# Truck Shuttle Simulation between Production Plant and Logistics Centre: Data Acquisition and Preparation

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**Abstract.** The present text reports on data acquisition and preparation in a simulation for evaluating a planned truck shuttle operation from a production facility to a logistics centre. Special aspects include the development of time intervals for the provision of finished goods that must be transported to the logistics centre by truck. Furthermore, the text describes how the travel time between the production facility and the logistics centre can be determined using various approaches. Finally, the results demonstrate the impacts that a more detailed consideration of the aforementioned aspects can have, particularly with regard to dynamic truck allocation and production planning.

## Introduction

Manual loading and unloading using forklifts involves considerable truck downtime, forklift operation and corresponding costs. Therefore, automated truck loading systems (ATLS) are increasingly used for regular transport routes [1].

**Figure 1:** Picture of an automatic truck loading system [2].

This applies in particular to short transport distances, as the time spent on loading and unloading is greater in relation to the travel time and automatic loading and unloading therefore offers considerable savings potential [3].

Automatic loading systems are also suitable in the case of a correspondingly high loading volume [4]. Depending on the selected loading system, the loading time can be reduced from approx. 40 minutes for manual loading and unloading to approx. 5 to 8 minutes for automatic loading [5].

In addition to the benefits of minimized loading time, ATLS increase occupaional safety and can be directly connected to appropriate warehouse management systems.

Furthermore, ATLS offer the possibility of loading outside regular working hours, as no forklift personnel are required [7].

In addition to the benefits of minimized loading time, ATLS both, the installation of the loading and unloading equipment in the production plant and logistics center and the equipment of the truck trailers, involve significant investments [8].

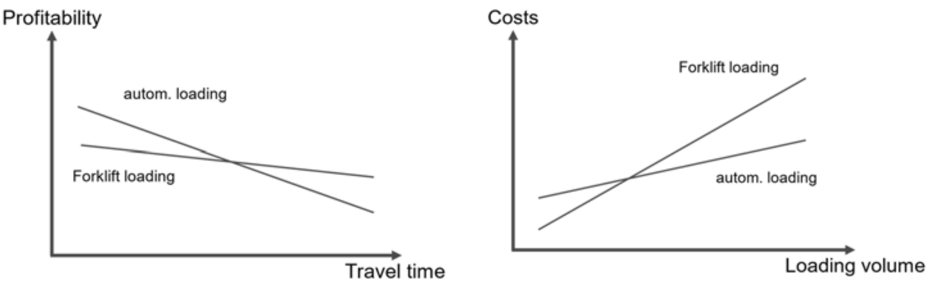


**Figure 2:** Profitability vs. travel time & costs vs. loading volume [6].

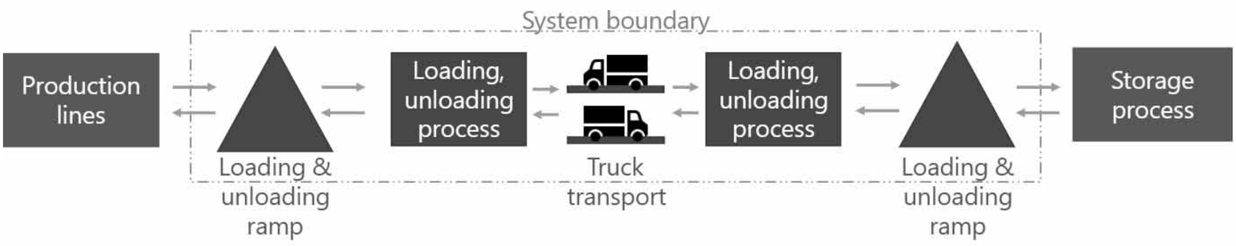


**Figure 3:** System boundaries.

Therefore, the number of necessary loading and unloading facilities as well as the number of truck trailers must be determined as precisely as possible during the design phase. However, a static consideration with average travel times and average loading and unloading times is not sufficient. A dynamic consideration over time is required.

## 1 The System

A company from the beverage industry is also facing this challenge. In cooperation with AcuroSim, a transport concept (including automatic loading systems) from the production site to the logistics centre, approx. 20 km away, is to be developed and optimized.

The following questions are in the focus:

- What influence do different routes have on the transport capacity on the respective weekdays and at the different times (24/7)?
- What influence do different production schedules and product/line combinations have on the transport requirements?
- Which concept of automatic loading systems in the production area and in the logistics centre are most suitable?

