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Development of a VR planning model of a river lock for risk assessment in the construction and machinery industry

Peter Nickel [1*], Eugen Pröger [2], Rolf Kergel [3], Andy Lungfiel [1]

[1] Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA)
[2] Federal Waterways and Shipping Administration (WSV, FVT), Germany
[3] German Social Accident Insurance Institution of the Federal Government (UK-Bund)

Abstract

There is a growing interest in prospective risk assessments to enable design improvements early in machinery development. Though simulation-based methods such as virtual reality (VR) may provide assistance for risk assessment, knowledge available about the suitability and effectiveness of a VR planning model in the future context of use is rather limited. Based on planning information available, a dynamic VR planning model of a river lock has been developed in 1:1 scale and visualised for risk assessment. VR considerably supported the risk assessment of a future river lock. The risk assessment yielded improvements with regard to the operational concept and allowed for identifications of hazards and design flaws. Results could be fed back into the planning stage. The project therefore facilitated ergonomics and safety through design and supported prevention for occupational safety and health from early on.

Categories and Subject Descriptors (according to ACM CCS): H.1.2 [Models and Principles]: User/Machine Systems—Human factors, I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—VR.

1. Introduction

Developments with regard to the Machinery Directive [Dir06] resulted in new challenges for machinery safety and design. There is a growing interest in prospective risk assessments to enable design improvements early in machinery development. Risk assessments in practice often benefit from functional knowledge, experience with similar machinery, mental simulation and imagination in order to compensate for incomplete predictions of machinery in future contexts of use [WH00]. Increasingly, this is supported by model based simulation and animation methods for machinery components (e.g. 3D CAD), for whole machinery (e.g. mock-ups), and for contexts of use (e.g. work system).

Simulation-based methods such as virtual reality (VR) may provide assistance since it has been matured to support systems analysis, design and evaluation [SC12]. VR has the potential to bridge gaps between laboratory and field studies. The knowledge available about the suitability and effectiveness of VR model based simulation for machinery in the context of use to support risk assessment at early design stages, however, is rather limited [Wil00, Mää07, DGJS13].

Since it has been established that river locks are machinery, risk assessments are being mandatory [Dir06]. This seems reasonable because re-design due to safety issues would be highly resource-demanding, if not impossible, when river lock construction has already been completed. Because of uncertainty about whether and how VR may be of benefit for risk assessments, a project has been initiated by the German Social Accident Insurance Institution of the Federal Government (UK-Bund). The Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) in cooperation with the Federal Waterways and Shipping Administration (WSV, FVT) were asked to investigate VR support for risk assessments.

2. Methods

River locks are treated as machinery and therefore mandate risk assessments [Dir06]. Among 13 locks of the River Neckar that will be extended over the next two decades, lock Kochendorf has been chosen as a prototype (see Fig. 1, top). It will be the first to be extended in reality. Currently, Kochendorf allows locking of river barges with a

* peter.nickel@dguv.de

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length of 110 m and a width of about 11.45 m at maximum. In future the River Neckar locks will be extended to allow locking of river barges of 135 m [Len07, NLH*12].

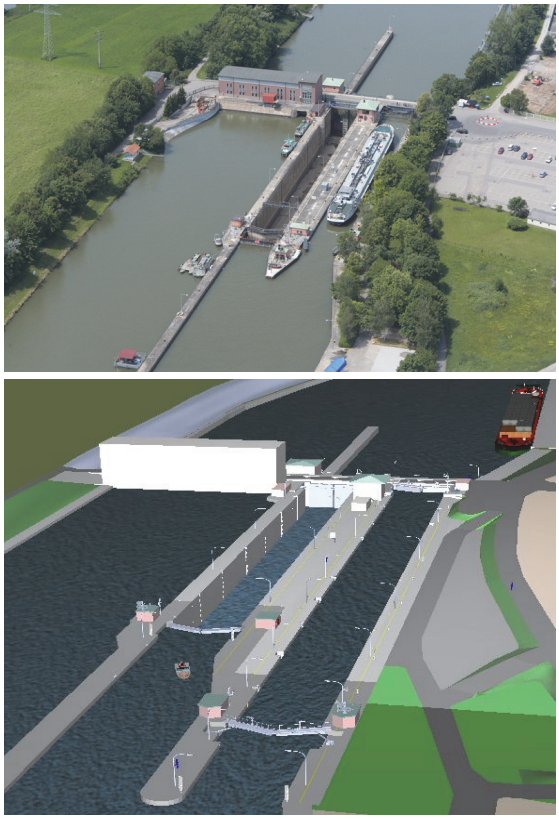

Figure 1: *River Neckar lock Kochendorf as of today (top, © Wasser- und Schifffahrtsamt Heidelberg) and VR planning model for the future lock (bottom)*

Because risk assessments should be performed similar to reality it was seen necessary to set up a model of the river lock within specified contexts of use. In addition, it has been seen important to simulate the prospective design for an extension of the specific river lock in 1:1 scale intending to serve risk assessments in line with [EN10]. This calls for a three step procedure in risk assessment starting with risk analysis, followed by risk evaluation and resulting in risk reduction [Mää07, NLH12, DGJS13].

