MODELLING AND ANALYSING THE IMPACT OF MANUAL HANDLING PROCESSES IN SEAPORTS

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ABSTRACT
The handling of general cargo in seaports is a time-consuming and resource-intensive activity. In order to sustain competitive, ports have to offer efficient handling processes, leading to short vessel laytimes and fast handling operations. A possible solution approach is the implementation of novel handling technologies. This paper evaluates the potentials of a magnetic device for the handling of steel metal products in seaports. Due to the dynamics of that specific handling process and the interlinks to other actors in the process a simulative approach is applied for analyzing possible benefits concerning the handling frequency.

Keywords: material handling, seaport, process time variation, simulation

1. INTRODUCTION

The traffic of cargo is exposed to an intensive growth during the last years. Especially, the world-wide maritime traffic is strongly affected from this trend (Stopford 2009, Amerini 2007). Accordingly, efficient handling and warehousing processes are necessary to handle the increasing traffic and to stay competitive (Zondaga et al. 2010). Technical innovations are a driving force in the development of ports and naval processes. Especially general cargo, which cannot handled with standard containers, comprise improvement potentials regarding technical automation. The handling of steel metal sheets is a classical example of such processes. This process is characterized by mechanical load handling devices like hooks, chains, ropes and belts, which are attached manually to the steel sheets. Thus, the handling of steel sheets is labour-intensive and inference-prone. Scholz-Reiter et al. 2010 identified four major weak points of these processes, and proposed the introduction of an innovative magnetic handling device. Especially, the process stability can be improved by this new technology. It is well known, that automation of processes provides lower process variability and a higher degree of process reliability (Hopp and Spearman 2008, Groover 2008, Gudehus 2005). In order to evaluate the potentials of this novel technology in the early phases of planning quantitave analysis are necessary. Scholz-Reiter et al. (2010) stated that the introduction of an automatic magnetic handling device may reduce the variations of process times in the manual attachment. In this context it is assumed that the implementation of a magnetic device will lead consequently to higher performance of the total process. This paper investigates the connection between the process stability (in terms of reduced standard deviations of manual process times) and the performance of the total process with a discrete event simulation model. Therefore, two different statistical distributions are implemented and compared regarding stochastic variations process times. This paper will demonstrate the impact of these variations on the performance of the total process.
Therefore, this contribution is structured as follows: Section 2 gives a description of handling processes and possible potentials of novel handling technologies. Subsequently, section 3 discusses possible sources of stochastic variations in process times. The simulation approach is introduced in section 4. On this basis section 5 presents the results of numerical simulations experiments. Finally, section 6 gives a summary and provides an outlook with further research directions.

2. HANDLING OF STEEL SHEET PRODUCTS IN SEAPORTS

The handling of steel products is a classical general cargo process. Due to the size (4m x 12m) and the weight (up to 8.5t) of the steel sheets a containerized handling is not possible. The handling is done piece or bulk wise. In the conventional case the handling devices can be attached to multiple steel sheets as a steel ply at ones. The number of sheets per handling operation depends on their weight. Normally, the crane, which is equipped with the mechanical handling device, can lift a weight up to 16t, which corresponds to two or three steel sheets (Scholz-Reiter et al. 2008).

The handling process can be divided into three parallel running sub processes: pick-up form storage, transfer to the bulk carrier and placing dunnage (Scholz-Reiter et al 2010). Figure 1 depicts the conventional handling process schematically.

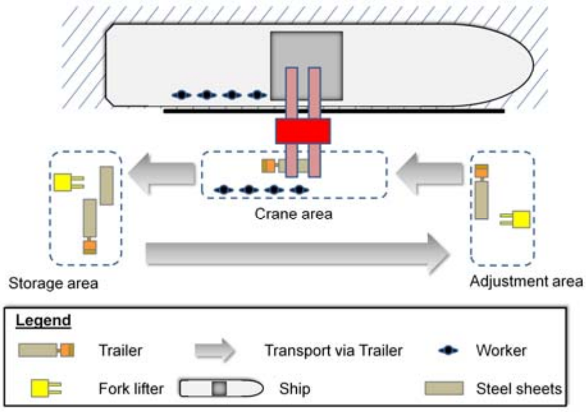

Figure 1: Scheme of the handling process (Scholz-Reiter et al. 2010).