In order to investigate these issues also taking into account the dynamic aspects, especially due to the influence of traffic or the different production schedules, the company decided to use a simulation.

Figure 3 shows the system to be modeled including the corresponding system boundaries.

Thus, the process from the provision of the finished goods to the loading and unloading process as well as the transport is mapped. A mapping of the respective production and detailed putaway processes does not take place.

Overall, the production plant is divided into two production areas.

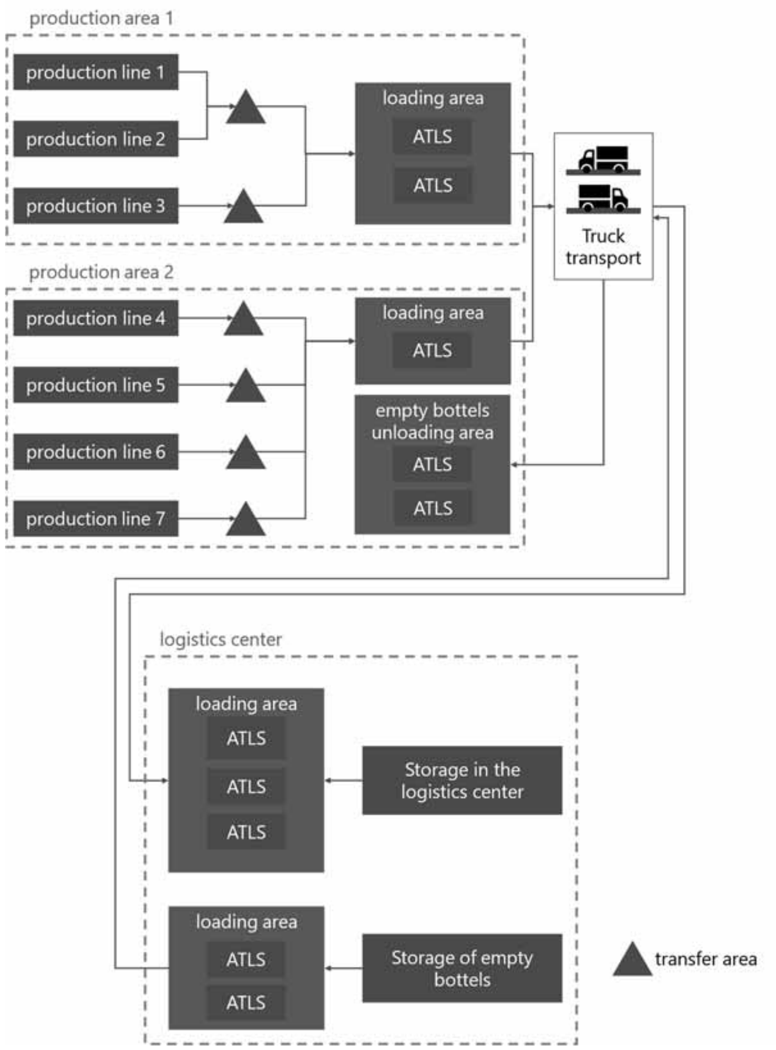


**Figure 4:** Simplified representation of the material flow.

In production area one, there are a total of three production lines that produce finished goods ready for transport. The finished goods are provided on a corresponding Euro pallet (EPAL).

Two automatic loading systems are available for this area. The corresponding production lines are connected to the respective automatic loading systems by means of appropriate conveyor technology (continuous conveyors). Production lines 1 and 2 fill the first ATLS, while production line 3 supplies the second ATLS. The installed production capacity of line 3 is about twice as high as that of lines 1 and 2.

In production area two, there are a total of four more production lines, but with a significantly lower production output compared to lines 1-3. One automatic loading system is available for loading the finished goods onto the corresponding truck. The production lines in production area 2 (production lines 4 to 7) are also connected to the automatic loading system. In addition, there is the option here of manual removal and feeding of EPAL by a forklift operator. This is not provided in production area one. In addition, two further automatic loading systems are available in production area two. These are intended exclusively for the delivery of empties.

Three potential routes are available for transport between the production plant and the logistics center. These differ on the one hand in their length and travel time and on the other hand in the traffic load (see Table 1).

| Route | Length [in km] | Ø travel time [in min] | Traffic load |
|---|---|---|---|
| **1** | 12.1 | 20.1 | medium |
| **2** | 8.6 | 17.5 | high |
| **3** | 17.4 | 22.5 | medium |

**Table 1:** Comparison of the routes.

Once at the logistics center, three automatic loading systems are available for receiving finished goods. Two ATLS are provided for receiving finished goods from production area 1, while the third ATLS is provided for receiving finished goods from production area 2.

