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1. Zoran MIODRAG, 2. Christian TESCH, 3. Andreas MÜLLE, 4. Uwe CLAUSEN

ENHANCING LOGISTICS PRODUCTIVITY OF LARGE FACTORY SITES

1-4. TU DORTMUND UNIVERSITY, INSTITUTE OF TRANSPORT LOGISTICS, LEONHARD-EULER-STRAßE 2, DORTMUND, GERMANY

ABSTRACT: Due to the growth in shipment volumes in recent years, many plants have reached the limits of their capabilities, leading to bottlenecks in transport-chains. There is a great potential for increasing the efficiency of transport processes in logistics facilities such as terminals, distribution centers, or production sites and thus ensuring economic growth. These logistic facilities are contributing factors in determining the performance, quality, costs and carbon emissions of superior supply-chains and transportation networks. The aim of the collaborative project "Efficiency in Logistic Facilities" is to develop a software prototype "EcoSiteManager (ESM)", a suitable tool for the control of large logistics facilities.
KEYWORDS: Logistics Facilities, Efficiency, Mathematical Optimization, Scheduling, Logistics Management

INTRODUCTION

The productivity of large factory sites is a major challenge for the Ruhr metropolis. With approximately 5.2 million inhabitants the region is the third biggest population center in Europe next to Paris and London [1]. Approximately 20 million people are accessible within a two hours travel. Hence, the Ruhr metropolis and its adjacent regions represent a unique consumer region and thus a center for work and consumption in Germany and in Europe. 20% of the federal freight haulage is generated in North Rhine-Westphalia and a majority of it in the metropolis Ruhr [2]. Consequential, a high number of logistics facilities established in the region to supply the population and resident enterprises.

As a result, the shipment quantity increases and many facilities reached the limit of their performance ability. They become a bottleneck for the superordinate transport, procurement or distribution nets and turn into an endangerment for defined cost and service goals. New facilities to provide more capacity seem to be obvious. However, additional surface and financial investments are needed but not obtainable for facility enhancements.

Nevertheless, various unused potentials exist for increasing productivity of logistic facilities instead of enhancing through building activities [3]. For example, processes and procedures can be intelligently steered. Decentralized information can be made transparently and available. In order to strengthen the competitiveness the efficiency of logistics facilities (i.e. quantity, speed and quality by the same amount of resources) has to be increased as well as to adapt the facilities layout to future developments.

Summing up, an efficient operation of existing logistics facilities is essential for the development of metropolitan regions such as the Rhine-Ruhr. Regarding the economic power and the global commodity flows of the region and in addition against the tightening of space for logistic facilities innovative control and steering mechanisms like mathematical optimization, material-flow simulation, or effective key performance indicator systems are needed. To integrate such mechanisms the project partners develop a prototypical software application named "EcoSiteManager – ESM". The ESM is a parametrizable software tool for logistics systems and consists of the modules: unitCV, Hugo and X-Ray. UnitCV creates an electronic history and provides an interface for full data collection of shipment. Hugo is used to provide user-guided algorithms and software for interactive control of logistics systems. Finally, X-Ray is a monitoring module for continuous Coordination and supervising of all vehicles and resources. Therefore, this paper gives an overview about the solution approaches and special software requirements for the control of large logistic facilities.

PROJECT AIMS

First of all, the object of investigation has to be pointed out. Therefore, a logistics facility can be understood as a terminal, a distribution or a production site [4]. In the following, figure 1 shows *the processes considered. These processes extend from the loading ramp, delivery places for shipment to the processes inside the transshipment hall or logistics buildings.*

