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COMBINING AUGMENTED REALITY AND SIMULATION-BASED OPTIMIZATION FOR DECISION SUPPORT IN MANUFACTURING

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ABSTRACT

Although the idea of using Augmented Reality and simulation within manufacturing is not a new one, the improvement of hardware enhances the emergence of new areas. For manufacturing organizations, simulation is an important tool used to analyze and understand their manufacturing systems; however, simulation models can be complex. Nonetheless, using Augmented Reality to display the simulation results and analysis can increase the understanding of the model and the modeled system. This paper introduces a decision support system, IDSS-AR, which uses simulation and Augmented Reality to show a simulation model in 3D. The decision support system uses Microsoft HoloLens, which is a head-worn hardware for Augmented Reality. A prototype of IDSS-AR has been evaluated with a simulation model depicting a real manufacturing system on which a bottleneck detection method has been applied. The bottleneck information is shown on the simulation model, increasing the possibility of realizing interactions between the bottlenecks.

1 INTRODUCTION

Augmented Reality is not a new technique within manufacturing (Doil et al. 2003, Nee et al. 2012), but as wearing the hardware becomes more comfortable and capacity increases, new application areas emerge. The Augmented Reality technique makes it possible to present information in a way that is not feasible using traditional screens. Information can be superimposed on real objects in the users' environment, in order to increase understanding. The technique of Augmented Reality is increasing its usage in various application areas, such as games, sports broadcasts and professional use cases.

The need to present data is increasing in manufacturing environments, with more and more connected equipment generating and storing data (Drath and Horch 2014). This data are used as performance measures or to improve manufacturing systems. It is a necessity for companies to continuously improve their manufacturing systems, in order to stay competitive and to reduce their environmental footprint (Pehrsson 2013).

The analysis and improvement of manufacturing systems are often complex tasks, due to the non-trivial nature of such systems. Simulation and simulation-based optimization can be helpful in solving these tasks (Pehrsson, Ng, and Stockton 2013). Simulation has the ability to answer what-if types of questions and, combined with optimization, the simulation model can also be used to find the most efficient setup of the manufacturing system. Since simulation-based optimization generates a significant amount of data, it can be difficult to conduct the analysis manually. Recent work shows that data mining can be used as a powerful tool to extract knowledge from the data generated by simulation-based optimization (Bandaru, Ng, and Deb 2017).

The large amount of data resulting from simulation-based optimization, together with information generated by data-mining, requires that the knowledge is interpreted correctly. In addition, the knowledge gained from the data also must be communicated to the management as well as to the technicians working with the manufacturing system. Accordingly, Augmented Reality provides new ways of presenting data to decision makers, as well as to groups of people.

This paper discusses how Augmented Reality can help decision makers in manufacturing make decisions and how it can present the different options available within a manufacturing system to its stakeholders. To illustrate how this can be achieved, a decision support system that uses Augmented Reality, IDSS-AR (Intelligent Decision Support System using Augmented Reality), is presented. The following section discusses previous work using Augmented Reality in manufacturing. Section 3 describes the IDSS-AR system, while Section 4 presents and discusses an application study used to evaluate this system. Section 5 concludes the paper together with a proposal regarding future work.

2 BACKGROUND

This section presents the use of Augmented Reality in manufacturing for training and collaborative purposes, as well as how Augmented Reality has been used for production planning and simulation.

2.1 Augmented Reality

Augmented Reality is a technique that superimposes a computer rendered picture onto the real world. This can be achieved using goggles/helmets, regular computer monitors, or hand-held devices. The term, Augmented Reality, was defined by Caudell and Mizell (1992) for their development of a see-through heads-up display. Augmented Reality is closely related to Virtual Reality (VR) which totally immerses the user in a virtual environment. Syberfeldt et al. (2016) categorize the Augmented Reality screen types and hardware into three different groups, head-worn, hand-worn and spatial, see Figure 1. All of these techniques have their advantages and disadvantages, depending on the application. Nee et al. (2012) summarize the types of hardware and their capabilities in the manufacturing area and emphasizes that the human interface is very important to make Augmented Reality effective.

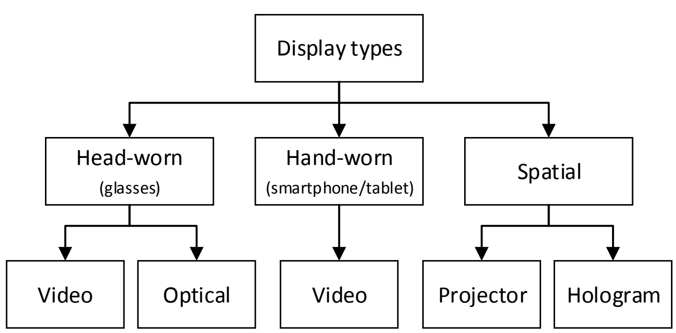


Figure 1: Augmented Reality hardware types.