Furthermore, two additional automatic loading systems are provided in the logistics center, which supply the required empty bottels to production area 2. Depending on the demand in the production plant, corresponding empties can be picked up and transported to the production plant.

## 2 Problem / Challenge

A total of several hundred different products are manufactured, packaged and then palletized on seven production lines.

The execution of the simulation study to validate the transport concept is oriented in the procedure of VDI 3633. Thus, following the goal description and the task definition, the planned system was first analyzed and described in a concept model. This was followed by formalization and implementation. In parallel, the collection and preparation of the required data as well as a V&V of the respective phase results took place [9].

In particular, the acquisition of the data in the necessary quality proved to be a complex and time-consuming process. This is especially true for the data that have a significant impact on the simulation results.

Among other things, the time period in which finished goods are made available for removal from the production line has a significant influence. This data is needed to simulate when the capacity limits of the buffers between the production lines and the loading systems are reached and an automatic shutdown of the production lines, due to the backlog, is required.

Likewise, the transport route and thus the travel time of the trucks has a relevant influence on the simulation results. This time can vary depending on the selected route, day of the week and time of day. Accordingly, a correspondingly meaningful data basis is also required here.

In addition to obtaining the necessary data, other restrictions must be taken into account in the simulation model.  For example, the truck capacity for the number of pallets is limited to 30. These are arranged in the truck on 3 rows of 10 pallets each, whereby the loading of the 3 rows always takes place in parallel with an article from one production line. This is necessary because the finished goods are to be stored in the logistics centre in an article-specific manner with a triple stacker. The article-specific loading sequence of the 3 rows is determined by the incoming production quantity per production line. Due to the load securing specifications, care must be taken during loading to ensure that complete rows of pallets are always loaded. Thus, the number of EPAL is always a multiple of three. (see Figure 4)

In addition, it must be ensured during loading that the maximum permissible load of 22.5 t per truck is not exceeded. With the variety of different products, the weight per pallet varies between 600 kg and 1,000 kg per pallet.

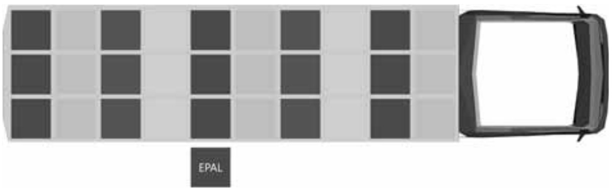


**Figure 5:** EPAL layout on the truck.

Thus, depending on the product produced, the maximum payload can already be exceeded after 21 pallets (worst case). Theoretically, it is still permissible to take on an additional pallet due to the payload of 22.5 t, but this is not permitted due to the restrictions on load securing described above.

The production schedule and the articles to be produced also influence the output of the different production lines. Thus, the output varies between 8 EPAL and 40 EPAL per hour.

## 3 Determination of the Data

In the area of finished goods provision, only the peak output of the respective production lines is known. Due to technical malfunctions, setup times, cleaning times, etc., the real data deviates from these theoretical peak outputs, in some cases considerably.

Furthermore, different products, packaging forms and production schedules influence the throughput of the respective production lines. Thus, the representation of the peak output in the simulation model does not provide a sufficient data basis.

In order to obtain the required data, it is possible to perform a manual time recording per production line and product [10]. However, this is associated with a high effort. Alternatively, it is possible to install an automatic counting device temporarily. This is associated with corresponding costs and also, due to the short recording period, does not result in sufficient data accuracy.

In practice, data is often collected and stored in certain application areas for various reasons (energy consumption, quality aspects, etc.), but not used further. This is also the case on production lines, in the area of palletizers.

At the end of the respective production line, each finished goods pallet is provided with a pallet label and the number of the shipping unit, or NVE for short [11]. This is applied by an automated label application. During this process, data on item number, order number, batch number, number of products, weight per pallet, and a corresponding time stamp, among others, are recorded and stored in a database for tracking purposes.

By means of the recorded time stamps and the differentiation per article number, the time intervals for each product can be de-termined by a corresponding data analysis.

