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Simulation of Mental Workload in a Logistics System

Simulation mentaler Belastung in einem Logistiksystem

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Abstract: In the current paper, we present a modelling approach that integrates the attentional resources of employees into a simulation model. The investigated work system is a distribution centre in which employees pick articles from multiple racks (picker-to-part method). Automated guided vehicles are operating in the work system and share certain paths with the employees. Mutual obstructions or collisions can occur depending on the individual attention level of the employee. Effects of different model parameters are analysed within the dynamic simulation environment by running an analysis of variance. Meaningful prediction regarding different attentional states in a working environment can be derived from this theory-based model.

1 Introduction, Motivation and Problem Description

These days changing market demands, shorter product life cycles, and increased product variety require higher flexibility of production and logistic systems. In the context of Industry 4.0, new technologies are emerging that connect the real world with the virtual world. While most young people are enthusiastically adopting new technical devices, especially older people are struggling with ever faster technological change. We are facing a trend towards a continuously ageing working population causing a need to adapt to this change by providing appropriate working environments for elderly workers (Harper 2014). The implementation of new technologies leads to changes in the physical, cognitive, and psychosocial demands of the working environment. Thus, the successful adaptation of new technologies in an existing work system is of high importance (Caple 2019). Further, there is a significant difference between the cognitive, sensory, and motor abilities of different age groups (e.g. Craik and Salthouse 2008). The method of simulation, which is already used for planning and improving the structures and resources of a factory (VDI 3633, 2014), can also be used to model these individual differences. In the current paper, we combine psychological models and data with the capabilities of simulation in order to gain new insights and make work systems more employee-friendly. Thereby, we particularly focus on the employees' mental resources and attention.

A work system consists of seven elements: task, workflow, input, output, worker, work equipment, and environmental factors. In our study, we focus on the worker, while the other elements form the system's environment. The specific work system is a distribution centre including order picking where each order consists of multiple picking operations (picker-to-part method). In such systems, the proportion of manual work is high. Thus, the human factor has a significant impact on the performance of the work system.

As mentioned earlier, the impact of new technologies has to be taken into account when designing work systems. Thereby, physical, cognitive and psychosocial effects on employees as well as the interaction between technology and employees are important aspects that need to be considered. For example, in the field of intralogistics order pickers usually are supported by dedicated devices such as pick-by-scan, pick-by-voice, pick-by-light, or pick-by-vision. The picking methods determine the effectiveness of the picking process and the cognitive workload of the workers. We assume that different picking devices bind attentional resources to different degrees. Attentional resources occupied by a picking device are no longer available for the perception of and interaction with the working environment. This state of limited attention causes potential critical situations, i.e. when humans and autonomous robots interact in the same environment. Previous research revealed that especially older people are negatively affected by task requirements which require shared attention (e.g. Scialfa et al. 1994). For example, obstacles such as autonomous vehicles are perceived too late and the risk of collisions increases when engaged in a demanding task.

2 State of Research

The main task of ergonomics is to assess the impact of technology and work systems on human workers. There are approaches in the field of production and logistics that facilitate the method of simulation for the analysis of ergonomic aspects. Nevertheless, ergonomic considerations of work systems often focus on physical aspects of the musculoskeletal system. Müller and colleagues (2015), for example, introduce a simulation tool for the age- and stress-based assessment of work systems by modelling the physical capabilities of workers. Pakdamanian and colleagues (2016) point out that many simulation studies on ergonomics focus on physical aspects of working conditions, rather than psychological aspects. For instance, mental workload on the employee varies with differential aspects of the work system, such as different technical devices used to support order pickers. In this respect, Caple (2019) indicates that ergonomic requirements for repetitive work involves a greater requirement for cognitive and psychosocial skills and less on the physical capacity, as technical resources already reduce the physical workload.

Pakdamanian and colleagues (2016) provide a proof of concept on the importance of workers' emotional state and its impact on the productivity of the manufacturing system. They suggest the use of simulation to address psychological difficulties (e.g. emotional and cognitive factors) that may affect worker efficiency beyond physical ergonomics. The novelty of their approach is that they integrate psychological aspects into a discrete-event simulation model. This was done by transferring collected data into a matrix, which assigns a factor to an employee according to his discrete emotional state. During the simulation, the processing times of manufacturing processes were then manipulated by the factor that applies in the situation. Although this approach includes data with psychological aspects, it does not attempt to model the employee as a separate interacting element of the system.