The steel sheets are picked by a fork lifter in the storage area. By using a magnetic device the fork lifter is able to handle multiple sheets with one movement. It discharges the steel sheets on a special trailer which is designed to transport the steel sheet from the storage area to the crane area. Before handling with a crane, the steel sheets have to be adjusted in the so called adjustment area. Here a second fork lifter pushes the steel sheets in a predefined position. The crane can only pick up steel plies with a plain geometry. Thus, the process step of adjustment is necessary. Subsequently, the trailer transports the steel sheets directly to the crane area. In this area the crane lets down the mechanical handling device which consists of chains and four handling claws. Four workers attach these claws to the steel sheets. After the attachment, the workers have to press manually against the claws until the crane lifts the sheets slightly. This slightly lifting of the steel ply causes the correct mechanical force transmission between load and the handling device. After this step the workers leave the danger area near the hanging load. The crane waits until all workers are out of the danger area and turns the load into the ship. Inside the ship again four workers detach the material handling claws from the latest steel ply. After the detachment they place timber beams as dunnage on this ply. This step is indispensable for the unloading procedure in the port of destination. Without placing the dunnage there is no jacking point for further handling in this port.

Scholz-Reiter et al. (2010) identified four major weak points in this process and proposed a solution on the basis of a magnetic handling device. Figure 2 presents these weak points and the corresponding potentials of the magnetic solution.

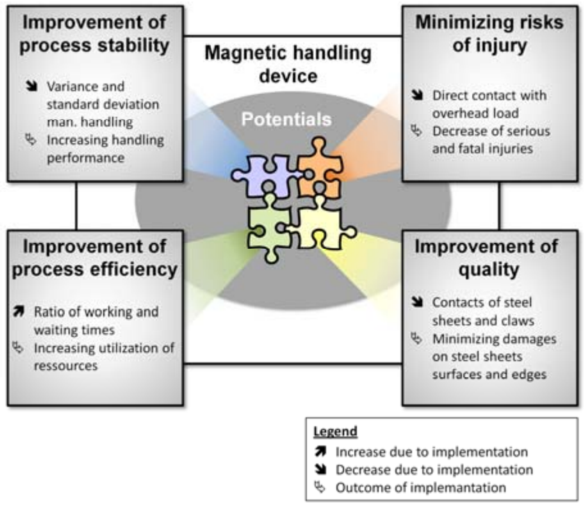

Figure 2: Weak points of the mechanic handling process and potentials of a magnetic handling technology.

The implementation of this technology minimizes the risk of serious injuries (e.g., bruises) during the attachment of the claws. Bruises are besides fractures a common type of injuries in the maritime sector (Ellis et al. 2010). Furthermore, it reduces the risk of scratches on the surface of the steel sheets. This effect helps to improve the product quality of the handled goods.

From an economical point of view the process stability and the process efficiency are crucial points. The manual attachment of the material handling claws is the bottleneck of the entire process. Due to the manual attachment there are deviations in process times. These deviations may affect the process times of subsequent steps. A result of these process delays is a reduced frequency of crane moves which corresponds to lower performance of the entire handling process. Table 1 confirms this assumption. It presents real process data concerning the handling process. The original data comprises data of 46 shifts. Table 1 presents the main performance indicators extracted from this dataset.

Table 1: Process performance

performance indicator	value
average amount of crane moves *[moves/shift]*	151.18
standard deviation *[moves/shift]*	41.43
average tonnage *[t/h]*	187.6
standard deviation tonnage *[t/h]*	64.97

In this context a crane move describes the complete cycle of the crane movement starting and ending at the same point (Arora and Shinde 2007). Table 1 shows a high proportion of standard deviation concerning the average amount of crane moves per shift. According to Hopp and Spearman (2008) the process variability can be defined by the coefficient of variation (CV), which is the ratio of standard deviation and mean value. In the case at hand the CV is CV=0.274 for the average amount of moves per shift. Regarding the tonnage this proportion is even bigger (CV=0.346). In both cases the CV indicates that these processes underly strong variations.

It is assumed, that a reduction of standard deviations in this process step leads to higher handling quantities in the total process. Due to the strong interdependencies in this process (cf. Figure 1) an analytical analysis of the impact of standard deviations in the attachment processing times seems to be challenging. Thus, this objective paper proposes a simulation based approach for this analysis. In the following sources of variations in process times of manual attachment are discussed.