These devices make it possible to test new areas of use for Augmented Reality in manufacturing. Training together with collaboration and production planning are important areas within manufacturing to increase the productivity. The use of Augmented Reality within these areas are reviewed in the following sections.

2.2 Augmented Reality in Training and Collaboration

The use of Augmented Reality for training purposes is suitable for both schools and businesses. It can provide new and innovative ways of educating students, as well as workers and managers (Lee 2012). The technique also can be applied in a manufacturing environment which may involve complex processes and machinery. For example, Gonzalez-Franco et al. (2016) conducted a study on a group of participants that used head-worn Augmented Reality hardware to investigate how the technique can improve training in a complex manufacturing environment.

The study shows that Augmented Reality can increase the performance of collaborative training. Gavish et al. (2015) applied Augmented Reality to maintenance training and assembly tasks and demonstrated that fewer errors are made as a result of using the Augmented Reality technique. The groups that were equipped with Augmented Reality hardware also needed less training time and could perform their tasks more quickly. In relation to training, Augmented Reality also can be used for collaboration and in meetings, regardless of whether the participants are at the same location or not. Gauglitz et al. (2014) propose a system that enables participants to collaborate through, for example, annotations, in an Augmented Reality environment, without the need to be at the same location.

2.3 Augmented Reality in Production Planning and Simulation

Using Augmented Reality for simulation has shown promise in earlier work. For example, Doil et al. (2003) present a range of applications for using Augmented Reality in production planning. One of the applications is an interactive table-based planning where the user places objects and can see the virtual manufacturing objects in Augmented Reality. According to the authors, their system can increase the interaction between the planning personnel and the manufacturing objects. Dangelmaier et al. (2005) present a system that employs Augmented Reality to simulate real manufacturing machinery by using virtual objects. Since their system can superimpose the machines from CAD-drawings onto the real world, it is possible to immediately see any issues. This can reduce errors in the planning process of new manufacturing systems and thereby reduce costs. Jiang and Nee (2013) propose a similar system, which integrates a facility layout planning (FLP) tool with Augmented Reality, and show its effectiveness in a case study.

Discrete-event simulation (DES) is commonly used for simulation in manufacturing systems. In a thorough review, Turner et al. (2016) discuss how DES together with Virtual and Augmented Reality can be combined to achieve benefits, such as meeting the visualization requirement of Industry 4.0. The application study presented here is an example of how some of these benefits can be implemented, for example Augmented Reality for bottleneck visualization, communication of results and gained knowledge.

3 DECISION SUPPORT SYSTEM USING AUGMENTED REALITY

This section introduces the IDSS-AR system with its capabilities and also discusses the motivation behind the system.

3.1 Motivation

Decision makers and simulation engineers in manufacturing companies and organizations need several functionalities from a decision support system that uses simulation-based optimization (Karlsson et al. 2015). To make the most out of their simulation models requires automatic as well as manual methods of analysis. The ability to convey knowledge obtained from the simulation models is also an important functionality.

Furthermore, the ability to enable several users to study and analyze the same model is an important requirement for collaboration. With this ability, the system can be used in meetings where the simulation engineer can display information and results obtained from the model. This information then can be used as a basis for subsequent decisions. In addition, this functionality can be used to train personnel on both current and non-existing manufacturing systems.

While these tasks are possible in ordinary simulation software, the authors believe that Augmented Reality can potentially increase the understanding of simulation models. This can be achieved by displaying the simulation models in 3D and superimposing the results of various analyses on them. Considering the challenge and complexity involved in understanding and exploring multidimensional data from multi-objective simulation optimizations and data mining, there is an increasing demand for capable visualization solutions.

3.2 Capabilities

The main objective of the development of the IDSS-AR system is to run DES and show the model to the user in Augmented Reality. The user should be able to study the simulation model in 3D, on a type of hardware for Augmented Reality, and conduct a detailed study of the behavior and results of an experiment. This requires the integration of a simulation engine that can load and run a simulation model. To gain the advantages of collaboration and training, the IDSS-AR system should support more than one user utilizing the system at the same time. The actions that users perform on a simulation model should be visible to other users, e.g., actions like changing the model or showing some object specific information.

