and tangential directions in the case of the slewing motion can be of the same magnitudes and are deserving of equal attention from the designers. Another conclusion is that the maximum values of the forces in the radial direction can exceed the value of the nominal centrifugal force by several times. Also interested parts of the research are the proposed procedure for the rapid determination of the horizontal inertial forces in the radial direction during the slewing motion of the crane and the calculated diagram of the newly introduced coefficient of radial horizontal inertial forces ψ_{hR}.

Because of the assumptions employed during the research the results are not assigned to be used in the design process, yet. The additional preliminary investigation included in the report, for instance, shows that the neglected deformability has a considerable influence on the results especially when more deformable (slewing) cranes are observed. The topic needs an extensive further research work. Before the practical usage also the confirmation of the findings by means of measurements is necessary.

Although the neglect of the dissipative effects, on the other hand, doesn’t have so significant influence on the presented results (especially for the commonly used slewing cranes) these effects should also be included in the further researches. During possible future simulations the capabilities of the implemented mathematical model should be used to a greater extent and the influences of the neglected properties should be studied in more detail.

NOMENCLATURE

$\bar{a}$	constant (average) acceleration;
d_i	damping coefficient ($i=1, 2, x, z, L$: see Fig. 9.8 and Assumptions);
$d_{ar\,3}$	coefficient of air resistance on mass m_3;
$d_{ar\,2}^{\,i}$	coefficient of air resistance on mass m_2 in i-direction ($i=x, y, z$);
$\bar{F}$	average horizontal inertial force in the case of linear motion;
$F_{C.nom}$	nominal centrifugal force;
$F_{h,\max}$	maximum horizontal inertial force;
F_{hR}, F_{hT}	horizontal inertial forces acting in the radial and tangential directions;
$F_{hR,\max}$	maximum horizontal inertial force acting in the radial direction;
$F_{hT,\max}$	maximum horizontal inertial force acting in the tangential direction;
f_Q	natural frequency of oscillations of the suspended payload;
f_S	natural frequency of oscillations of the crane-load system;
$\bar{F}_T$	average tangential force;
g	acceleration due to gravity;
H, H_0	height and initial height of the crane;
J_1	moment of inertia (see Fig. 9.8 and Assumptions);
k_i	stiffness coefficient ($i=1, 2, x, z, L$: see Fig. 9.8 and Assumptions);
L, L_0	length and initial length of the wire rope;
m_i, m_Q	point mass ($i=2$ and 3: see Fig. 9.8) and payload mass;
M_{SR}	moment of friction in the slewing ring;
Q_1^{fr}	generalized friction (*fr*) force caused by friction in the slewing ring;
q_j	generalized (independent) coordinates ($j=1, 2, 3, R, H, \xi, \eta, \zeta$);
Q_j, Q_j^{d}	generalized forces and generalized damping (*d*) forces ($j=1$-7);
$Q_j^{k}, Q_j{}'$	generalized conservative (*k*) and non-conservative (*’*) forces ($j=1$-7);
Q_j^{ar2},	generalized air resistance (*ar*) forces acting at mass m_2 ($j=2, 3, 4$);
Q_j^{ar3}	generalized air resistance (*ar*) forces acting at mass m_3 ($j=2$-7);
R, R_0	radial distance (and initial radial distance) of a load suspension point from the axes of rotation;
s	number of independent coordinates;
T, T_i	total kinetic energy of the system and the kinetic energy of the mass m_i (J_i) ($i=1, 2, 3$);
t_1	acceleration time;
t_i	time intervals for the slewing motion prescription ($i=1, 2, 3, 4$ – see Fig. 9.10);
t_Q	period of free oscillation of the suspended payload;