3. PROCESS STABILITY OF MANUAL PROCESSES

The problem of variability of processing times is not only limited to the material handling in seaports. Mapes et al. (2000) stated that the variability of processing times at single stations of production systems is a major driving force of the increasing complexity in planning and scheduling the overall production activities. In this context variability causes longer throughput times thwarts the delivery reliability, decreases the utilization of the system and lowers the productivity. The occurrence of variability in process times has different sources (Hopp and Spearman 2008):

- Natural variability: this category includes the inherent deviations which are caused by manual operations. It describes variations occurring in normal operations.
- Preemptive outages: unscheduled break downs of machines or resources belong to this category
- Nonpreemptive outages: downtimes of machines or resources which can be scheduled (e.g., maintenance activities)
- Rework: variability in the process output due to deficits in the product quality. This category also includes variations in the resources availability due to reworking activities.

In order to evaluate the potentials of the magnetic handling device against the current situation with the manual attachment especially the first category of the natural variability is of importance. This category comprises the characteristics of manual operations under normal operational conditions. Conventional approaches like the Methods-time measurement (MTM) methods aim at estimating mean values of manual activities, but they are not suitable to determine variability in these operations (Turek and Krengel 2007). Different authors propose modeling with statistic distributions like the normal distribution (e.g., Tiacci and Saetta 2007), exponential distribution (e.g., Doerr and Arreola-Risa 2000) or the weibull distribution (e.g., Buxey and Sadjadi 1976). Due to the characteristic of manual operations manual work studies showed that often distributions with a positive skew are observed. Turek and Krengel (2007) investigated empirically processing times of manual order picking activities. In this context they stated that the type and the shape of the underlying distribution (skewness) may depend on the process type. On this basis this contribution uses two types of distribution for the analysis. First, a normal distribution is used due to its comprehensibility. Second, a gamma distribution is used as a representative of a positive skewed distribution.

4. SIMULATION SCENARIO

The general scenario depicted in Figure 1 can be modeled as a closed queuing network with three service stations as indicated in Figure 3.

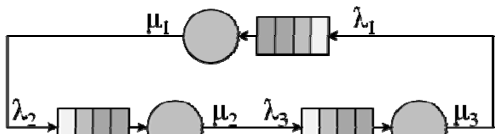

Figure 3: Scenario representation as queuing network.

All processes in the respective areas are modeled as service station with a certain service rate (μ_1, μ_2 and μ_3). The round course movement of the trailers in this model is given by the arrival rates (λ_1, λ_2 and λ_3), which directly depend on the service rates of the servers. The amount of jobs in closed queueing networks is fix and known in advance (Bocharov et al. 2004). In this case the amount of jobs represents the amount of trailers used in the process. In the case at hand, the service stations 2 and 3 represent the processes in the storage area and in the adjustment area and station 1 stands for the crane area. In order to evaluate the impact of randomness and standard deviations of the manual attachment, service rate μ_1 is modeled by statistical distribution. The remaining service rates are kept constant in the simulation study. Additionally, the service rate μ_1 covers the movement of the crane. This means that a succeeding trailer can only be severed, if the crane completes an entire move. Thus, a recovery time is modeled for this station. This is done by defining a minimum cycle time C_m for the crane move.

A further constrains coming from the real process is the transport distances between storage and the crane area. These distances are considered by traveling time for passing theses distance, denoted by d. The duration of the non handling processes is cumulated in D and defined as follows:

$$D = d + \mu_1 + \mu_2 \tag{1}$$

In the real world process the amount of trailers is determined by the distances. Accordingly, the planning of the trailer operations aims at balancing the total process times and increasing the utilization of the crane. Before starting the process, the amount of trailers (n) is determined as follows:

$$n = \text{int}\left(\frac{D}{E(\mu_1) + C_m}\right) + 1 \tag{2}$$

In the case that the remainder of the division equals zero the amount of trailers is ideally attuned to the processing times of the crane. The simulation study focuses on three different degrees of trailer balancing: a balanced situation, an under-balanced situation and an over-balanced situation. All degrees are based on a predefined travel time D_0 according to equation 1. The under- and over-balanced situations are generated by the introduction of a scale factor δ, which compresses or stretches the predefined travel time D_0:

$$n = \text{int}\left(\frac{\delta \cdot D_0}{E(\mu_1) + C_m}\right) + 1 \tag{3}$$

Accordingly the situations are defined as follows:

- The balanced situation δ=1
- The under-balanced situation δ<1
- The over-balanced situation δ>1

In order to model variation in the process times of station 1, the processing rate μ_1 is set to different probability distributions: a normal and a gamma distribution are chosen. The simulation results, using both types of distribution will be compared.