The secondary objective is to enable the users to run simulation-based optimization experiments and show/analyze the results. This requires that the system is able to store data from simulation-based optimizations and give the user access to tools, such as diagrams and data mining for automated analysis of data.

3.3 System Design

The IDSS-AR system employs a previously developed decision support system that uses simulation-based optimization (Karlsson et al. 2015), hereafter referred to as DSS. The DSS the IDSS-AR requirements for simulation and simulation-based optimization; it also can store simulation and optimization results in a database. In addition, there are applications for running DES within DSS as well as for analyzing optimization results, both manually and automatically.

The DSS is extended with features for Microsoft HoloLens, which is a head-worn hardware for Augmented Reality. The selection of Microsoft HoloLens is due to its high fidelity and its ability to show 3D holograms on a table, a feature made possible thanks to its ability to map the user's surroundings. Head-worn hardware for Augmented Reality gives the user a higher level of immersion than, for example, a hand-held screen.

A system architecture for IDSS-AR, together with a prototype of IDSS-AR, has been developed, which fulfills the required capabilities. Figure 2 shows the architecture which consists of five major components.

The IDSS-AR-Service is a web service that acts as a message broker between the client applications and the server components of the system. In the Microsoft HoloLens, a client software runs, showing the simulation models, and this component retrieves data from the IDSS-AR-Service. The simulation-based optimizations run in the simulation-based optimization platform which stores the results in a database. When a user requests to show a model, the HoloLens-client requests the model from the database via the IDSS-AR-Service. To be able to run the simulation model, the system has access to a DES engine which also is connected to the IDSS-AR-Service. In addition, there are companion applications to IDSS-AR which allow users to start optimizations and analyze the results, both from optimizations and single experiments.

The IDSS-AR system can support multiple simulation software; however, a DES software called FACTS Analyzer (Ng et al. 2011) is used in this work. FACTS Analyzer acts as a simulation engine for the animation and also is used for simulation-based optimization.

To increase the connectivity, the IDSS-AR-Service can be made accessible through a company computer network, thus enabling multiple users to gain access to models and results at the same time.

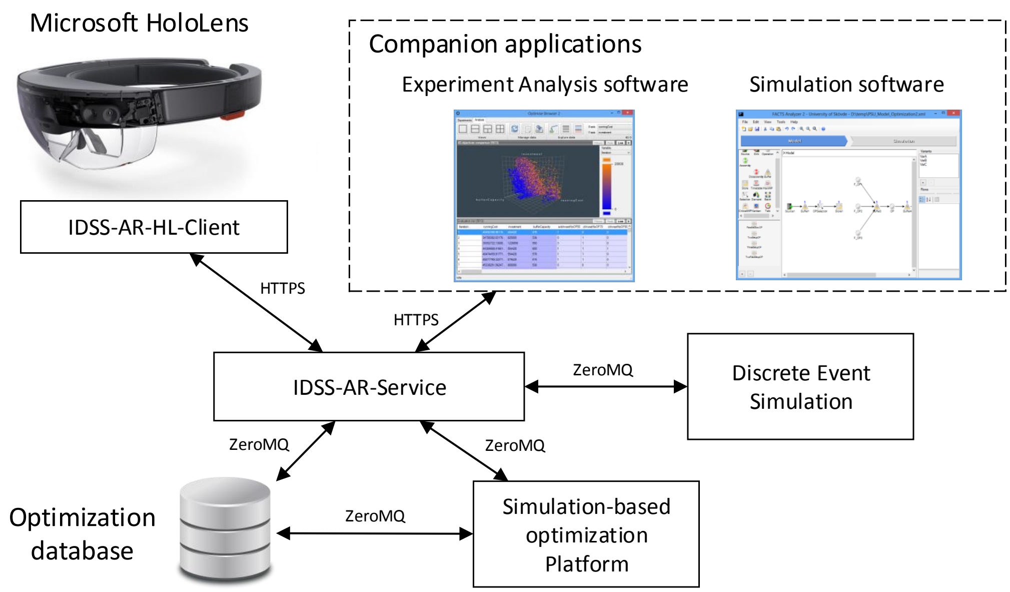


Figure 2: System architecture for IDSS-AR.