For this purpose, with 7 existing production lines and more than 200,000 data entries per production line and year, over 2 million data records have to be cleaned and evaluated. Furthermore, these data have to be combined to meaningful product families.

In order to transfer the data into a distribution for the corresponding arrival interval of the article-specific pallets, the data preparation was automated. This procedure allowed realistic arrival intervals per product to be taken into account in the simulation model.

For this purpose, the time difference per EPAL was first determined for the same article. The respective intervals were then subdivided into corresponding product families. The assignment to the respective product families was specified by the industrial company. In the next step, the time intervals were transferred to a histogram and analyzed. In some cases, significant differences in the time intervals were identified. The time intervals were between approx. 1 minute and 1.5 days. These differences were caused by longer downtimes of the production lines or manual interventions. Reasons for this include technical malfunctions, as well as maintenance or repair measures or extensive cleaning.

In cooperation with the industrial company, corresponding upper limits were then defined for the histogram depending on the production family and production line. These still include the influence of corresponding course time disturbances, but filter out the influence of major disturbances and maintenance.

The final distributions were then saved in an appropriate file format and made available to the simulation model. In addition to the time intervals, the pallet weights were also evaluated and assigned to the respective product families in order to also take these into account in the simulation model.

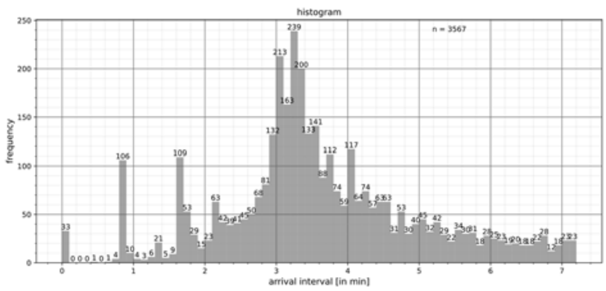


**Figure 6:** Processed data of a product.

No data is available for truck travel time because the logistics center is still under construction. Here, three possible methods were evaluated for determining the missing information:

The first method is the calculation of an estimated time of arrival, or ETA. Here, the estimated time of arrival is determined on the basis of the current vehicle speed, the day of the week, the time and the current traffic situation. By using historical data, it is possible to evaluate different transport times for the respective weekdays and times. The accuracy depends on the number of available data sets and the vehicle used (car vs. truck). Furthermore, the accuracy is much better for longer distances than for short distances, since individual stops have a much greater impact for short travel times than for longer distances. Sufficient data is available for heavily traveled routes and highways, such as long-distance traffic. For rural or county roads, these are often missing. This makes an ETA calculation for these routes inaccurate.

Due to the rural region of the production plant and logistics center and the use of predominantly rural and county roads, this approach does not provide sufficient data quality for determining travel time. Furthermore, depending on the service provider, the calculation of the ETA does not distinguish whether the vehicle under consideration is a car or truck.

An alternative to the calculation of the travel time can be provided by data from electronic traffic counts. These can be used to derive speed profiles for certain subroutes depending on the day of the week and the time of day. However, the number of such facilities in rural areas is also limited. In the context of the project, a maximum of two facilities were available that could be used to generate speed profiles for partial routes. Due to this, a sufficient amount of data cannot be provided via this approach either.

Thus, a manual time recording of the transport times had to be resorted to. For this purpose, it was precisely defined from which point the time recording starts and from which point it ends. The time, the day of the week and other comments were also recorded. This was done several times for each route using GPS trackers carried in the truck. The average travel time for each time of day and route is shown in Figure 7.

The data obtained in this way revealed in some cases considerable time differences. In particular, slow vehicles, such as agricultural vehicles, which cannot be overtaken in some sections, cause the average transport time to increase from about 20 minutes per trip to up to 30 minutes and more.

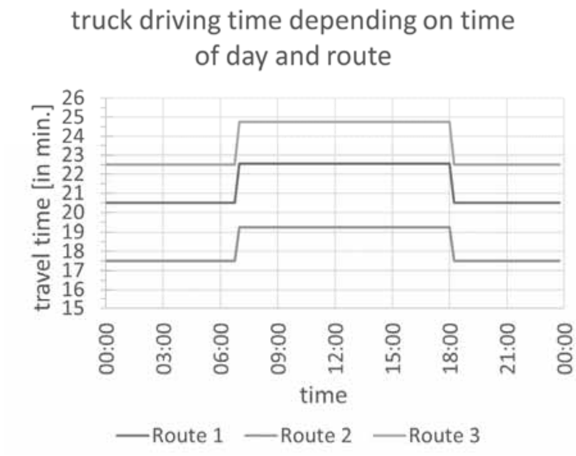


**Figure 7:** Average travel time per route and time.

In order to take these dynamic influences into account in the simulation as well, a transfer of the recorded trip data into an appropriate distribution (per weekday and time) is necessary. However, the amount of recorded data was not sufficient to derive such a distribution. Only the average transport time from Figure 7 was determined and confirmed by the empirical experience of the truck drivers.