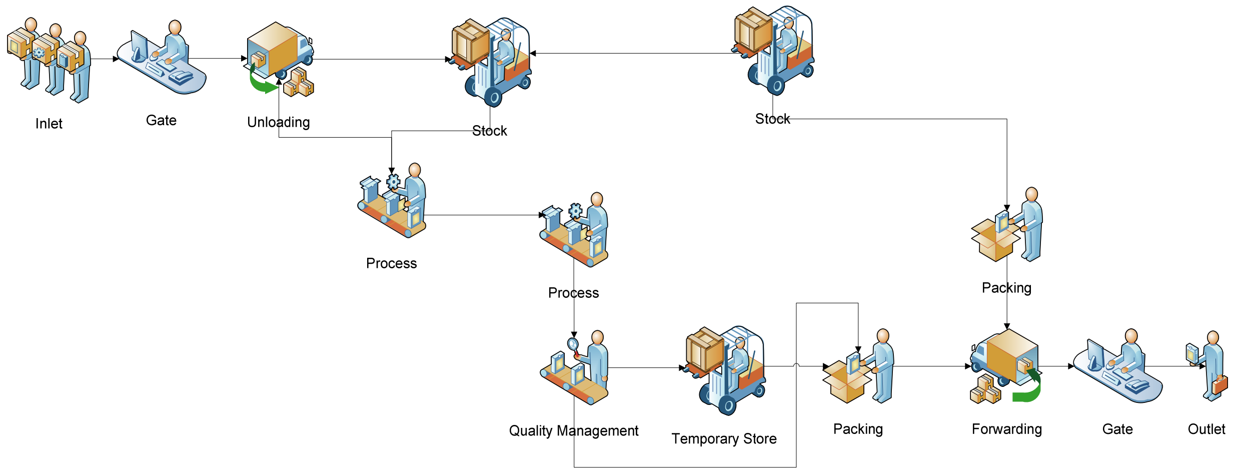

Figure 1 – Objects of logistic facilities

In the following, the necessary key aspects to model a logistics facility are shown [5]:

***Objects** (e.g. shipments or vehicles) are in its characteristics (e.g. volume, form, arrival plans, technical criteria) not sufficient accurate and continuously transparency sized. Often, e.g. transportation characteristics are not well known. This leads to the fact that objects cannot be coordinated, planned and steered optimally.*

*Furthermore, **Resources** instituted in logistic facilities and their current status (e.g. filling degree, orders on forklift trucks, allocation of unloading points) are not accurately described. This leads to the fact that scientific methods, e.g. mathematical optimization, material-flow simulation or effective key performance indicator systems have not reached a sufficient penetration in logistics facilities. The application of these methods is actually not expedient due to missing real time data and a missing comprehensive fielding. Especially the results are based on hypothetical conditions of resources.*

*Finally, **Human expert's decision mechanisms** are the basis of current control and planning mechanisms for logistics facilities. In practice decisions highly depend on this human expert knowledge. The above specified scientific methods are used rarely or only in sub-sectors (e.g. picking). Here, a transmission of the expert knowledge in formalized and automated procedures in a software tool is missing. With the application of formalized expert knowledge, logistics facilities can be controlled and steered in order to increase their productivity.*

To build up a model of a logistics facility, the infrastructure and the operating resources has to be pictured. Therefore a universal model has been developed. As shown in figure.2, the model includes a Dock (with various possibilities of loading), rail handling and loading stations, railway gates, different types of Warehouses, conditioning areas (for various branches), gates and weighting stations. Furthermore, operational stuff e.g. trucks, forklifts, or stuff can be modeled. The overall aim is to cover 80 % of the common types of logistics facilities.

*To cover a wide range of challenges of several kinds of logistics nodes the ESM will be made up of three individual modules named, **unitCV**, **HugO**, and **X-Ray**. The ESM assigns the right shipment to the right resource at the right time, referring to stored data of the unitCV. The unitCV obtains object information and the current resource state. Thus, resources can be used more efficiently by human guided optimization methods and controlled by the X-Ray module. This modular concept improves knowledge in logistics facilities, supports the dispatcher with a decision support tool. Therefore, the ESM will be composed of three control levels as shown in figure 3.*

*The **Management level** enables the human expert to recognize the facilities status at first sight. Therefore, a Management Cockpit has been modeled. It summarizes the necessary data and arranges the needed information in an efficient way. It contains recapitulatory Information and represents the highest control level.*

*The **Sector Level** consists of a forecast module and the possibility to optimize the sector utilization. In opposition to the management level, the sector level focusses on comparable stations, e.g. weighting or loading stations.*

*The **Resource level** is the most operational level. Here the human expert has the opportunity to enable or disable specific resources. Moreover, transports can be prioritized, redirected or even roads closed.*