A disadvantage of the normal distribution in this case is the modeling of the lower bound of the cycle time of the crane. A normal distribution has an infinite co-domain, which contradicts the modeling of a lower bound. However, this is taken into account by cutting off random values below this lower bound. The gamma distribution seems to be more suitable to the case at hand. This distribution is defined in the interval [0,∞]. Hence, a lower bound of processing times can be defined by shifting the distribution to this lower bound. The distribution is described by two parameters α and β, which determine the expectancy value and the variance. As mentioned before, the variance is seen as running variable and the expectancy value is kept constant. Thus the parameters used for building the corresponding gamma distributions are given by:

$$\alpha = \frac{E(\mu_1)^2}{Var(\mu_1)} = \frac{E(\mu_1)^2}{\sigma_{\mu_1}^2} \tag{4}$$

$$\beta = \frac{\alpha}{E(\mu_1)} \tag{5}$$

Figure 4 depicts exemplarily different density functions of the gamma distribution with a fixed expectation value and different variances.

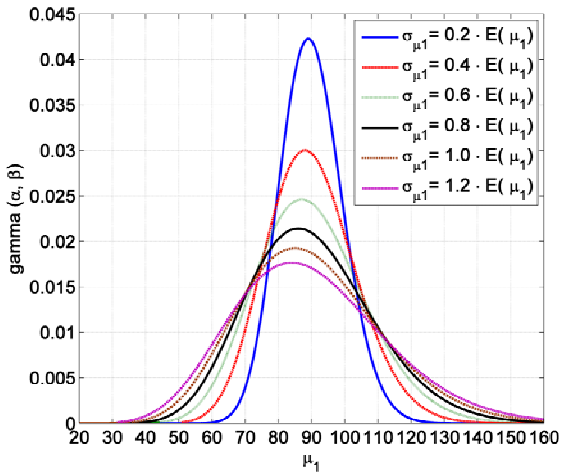

Figure 4: Density functions of the gamma distribution with constant mean value $E(\mu_1)$=90 and varying standard deviation

Due to the mentioned extensions, like modeling with normal distribution or recovery times, a conventional modeling of the scenario as a standard closed queuing network and an analytical evaluation is not possible. Thus, the scenario described is implemented to a discrete event simulation model and analyzed by the evaluation of different simulation experiments.

5. SIMULATION AND RESULTS

5.1. Simulation setup

According to these preliminary considerations a set of simulation experiments is defined (Table 2). Thereby, the trailer balancing is defined by the variable δ. An under-balance situation is represented by the choice of δ<1. With δ=1 a balance situation is considered. By contrast, the choice of δ>1 an over-balance situation is modeled. In addition to this, the variance in every simulation run is varied as a percentage value of the predefined expectation value $E(\mu_1)$ in steps of 1%.

Table 2: Simulation setup

Parameter / variable	Type	Value	Dimension
D_0	constant	600	seconds [s]
C_m	constant	210	seconds [s]
$E(\mu_1)$	constant	90	seconds [s]
$Var(\mu_1)$	variable	{0.01· E(μ_1) .. 1.2· E(μ_1)}	seconds [s]
δ	variable	{0.5, 1, 1.5}	[-]

The evaluation of a specific parameter constellation is done by calculating the number of moves per hour of a simulation run. In order to reduce stochastic effects, a certain parameter constellation is simulated 10^3 times.

The average number of moves per hour is used for the evaluation.

5.2. Simulation results

Figure 5 presents the results of the normal distribution. It depicts the average number of moves per hour for each combination of δ and σ. Additionally, the black dotted plane in Figure 5 indicates the theoretical maximal amount of moves per hour on the basis of the expectation value and the recovery time of the crane.