Nevertheless, in order to derive an appropriate distribution of travel times, empirical values of the statistical fluctuations in the ETA calculation for short distances (10 to 30 km) were used [12]. With this information, the distribution of travel time for the simulation was modeled. Figure 8 shows such a distribution for Route 1 and the time of day 12:00. Finally, these distributions were also validated with the experienced truck drivers and checked for plausibility.

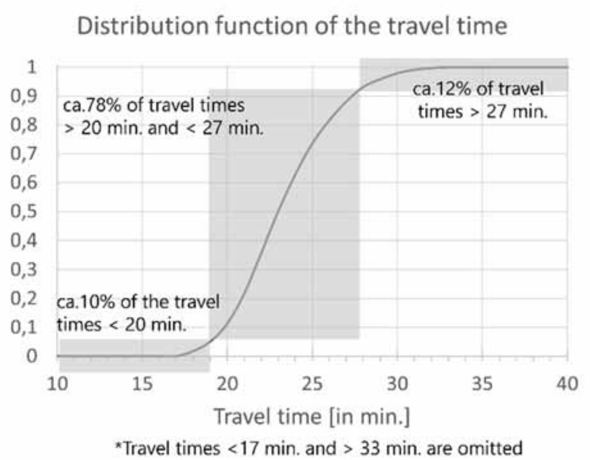


**Figure 8:** Distribution function of travel time for route 1 (12 o'clock).

## 4 Simulation Model

The simulation model is mapped in the WITNESS Horizon simulation software. For this purpose, the system components described in chapter 2 and the re-strictions explained in chapter 3 (load securing and maximum permissible load) were mapped, verified and validated.

The production lines are stored in the simulation model as a corresponding source. A production plan including setup times and cleaning shifts can be stored for each production line. The time to generate an EPAL is product-specific using the histograms described in chapter 4.

The transfer area maps the capacitive buffers between the respective production lines and automatic loading systems. In addition, a minimum dwell time is provided for this area, so that the corresponding transfer times are taken into account. A mapping of the control logic of the conveyors as well as like the respective conveyor speed is not necessary due to the negligible influence.

Following the transfer area, the simulative mappings of the automatic loading systems take place. The area ATLS-L marks the systems which are used for loading a truck. The area ATLS-U marks automatic loading systems, which are used for unloading a truck. An automatic loading system that performs both loading and unloading operations is not currently intended. With the loading systems shown, 30 EPALs can be loaded in approx. 2.5 minutes. In addition, the simulation model also provides for a reversing process of the automatic loading systems.

This is carried out as soon as there are residual pallets on the automatic loading system after the loading process. This occurs, for example, if there are 30 EPALs on the automatic loading system, but only 27 EPALs can be picked up due to weight restrictions. The three remaining EPALs then go through the reversing process.

In the case of the implemented ATLS, which are intended exclusively for unloading a truck, a simplified storage process is also implemented. This represents a simplified unloading of the corresponding ATLS. This ensures that after unloading a truck, another truck cannot be unloaded immediately. This is only possible once the corresponding EPALs have been removed from the respective ATLS. Since these storage processes are a manual activity, the storage time is provided with a corresponding Erlang-K distribution [10].

In the SE area is the provisioning of the empties. This is generated as soon as the demand is triggered in the production area. Subsequently, the provision of the necessary empty material takes place in a quantity of 30 EPAL in a time interval of approx. 25 minutes. After provisioning, the material is picked up by a truck. Due to the manual provision of the empties on the corresponding loading system, this time is also provided with an Erlang-K distribution.

The area R marks the implementation of the different routes. Here, the corresponding travel times incl. distribution (as described in chapter 4) are stored in the simulation model.