Our modelling approach specifies individual agents with different levels of attention and variable probability of being distracted. In order to evaluate the influence of parameters determining the attention model and their effects on the work system we developed a simulation model of a distribution centre including order picking. The system is characterised by the fact that order pickers and Automated Guided Vehicles (AGV) interact with each other which can be considered as human-robot interaction (Onnasch et al. 2016). For the analysis, the number of critical encounters between order pickers and AGV are of particular interest. A critical encounter occurs when an order picker is distracted (or inattentive) and collides with an AGV. A collision does not necessarily lead to a physical contact, but the order picker as well as the AGV are hindered in their intended motions.

3 Modelling

For the purpose of this paper, the modelling method is of particular interest. Thus, in section 3 the attention model and the implementation into the simulation model are introduced. In subsection 3.1 the concept of modelling attention resources is described. Subsection 3.2 follows with a description of the simulation model and the integration of the attention model in the simulation software AnyLogic 8.4.

3.1 Attention Model

The model integrates some simplified assumptions about attentional processing. For purpose of simulation, attention is determined by the width of the attentional focus and by the duration of the attention alignment. With respect to the width of the attentional focus, attention is considered as a selective gate mechanism which is comparable to a spotlight (Posner and Petersen 1990). According to this ideas, visual processing in visited ("illuminated") spatial regions is improved. The size of such a spotlight can be up to several degrees of visual angle (Sagi and Julesz 1985) and may be modified according to task demands (e.g. zoom-lens model, Eriksen and St. James 1986). An alternative notion of the spotlight metaphor is the "useful field of view" (UFOV). According to Ball and colleagues (1988) the UFOV is the visual field in which suitable information can be acquired without any eye and head movements. We assumed a maximum UFOV with a width of 60° (Ball et al. 1988) for order pickers in our model. Further, we modelled a distance of 4.5 m for the UFOV according to the findings of Kitazawa and Fujiyama (2010). They investigated the Information Process Space (IPS) which includes all potential obstacles by examining pedestrians' gaze patterns (see also Rios-Martinez et al. 2015).

In order to model the attention alignment, we followed ideas from traffic psychology about distraction towards displays and control panels. For example, it was reported that participants looked at potential distractions for about 1 to 2 s per instance (Zwahlen et al. 1988). We used the same average duration per distraction in our model. Moreover, circadian performance differences have been shown in a wide range of tasks. These variations can be influenced by factors such as fatigue and other physiological parameters. Several studies have shown that task performance is better in the morning than in the afternoon. This holds true for a variety of tasks like simple response, search and memory tasks (Rutenfranz and Colquhoun 1979). In our simulation, we subsumed these cognitive performance differences under the factor 'fatigue' and assumed that performance decreases with time. Hence, influence is lower in the first 4 hours of the simulation than in the second 4 hours.

3.2 Simulation Model

In logistic systems, discrete event simulation is an efficient method to investigate handling performance with varying system loads, productivities of resources, and interdependencies of processes (Clausen et al. 2013). Our model represents a distribution centre in which order pickers carry out a typical picking process. We developed the model with the simulation software AnyLogic 8.4. This Java-based simulation tool enables the modelling and simulation of logistic systems based on libraries containing building blocks. The libraries allow to use different simulation techniques such as discrete event simulation, system dynamics, or agent-based simulation. In addition, the building blocks can be individualised by adding code to enable an appropriate representation of the desired processes and system elements. Thus, it offers freedom in modelling and allows us to create the order pickers - or any other agent - in the required level of detail.

The model represents a work system within a typical distribution centre. In the distribution centre AGV and order pickers share two main driveways. This form of human-robot interaction is called 'coexistence' because they operate in different processes with different goals (Onnasch et al., 2016). In addition, the interaction is limited to a designated area in which AGV and order pickers may encounter. The layout shows the rack system, the order drop-off points, and the designated paths of possible encounters (see Fig. 1).