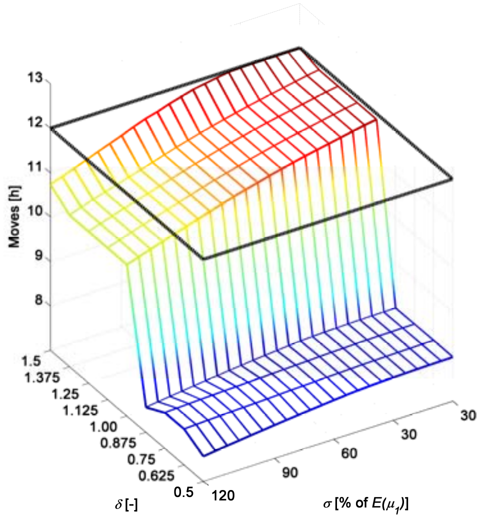

Figure 5: Simulation results of the normal distribution

As expected, in the under-balanced situation the performance is lower compared to the balanced and over-balanced situation. This effect is mainly caused by the lower number of circulating trailers, which lead to waiting times of the crane. Accordingly, the crane is underutilized and the average number of crane moves is lower compared to both other situations. However, the impact of rising standard deviations in the manual attachment process can be already observed in the under-balanced situation: The average amount of crane moves per hour decreases with an increase of the standard deviation.

This effect is even stronger in the balanced and over-balanced situation. In the balanced situation the performance of the process decreases on average about 0.07 moves per hour with an increase of the standard deviation of one unit. The biggest performance difference in the balanced situation is 12.22 %. A similar impact of the process variations can be observed in the over-balanced situation. For lower values of the standard deviation the process performance is near to its maximal capacity, but with an increase of the standard deviation the total performance of the process decreases like in the balance and under-balanced situation.

Similar effects can be observed for the second distribution type used in this study. Figure 6 presents the simulation results for the gamma distribution for each combination of δ and σ. In order to provide comparability with the previous simulation run the black dotted surface represents the maximal possible performance for this scenario. Similar to the results of the normal distribution, Figure 6 shows steps in the total performance depending of the chosen value of δ. The impact of the standard deviation is comparable to figure 5. Only the results for δ=1.5 differ. From this point an additional trailer is required. In this particular case the performance decreases slightly with an increase of the standard deviation.

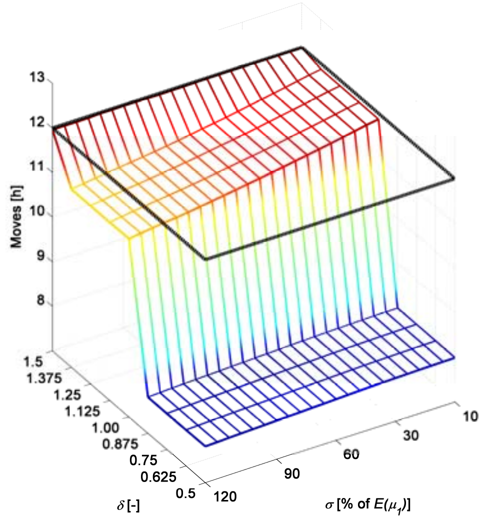

Figure 6: Simulation results of the gamma distribution

According to this result the impact of increasing variance can be compensated by an over-balance situation. Although an over-balanced operation compensates these effects and leads to a higher utilization of the crane, it causes to worse utilization of resources like trailers. In the case at hand the average utilization of the trailers for δ=1.5 is 49.59% compared to 62.78 for δ=1.

Summarizing the results of the simulation study it can notice that the impact of process time variations is similar for both distributions (normal distribution and gamma distribution) in the balanced and under-balanced case. There are only differences for the highly over-balanced situation (δ=1.5). In this case the performance decreases less with an increasing standard deviation by applying a gamma distribution. A detailed view on the utilization of the trailers showed, that this compensations is won by the expense of low trailer utilization.

6. SUMMARY AND OUTLOOK

This paper presented an analysis of the impact of process variations on the performance of the specific handling process in seaports. A general model of the process has been introduced and implemented to a simulation model. The detailed analysis of the simulations results showed a characteristic curve of the

process performance depending on the process variations. For this purpose two different statistic distributions were under consideration. The results show the sensitivity of the process against variations in process times for both types of distribution. A comparison of the trailers utilization shows a potential tradeoff dilemma between sensitivity against variations and the trailers utilization for the gamma distribution.
In general these results indicate that a reduction of variations in process times, i.e. induced by a magnetic handling device, leads to a higher process performance. This effect occurs especially in the balanced situation, which characterizes the normal operation mode.
Further work will focus on a holistic evaluation of the implementation of a magnetic handling covering process related and an economic analysis.

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