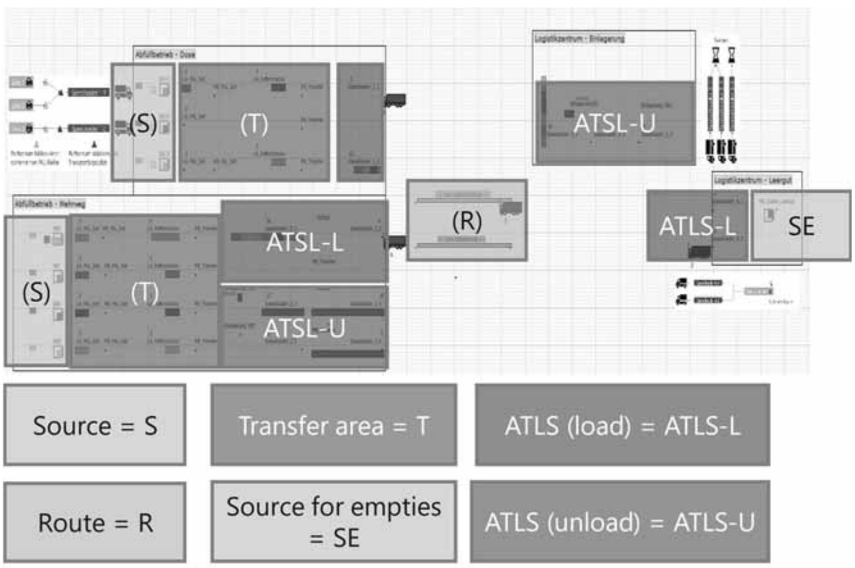


**Figure 9:** Simulation model overview.

For the outward as well as for the return journey one of the three routes can be selected in each case and thus the influence on the total system can be examined.

For the later analysis of the simulation model, various parameters and performance diagrams are implemented.

For example, the number of the respective transports including the number of EPALs transported, the weight of the payload and the kilometers traveled are recorded.

In addition, the utilization of the respective trucks per shift or the backlog behavior of the production lines are recorded.

This information can be used, for example, to examine how many trucks are needed depending on different production schedules and routes, and whether it is advantageous to use jumpers during breaks for the truck drivers.

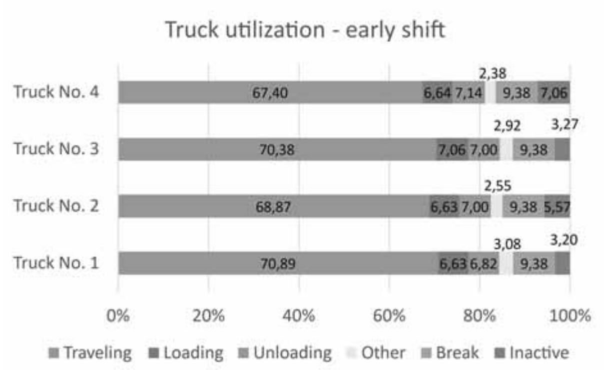


**Figure 10:** Example diagram - truck capacity utilization.

## 5 Results

With the help of this data, it was possible to evaluate different, realistic influences with regard to production planning and the significant influence of the driving time of the trucks. With only an average driving time and the respective peak load per production line, this would not be possible and a significant overdimensioning of the installations would be the consequence.

Among other things, it was possible to show what effect different production schedules (high output products vs. low output products) have on the risk for backlogging (see Figure 10). Especially during daytime periods with increased traffic volumes. This made it possible to derive corresponding recommendations for production planning, for example the production of certain product-line combinations at certain times of the day.