The system consists of many different components, which interlock the most part. Each component has its own special features and specific properties that are considered. They are divided *into three major groups of stations, nodes and edges. Areas for handling, storage and production are summarized as stations. The nodes and edges represent the network of roads and railway connections on the factory premises, where the nodes represent each connection point to the stations or junction points and the edges represent the individual roads. For the consideration of following or preceding processes it is possible to illustrate a hierarchical structure. For example, a hall-internal network of paths for forklifts can also be modeled by the use of edges, nodes and areas. The Figure 2 shows an example of factory premises with areas for handling (red), storage (gray) and production (purple). The areas are connected by a network of nodes (green dots) and edges (purple lines) that represent the road and railway network.*

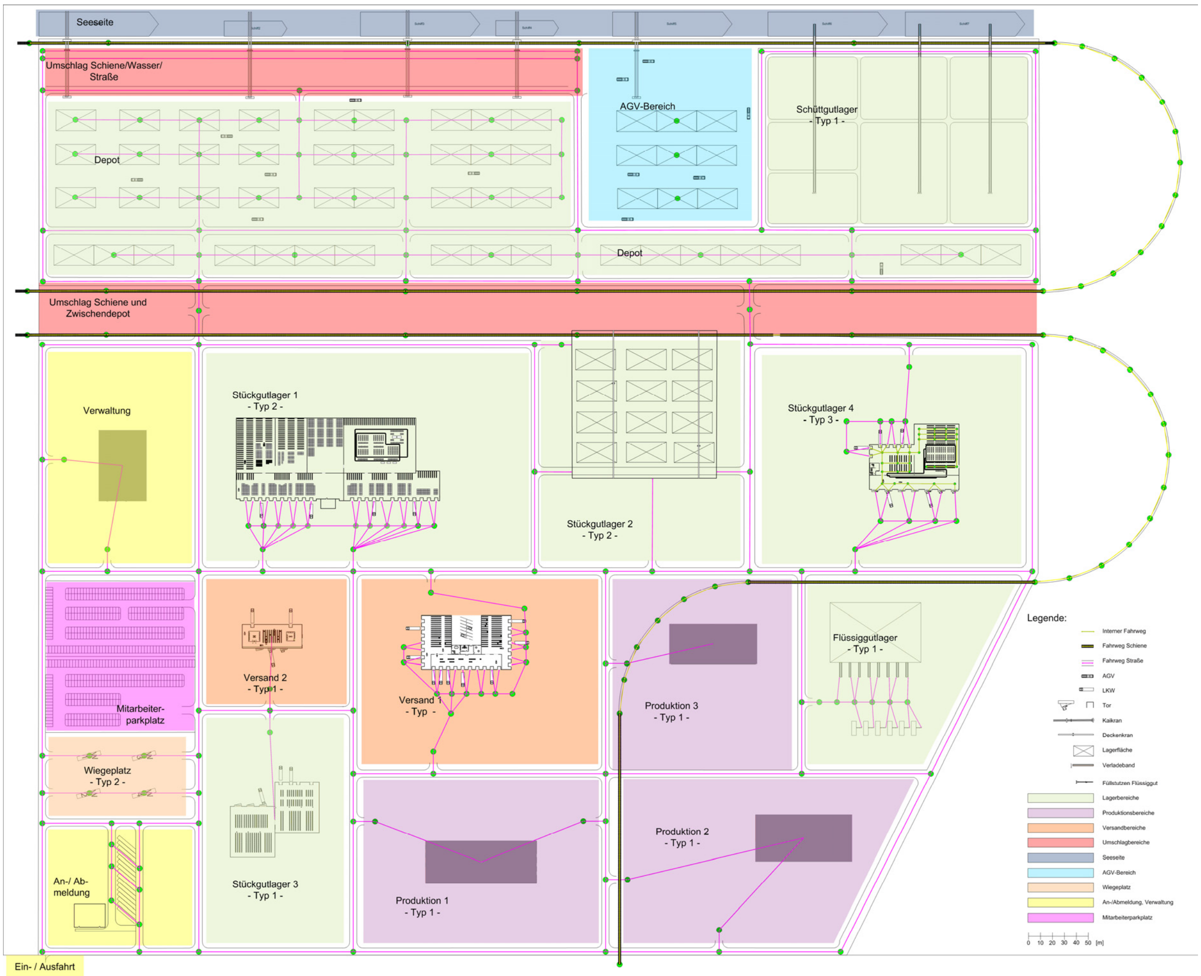

Figure 2 – Modeling a logistic facility

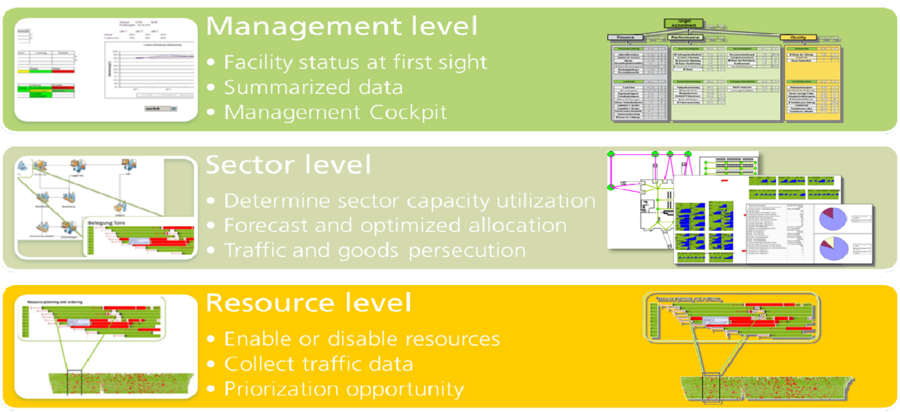

Figure 3 – ESM level

Regarding the optimization the characteristics of each component play a crucial role. One of the most important properties of each station is the number of simultaneous actions, which are, for example, defined by the number of existing ramps or filling nozzles. The three main properties of the edges are defined by the expected transit time, maximum passage capacity per time unit and the limitations on the possible passage, for example, on the basis of the maximum total mass of the vehicle.

The ESM is designed for daily use on a factory site and the group of users is spread across different levels of control. The acceptance of the user during operation is ensured by the fact that all the calculated schedules and routes can be adjusted later. This allows users to bring human intelligence and experience in the optimization. As a result a number of changes trigger adaptations, a dynamic optimization has to be initiated. This approach to user-guided optimization (human guided optimization) is reflected in the EcoSiteManager by different people having influence on the plans [9].

A planner overseeing the management of traffic on the site can make individual adjustments in the calculated plan that can help to improve planning. Since this type of interventions can cause very different consequences for the already calculated planning, it will usually be necessary to adapt the associated processes by the ESM.