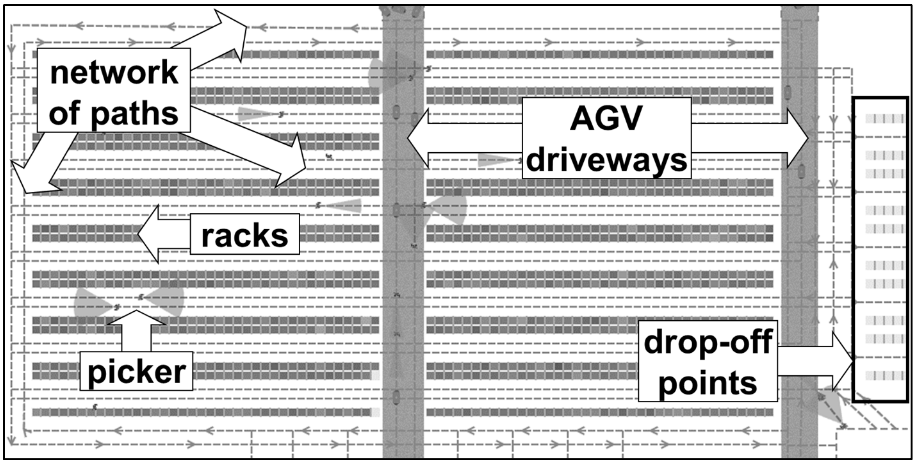

Figure 1: *Top view of the distribution centre model*

The simulated distribution centre consists of 18 racks, which store a total of 6,000 articles each. The orders are processed by 16 order pickers in an 8-hour shift, each order picker processes one order at the time. We use flowcharts to represent the logic of the picking processes as well as the AGV movements within the system. Orders are generated randomly and determine the corresponding articles to be picked. An order is then assigned to a random available picker and then executed. The quantity of picks per order is equally distributed between one and fourteen articles. An order picker must collect all of these articles from the corresponding racks and deliver them to a drop-off point to complete the order. After one order has been completed, the next one is started immediately, thus ensuring that order pickers in our model are operating at full capacity. As an order picker pursues his task, he moves on a network of pathways. Designated paths of the same network are also used by AGV who pursue an unrelated transport task in the distribution centre. This results in two zones in which potential obstructions or even collisions may occur. The occurrence of such an incident depends on the attentional state of an order picker. Since an attentive employee can avoid the AGVs, it is important to include the order pickers' states of attention into the model. Therefore, the attention model described in 3.1 is adopted into the simulation model by using an agent-based approach. Thus, the order picker is modelled as an individual agent that interacts with its environment in which it is located (Macal 2016). In order to represent the behavior and mental state of order pickers, the state chart shown in Figure 2 is implemented into each order picker agent.

States and state transitions of an order picker can be described as follows: Initially, an individual order picker is idle. As soon as he receives an order, he starts walking to the rack that contains the desired article. While he moves to his destination, his state of attention can alternate between vigilant and distracted. The distraction frequency, which we determine as potential distraction events per minute, can cause the state change from vigilant to distracted. However, every potential distraction event does not lead to an actual distraction. The probability of being distracted is determined by an individual parameter as well as by the assistive device the order picker is using. For simplification, the distraction probability is currently implemented by subdividing the order pickers equally into two main groups. Order pickers of the distraction-resistant group have a UFOV of 60° and are exposed to the simple probability of experiencing a distraction. Alternatively, likelihood of being distracted is twice as high for order pickers of the group that is susceptible to distractions. Additionally, these order pickers only have an UFOV of 20°. The probability of critical incidents is increased in the second half of the work shift for both groups to reflect effects of fatigue. Order pickers reaching a target rack, spend a few seconds in the handle state until they can continue walking to the next rack or drop-off point.

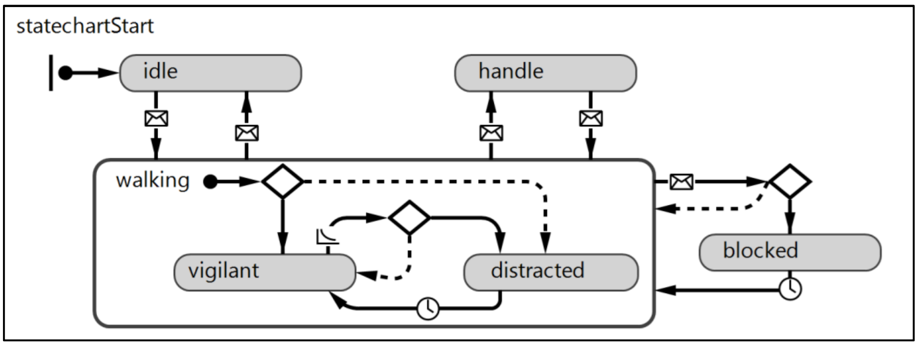

Figure 2: *State chart of order picker agents*

In the case that an order picker is in the state "distracted" while walking through the AGV driveway, he is exposed to the risk of obstructions and collisions. This incident occurs when all of the following conditions are true (see Fig. 3):

- an AGV approaches the order picker from outside the UFOV,
- an order picker is located within a radius of one-meter around the AGV,
- an order picker is in the state distracted.

Consequently, a collision is the result of several randomly influenced conditions. The number of these incidents is tracked in order to run a databased analysis. In the simulation, the order picker as well as the AGV stop for a few seconds before they continue their task.