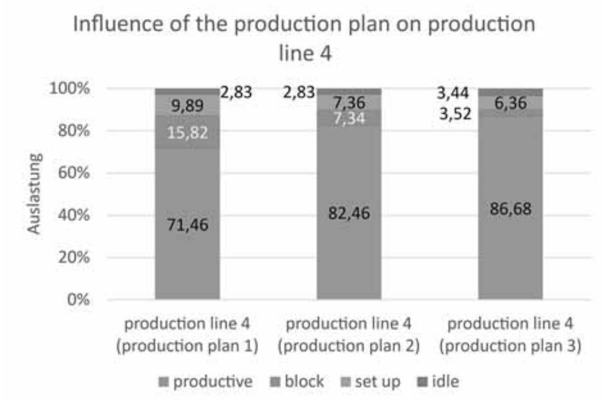


**Figure 11:** Comparison of the backlog of production line 4 with different production schedules.

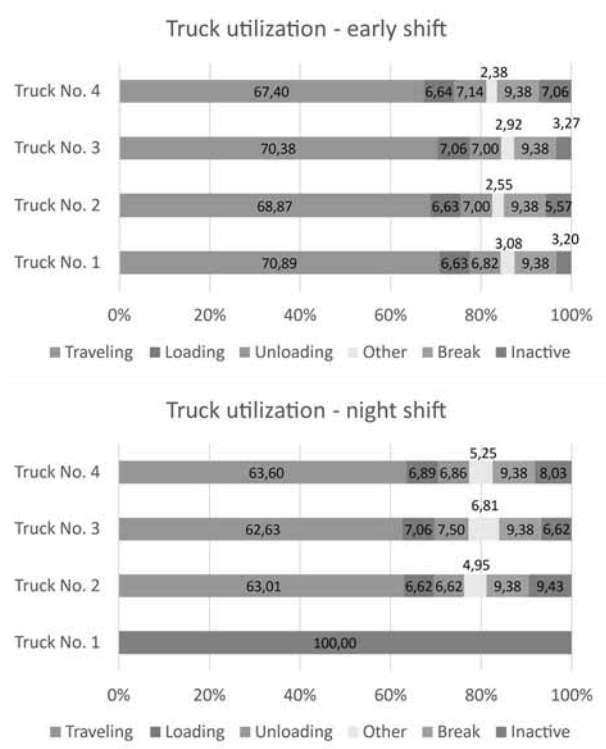


**Figure 12:** Utilization of trucks in early and night shift.

In addition, it was possible to show when there is an additional need for trucks or when a lower number is sufficient. For example, a number of four trucks is required for the production schedule in the early shift. During the night shift, on the other hand, 3 trucks are sufficient (see Figure 12). This led to initial considerations about implementing flexible personnel deployment in the area of truck transport and a dynamic break arrangement for truck drivers.

Furthermore, it could be shown that a higher loading capacity is available in production area 2 than for the unloading of finished goods from production area 2 in the logistics center. This resulted in waiting times for the trucks, as only an automatic loading system was provided for unloading the finished goods. The bottleneck here is not the unloading speed of the automatic loading systems, but the storage time in the downstream block storage. Thus, there was the possibility to invest in an additional loading system for the unloading of finished goods from production area 2. However, the simulation showed that breaking the strict allocation of an automatic loading system for the unloading of finished goods from production area 2 is sufficient to reduce waiting times to a minimum. Thus, no additional investment in another loading system is required.

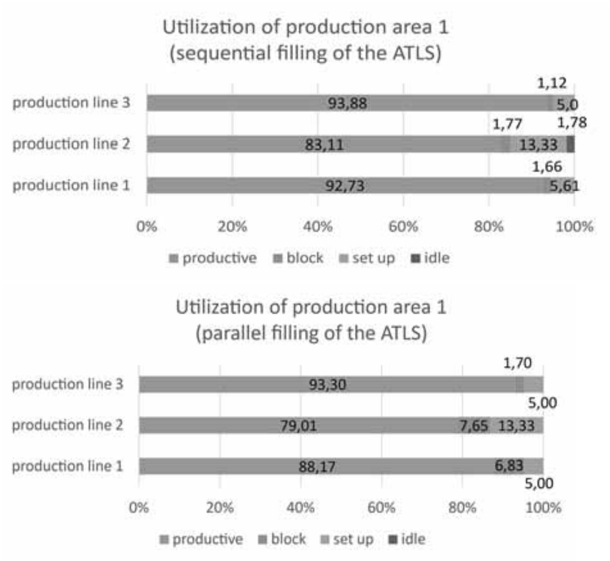


**Figure 13:** Influence of parallel and sequential filling of ATLS in production area 1.

The simulation was also used to check the connection of the production lines from production area 1 with the corresponding automatic loading systems. In initial concepts, as already described in Chapter 2, it was envisaged that production lines 1 and 2 would be connected to an automatic loading system, while production line 3 would be connected to the second loading system. Thus, production lines 1 and 2 fill the first ATLS while, in parallel, production line 3 fills the second ATLS. In the simulation, however, this led to a corresponding backlog in production lines 1, 2 and 3 (see Figure 12 - block). Only by adapting this concept was it possible to resolve the backlog. In the future, both automatic loading systems in production area 1 will be filled sequentially from production lines 1, 2 and 3.

In addition, further measures could be developed to optimize the corresponding transport concepts and reduce the risk of a production stop.

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