An employee at the sector level who is responsible for the control of incoming and outgoing traffic of one station can optimize the schedule by making changes in the processing sequence of trucks. Thus, non-functional constraints due to human optimization are integrated. Such changes can also cause major deviations from the plan, so that a calculation call for a new plan must be done once again. At the management level, the possibility is considered that an employee can influence long-term planning, such as the merging of two stations of the same type or to split a single station into two stations.

The solution to be developed includes the two scientific problems of route planning of vehicles on the site and their scheduling for unloading or loading. These two problems are directly interlinked, so that an individual examination is not suitable. The trip between two stations on the site may take different durations depending on the selected route, so that thereby the load planning is affected. A possible interchange of the processing sequence at two stations can lead to significant changes in driving time, so that here a combined analysis of both plans must be made. If a discharge or loading of a vehicle is completed later than planned, this has implications for the planned trip and the subsequent actions of the vehicle on the logistics site.

SOLUTION APPROACH

To test and compare the possible optimization procedures a suitable test environment is created, which covers many possible scenarios in order to offer the widest possible application of the procedures to be developed. For this reason, a notional test environment is created, since real environments usually cover only a portion of potential scenarios and do not meet many specific requirements.

To create the notional factory premises, the Microsoft Visio drawing program and ready-made sign elements such as freight handling facilities for water, rail and road as well as for storage, production and shipping areas are used for modeling. For each station, one or more nodes are defined, that represent access points to the road network on the site. Additionally, the entire road network is generated by nodes for the intersections and edges for the routes.

In order to use the modeled site efficiently as a data source all relevant information are transferred into a database. Based on the road network a graph for path finding is generated and also stored into a database.