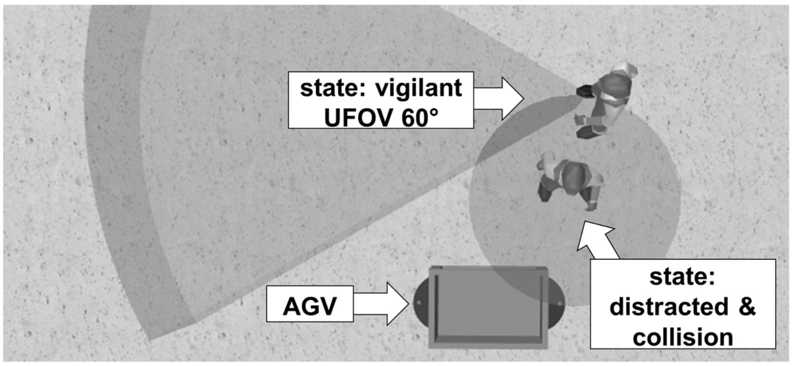

Figure 3: *3D visualisation of a vigilant order picker and a collision of a distracted order picker with an AGV moving through one of the main aisles.*

For the verification and validation of the model, we followed the applicable methods described by Gutenschwager and colleagues (2017). The temporal behavior of the model and the correct case discrimination in potential collision events were validated with the help of trace analysis and animation. The credibility of the model was checked by observing the detailed behavior of the animation during the simulation run as well as by analysing the information from the trace analysis in parallel and afterwards. In addition, the *Structured Walkthrough* procedure was carried out (see Gutenschwager et al. 2017).

4 Application and Results

On the basis of a three-factorial design individual agents are generated with different fatigue states (true, false), distraction probabilities (low, high) and distraction frequencies (low, high) for the simulation experiments. For each factorial combination, several simulation runs are performed. Subsequently, the number of collisions is submitted to an ANOVA with repeated measures. Results show that a higher degree of fatigue increases the risk of collisions. Similarly, for order pickers with a high probability of distraction, there are about twice as many collisions as for order pickers with a lower probability of distraction (see Fig. 4). Furthermore, the risk of a collision also increases with the frequency of distraction. In addition, interactions between the manipulated factors were also evident. The risk of collisions increases more for order pickers with a high probability of distraction when they are tired and when the frequency of distractions is increased. The results show that our modelling approach is able to represent possible effects of different attention levels of the employees.

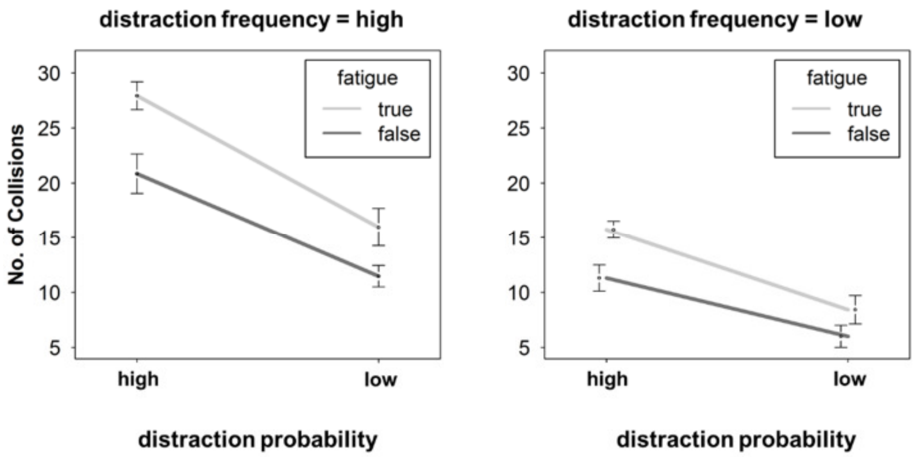

Figure 4: *Result of mean number of collisions separately for both simulated groups*

5 Conclusion

The paper presents a modelling approach that focuses on the impact of different attentional states in a discrete event simulation. Our findings show that meaningful results can be obtained based on assumptions from the literature. Both factors, fatigue and distraction frequency, have significant impact on collision probability. However, the presented modelling approach is only a first step to represent the employee adequately in a work system. Now, the aim is to further improve the approach and to add details to both the attention model and the simulation model. For instance, it was suggested that aging is associated with a restricted UFOV (Scialfa et al. 1987). In addition, the data suggest that age differences in visual search can be described by a model in which older adults take smaller perceptual samples from the visual scene and scan these samples slower than young adults. Such findings suggest that modelling should not only take the duration of attention alignment into account but also the width of the UFOV (see also Sekuler et al. 2000). Therefore, we want to empirically investigate the relationship between the age of the order pickers and the picking devices used to incorporate these aspects into the simulation model. In addition to age, we plan to integrate other parameters that determine the order picker, such as mental stress and reaction speed. Finally, the AGVs and their driving behavior, speed, braking distance, and sensor ranges may be further refined.

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