V, V^{ki}	potential energy of the system and the potential energy of the spring k_i ($i=1, 2, L, x, z$);
V^{mi}	potential energy of the mass m_i ($i=2$ and 3);
v_i	absolute value of the velocity of the mass m_i ($i=2$ and 3);
X_i, Y_i , Z_i	X, Y and Z coordinates of the mass m_i in the global XYZ frame ($i=2$ and 3);
$\bar{\alpha}$	constant (average) angular acceleration;
α_R, α_T	load swinging angle in the radial and tangential directions (see Fig. 9.8);
β	quotient between the acceleration time and the oscillating period of the load;
δA	total virtual work of the non-conservative generalized forces;
δA^d	virtual work of the damping (d) forces (by d_1, d_2, d_x, d_z and d_L);
δA^{fr}	virtual work of the friction (fr) in the slewing ring;
δA^{ar}	virtual work of the air resistance (ar) forces (at m_1 and m_2);
δ_{Xi}, δ_{Yi}, δ_{Zi}	virtual displacement of the mass m_i in the global X, Y and Z directions ($i=2$ and 3);
$\delta_{\Delta i}$	virtual displacements of the damping elements d_i ($i=1, 2, x, z$ and L);
$\delta_{\varphi 2}$	virtual displacement of a slewing ring;
Δ_1, Δ_2	deformation of a torsion spring k_1 and spring k_2;
Δ_L	change of the length of the wire rope L;
Δ_X, Δ_Z	change of the position of the mass m_2 in the x and z directions;
μ	quotient between the load mass and the mass of the load suspension point;
Φ	quotient between the new dimensionless coefficient Φ_0 and the coefficient β;
Φ_0	quotient between the nominal centrifugal force and the average tangential force;
φ_1	angle of rotation of a motor’s rotor, transformed on the rotating axes Z (see Fig. 9.8);
φ_2, φ_3	angle of rotation of a slewing platform and the angle of rotation of a jib (see Fig. 9.8);
ξ, η, ζ	position of mass m_3 in the local $\xi\eta\zeta$ frame;
ψ_{hR}	coefficient of horizontal inertial forces in the radial direction;
ψ_{hT}	coefficient of horizontal inertial forces in the tangential direction;
ψ_h	coefficient of horizontal inertial forces;
ω	constant maximum angular velocity.

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Excerpts from Reviews

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The Scientific Monograph “Next Generation Logistics: Technologies and Applications” is focusing on relevant topics of logistics management and warehousing and transportation systems. New emerging technologies for better efficiency, but also sustainability, are presented with nine chapters through theoretical approach using mathematical modelling of some logistics problems and considerations of managerial problems, as well as from practical approach presentig logistics in practice and case studies.

The scientific monograph represents definitely valuable contribution to the scientific community, both in terms of content and research approach, therefore I recommend it for publication as Scientific Monograph.

Assoc. Prof. Goran Đukić

* * *

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The Scientific Monograph, “Next Generation Logistics: Technologies and Applications” focus on a modern research in the field of logistics. It considers various fields of intralogistics / logistics and corresponding technologies and applications, such as warehousing systems, material handling machines and sustainability problems, but at the same time a wider logistics approach which includes logistics management and business processes, investments and supply chains. The presented monograph is well structured and includes nine chapters.

The monograph will strongly contribute the reader’s knowledge on the trends in logistics researches, including both scientific and practical approaches. For that reason I would like to express my strong recommendation to published it as a Sceintific Monograph.

Assoc. Prof. Nenad Kosanić

* * *

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The Scientific Monograph, “Next Generation Logistics: Technologies and Applications” focus on smart system modelling approaches to some logistics problems, sustainability applications on warehousing technologies as well as investment and management of logistics systems. The monograph includes nine chapters that approach to logistical problems from practical requirements.

The reader will find both mathematical modelling approaches to some warehousing, supply chain problems as well as management related issues in the related problems. Since it also includes some case studies in the chapters, I believe that this monograph contributes the next generation logistics in both theoretical and practical ways. Hence, I strongly recommend it to be published as a Sceintific Monograph.

Assoc. Prof. Banu Y. Ekren