An important part of the optimization of vehicle movements is the minimization of the distances on the site. It should be noted that the road network on the site can be changed by road closures or traffic congestion during operation which could also change the shortest paths in the network. In addition, the transportation order is subject to various constraints, which must be satisfied. For example, some road sections could be closed for dangerous goods or have restrictions on the maximum mass of the vehicle. This makes it necessary to consider the current situation for each calculation of a route. This is achieved by carrying out the current calculation on a graph that corresponds to the current situation in the route network and contains only edges that satisfy these constraints. Due to dynamic changes it is impossible to calculate optimal routes in advance, so these must accordingly be calculated at run time. Algorithms for searching for optimal routes may therefore only take as few computing time as possible. In the literature, various algorithms for solving the shortest path problem are presented [5]. These differ mainly by the number of pairs of start and destination nodes for which the shortest path could be computed simultaneously. The decision whether to calculate the shortest path for just a single pair of nodes (e.g. A algorithm), for all pairs of a single start to all destination nodes (e.g. Dijkstra's algorithm) or for all pairs of nodes (e.g. Floyd-Warshall algorithm), depends strongly on the reusability of the calculated routes.*

One possibility to decrease the computation time of routes is the use of caching methods. The dynamically calculated routes are stored in the database and can be retrieved at a later time without having to use computing time to calculate it again. The crucial factors for the future searches are that the same constraints are satisfied, the same situation in the network is present and, of course, start and destination nodes are identical. The stronger and more frequently, the situation in the route network changes and the more inhomogeneous the constraints of the search queries are the lower are the benefits from the calculation of multiple pairs of nodes and storing the results. By *combining some constraints, such as vehicle size and total weight to predefined vehicle categories, a greater homogeneity and greater re-usability can be achieved.*

Another essential part of the optimization is the scheduling of activities at each station and its ramps. The objective of this scheduling is to keep the cycle times of the vehicles in the system as small as possible. It should be noted that each vehicle must go through its own sequence of activities on the premises and that individual activities can only be carried out by a certain subset of the stations. This particular branch of scheduling is called job-shop scheduling. It is characterized by the fact that the problem is NP-complete. The calculation of an optimal solution for realistic problems is therefore only possible with a lot of time. There are many possible heuristics that use different approaches for finding the best possible solutions in a short period of time. A few approaches use local search algorithms [6] and others use evolutionary algorithms [7].

In the optimization of the system two basic situations can be distinguished. In the first situation a completely new plan for a planning period must be created and in the second situation changes in an existing plan have to be made because deviations from the design data have occurred during operation. The first case occurs when a planning period is considered for the first time. For this first optimization usually a longer period of time is available to calculate a solution as close as possible to the optimum. The second case occurs when delays or failures of machines occur during operation. In this case a new plan which includes these changes has to be created in a few seconds. The existing plan can be used as a basis where changes to one component affect other components so that the plan for the entire system must be adjusted.

Table 1 - Excerpt of the list of events

Event	Changes	Complexity
Late truck arrival	Check associated processes and recalculate schedules	All the schedules containing the delayed truck need to be adjusted. An optimization of all plans could be useful
Inoperative station	The trucks in the corresponding schedules will be distributed to other stations if possible	Recalculation of the entire plan is useful
Closed road	New routes must be calculated	Minor changes in the timelines
Exceeded process duration	The timeline of the ramp or filling nozzle is adjusted. The timeline of the truck are adjusted	All timelines containing the delayed truck need to be adjusted. An optimization of the plan is useful

How far-reaching the necessary changes in the system are depends on the type of each event. In particular, some of the events lead to schedule changes that affect the whole system. This directly affects the complexity of following optimization steps to use the system as efficiently as possible. To cover the various events in the optimization a list of possible events, their impact on the system and the following optimization is shown.

OUTLOOK

With this background, the aim of the project is to develop a software prototype that can be used at large logistic facilities or production sites by embedding methods of mathematical optimization, simulation and key performance indicator systems.

With regard to the combined problems of vehicle routing and resource scheduling the usability of dynamic optimization methods will be examined. Several approaches of dynamic optimization regarding vehicle routing problem [10] promise good results to be transferred to logistics nodes.

Thus, input and control concepts will be developed supporting operators of logistics facilities. Therefore, three management levels will be designed (Management, Sector and Resource) to offer a user friendly input of layout and operational data for each specific operator. The project results will be integrated in an application-GUI with intuitive handling and assistance systems for the operators of a logistics facility.

The ESM will increase the amount of available information and usable data at logistics facilities and lead to better resource utilization and economic growth.

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