In industry and services, VR has grown into a simulation tool for humans to interact with virtual environments and into a methodology for applied research in human-machine system design and evaluation. VR can facilitate assessments of fully functioning machinery in realistic work scenarios, of safety concepts for future work systems, and of the usability of safety measures in the context of use without placing operators or others in danger [SC12, NLN*12, HEV*07, NLNT13]. The SUTAVE laboratory of the IFA (www.dguv.de/ifa/sutave) offers effective prevention through design in occupational safety and health to be addressed by means of innovative technology. A curved presentation wall of 3 m x 8 m virtually extends the operating space of 7 m² in front of the wall.

The development of a VR planning model was based on information already available in 3D CAD (e.g. components of machinery such as electro-mechanical linear actuators), maps (e.g. landscape), photos (e.g. taken during site inspections), and drawings (e.g. water engineering); the latter being currently in the process of official approval of plans. Model composition consisted of systematic import of individual components into Python (Python Software Foundation, USA) and the Vizard Virtual Reality Toolkit (WorldViz LLC, USA), the application of kinetical and environmental models (e.g. gravity, water, sky), the animation of moving parts of machinery (e.g. lock gates, actuators, water level) and inclusion of components necessary for contexts of use under investigation (e.g. river barges, measurement devices). The model is dynamic and includes close to reality scenarios such as locking of ships, moving lock gates and controlling signalling equipment [NLH*12]. In addition, measurements can be taken of passage widths or cavern depths. Viewpoints can be chosen for particular observations.

A design review of the VR planning model (see Fig. 1, bottom) was conducted within the interdisciplinary project and resulted in minor adjustments. The model itself and the scenarios available were therefore evaluated as being suitable for performing the risk assessment [NLH*12]. External engineering consultants were assigned to perform a risk assessment of the virtual river lock according to [Dir06, EN10]. The risk assessment was performed in the SUTAVE lab of the IFA and supported by experts on VR-simulation, safety, planning, construction and operation of river locks.

3. Results

As an overall result it could be concluded that VR considerably supported the risk assessment for the future River Neckar lock Kochendorf. A risk assessment at an early stage in design could successfully be performed and documented by the external consultants. VR support for risk assessment was rated suitable, cost-effective and applicable. All relevant steps according to the procedure for risk assessment [EN10] could sufficiently be performed referring to the VR planning model [ARA14].

Not only has it been possible to support the risk assessment for the operational concept of the lock. It was also possible to detect several hazards and design flaws in dynamic VR scenarios and by taking measurements in VR and by flexible and adaptable visualisation (see Fig. 2). The VR planning model provided a common basis for discussions about the operational concept for different loci of control (e.g. control centre on the river lock or remote) and levels of automation for control (e.g. with or without

SPS). The model supported the identification of testing modes and logic reasoning during assessments as well as the technical and functional safety analysis.

The VR planning model in 1:1 scale served inspections similar to those in reality because of the three dimensions available, the dynamics of moving machinery components, and the context of use scenarios. Specific advantages of the virtual model were identified as easy navigation on the lock and in new perspectives during on-site inspections. Among them, Figures 2 illustrates a bird view perspective and Figure 3 shows a point of view from the barges bridge during locking of the river barge. Also visible in Figure 3 are alternative options of masts for remote video monitoring of the river lock. The selection of type and the location of the masts are likely to be more effective with the flexibility of the VR planning model and to be safer when taking into account the results of the risk assessment early in design.

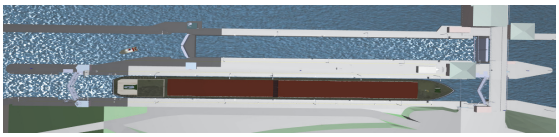

Figure 2: *Bird view facilitates new perspectives for risk assessment.*

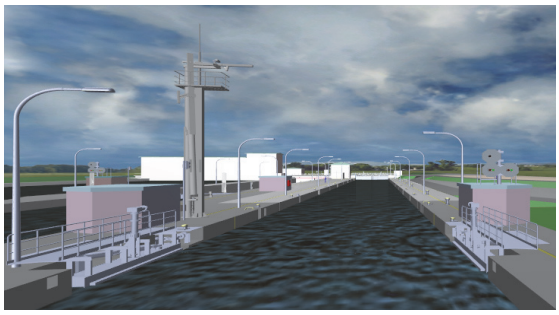

Figure 3: *Risk assessment can refer to points of view from different work positions and to alternative design options.*

Among hazards and flaws detected were (see also Fig. 4 and 5):

- Bollards in caves for hydraulic jack and cable
- Collision with guardrail
- Collision of superstructure of the lock
- Constrictions between installations and gate
- Constrictions for maintenance work
- Mast for video camera hides signalling

Some of the hazards and design flaws could already be detected with the static VR planning model, i.e. while virtually walking on the lock and in the caves, without moving components of machinery or use scenarios. The number of detections increased, when inspections were supported by the flexible and dynamic VR planning model, i.e. when scenarios of locking or of passing of barges [NLH*12] were applied, measurements were taken in the virtual environment, viewpoints were specifically chosen and components of machinery or superstructure of the lock were moved repeatedly or with different speed.

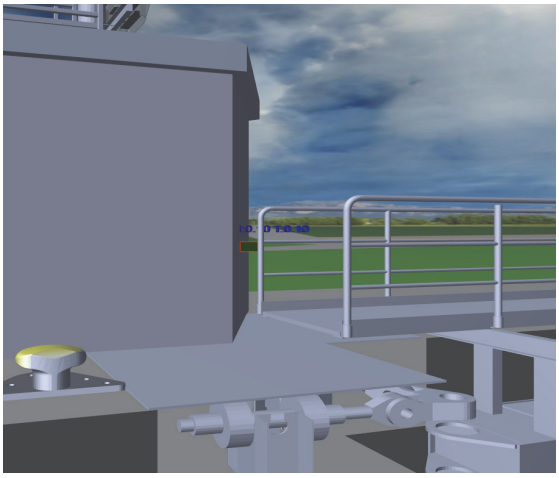

Figure 4: *Crushing hazard between machine house and the rail guard of the gate detected during on-site inspection when opening the upper gate.*

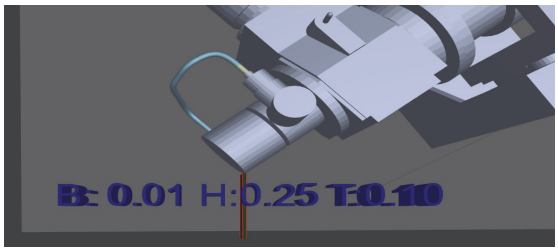

Figure 5: *Ergonomics hazard detected for maintenance work on actuator within cave during on-site inspections when opening the upper gate.*

Discussions during inspections often already resulted in suggestions for risk reduction. Because risk assessment was performed during the planning stage of the river lock, it was possible to feedback results into the planning stage. Some of the hazards and design flaws detected, however, where due to planning processes for components not yet completed. An example given is that final locations for masts for illumination had not been decided on. Therefore, some constrictions and collisions of some these masts with other components of the river lock were found. In these cases, the VR planning model also served as a planning tool, suggesting locations as well as other factors to be taken into account for decisions on suitable locations.

4. Conclusion

A prospective risk assessment has successfully been conducted referring to the VR planning model specifically developed for the River Neckar lock Kochendorf in its future contexts of use. The risk assessment yielded improvements with regard to the operational concept as well as to hazards and design flaws identified. Thereby it fostered the implementation of occupational safety and health requirements before starting the process of construction in reality, i.e. prevention through design early in machinery development.

Some of the advantages of conducting the risk assessment with the VR planning model may also be explained by the situation, that solely one common planning model has been developed in VR. Risk assessments in reality in early stages of design often refer to different planning models for several components of machinery, consisting of several layers of information. Even without VR, all information for performing a risk assessment would have been available, though not necessarily easy to identify and to integrate for all members of the inspection group. In the current study, model components from mechanical engineering often were available in 3D CAD while components from civil engineering usually were not, to name but a few. It could therefore be assumed that the development of one common VR planning model in 1:1 scale not only served risk assessment support, but also supported an integration of information available; and as a consequence made reality more accessible.

With or without VR support, one single risk assessment for complex machinery often is not sufficient to meet all safety requirements [Dir06]. Final assessment of risks should always refer to what has been done in terms of construction of machinery in reality. A VR planning model – like any other model – per se is a reduction of reality. However, the VR planning model as developed in the present study has its benefits and limitations for risk assessment support as has already been described in more general terms [WH00, SC12, NLH*12] and as could be shown more specifically in this paper.

Although the project aimed to inform about potential OSH issues at a specific river lock, results will also be beneficial for other river locks at River Neckar. In addition, it could be assumed that several benefits and limitations identified in the current project on a river lock as machinery will also hold for other machinery and work systems in industry and services. This provides a sound basis for guiding similar projects along lessons learned and experiences gained in the present study.

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