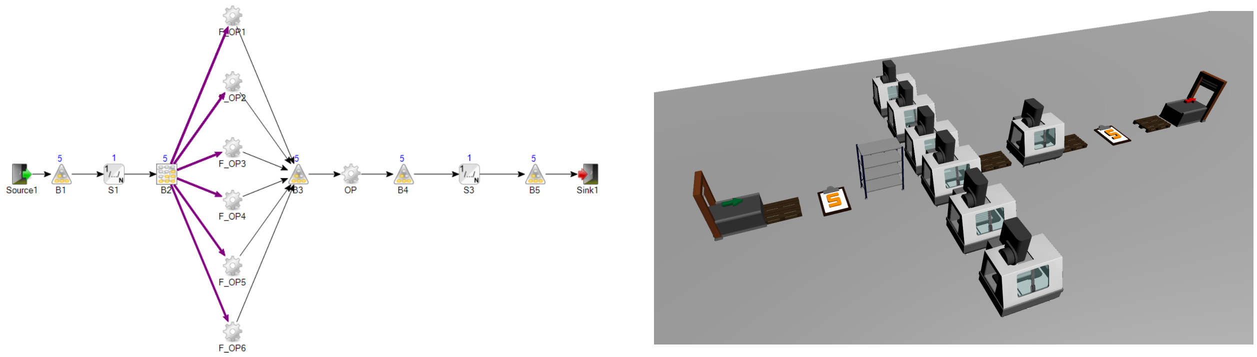
3.4 Augmented Reality Client

The Augmented Reality client is the main interface between the user and IDSS-AR. The client is developed in the game engine *Unity*, which is supported by Microsoft HoloLens and connected to IDSS-AR through the IDSS-AR-Service component. The client is made as lightweight as possible and only produces the graphics for the Augmented Reality experience. All simulations and optimizations are run in the other components of IDSS-AR, in order to gain performance and to facilitate the sharing of information between multiple users.

For this work, the IDSS-AR has been integrated with the FACTS Analyzer DES engine. FACTS Analyzer provides different objects that can be used to model complex manufacturing systems, such as sources, sinks, operations, buffers, and so on. For each of these objects, a 3D representation has been modeled, so that the user can identify the objects. These objects have been modeled for generic manufacturing use, for example, the Operation is modeled as a CNC-machine. However, all the 3D objects can be replaced for use in other areas, such as health care; ideally, 3D-models of the real-world objects can be used. Figure 3 shows a simple FACTS Analyzer model containing a sample of its different objects, such as Source, Buffer, Store, Operation and Sink, in 2D as well as 3D.

When a user starts the IDSS-AR client and opens a simulation model, it tries to place it on a table in front of the user. The model is then locked in that position. The user can walk around it and look at it at different angles. Taking a step back enables an overview of the model and stepping closer to the table reveals the details. In large models details can be difficult to see, requiring IDSS-AR to be able both to scale and to show smaller parts of the model. Figure 4 demonstrates a composite image showing how a simulation model is placed on a table, which is the image a user sees through the HoloLens. The HoloLens can automatically detect the table; no markers or other objects are needed.

Augmented Reality provides new ways of displaying information, which cannot be achieved on a traditional screen. The following section describes an application study where bottleneck information is added to a simulation model in IDSS-AR.



2D model in FACTS Analyzer.

3D model in IDSS-AR.

Figure 3: Simple FACTS Analyzer model.

Figure 4: Composite image of a simulation model placed on a table.

4 APPLICATION STUDY

The IDSS-AR system is able to show many different statistics together with the simulation model. This section describes an application study of an in which the performance of a manufacturing system is to be improved. It specifically details how IDSS-AR can help a decision maker reach high-quality decisions regarding improvements.

4.1 Bottleneck Detection

An important task for production and simulation engineers is detecting and analyzing bottlenecks in a manufacturing system, in order to achieve the highest possible efficiency of the system under study. SCORE (Simulation-based COnstraint REmoval) (Pehrsson 2013, Pehrsson, Ng, and Bernedixen 2016) is a method of detecting bottlenecks as well as their main causes. This method extracts and ranks bottlenecks in a manufacturing system with the help of simulation-based optimization. All bottlenecks and their causes are sorted according to their importance. In a large simulation model, this information must be presented to the user in an efficient manner. Until now, the SCORE results have been shown in a frequency diagram, identifying the most important bottleneck first and then the less prominent bottlenecks in a decreasing order of importance. Turner et al. (2016) mention that showing bottleneck information is one of the advantages of Augmented Reality together with DES.

4.2 Manufacturing System Case

The SCORE method has been shown effective in a real manufacturing system (Bernedixen et al. 2015). To demonstrate the potential for displaying SCORE information in Augmented Reality, the same simulation model has been tested in IDSS-AR. The manufacturing system contains a number of operations (71), buffers (72) and assembly/disassembly stations. The model used is made in FACTS Analyzer and is illustrated in Figure 5.

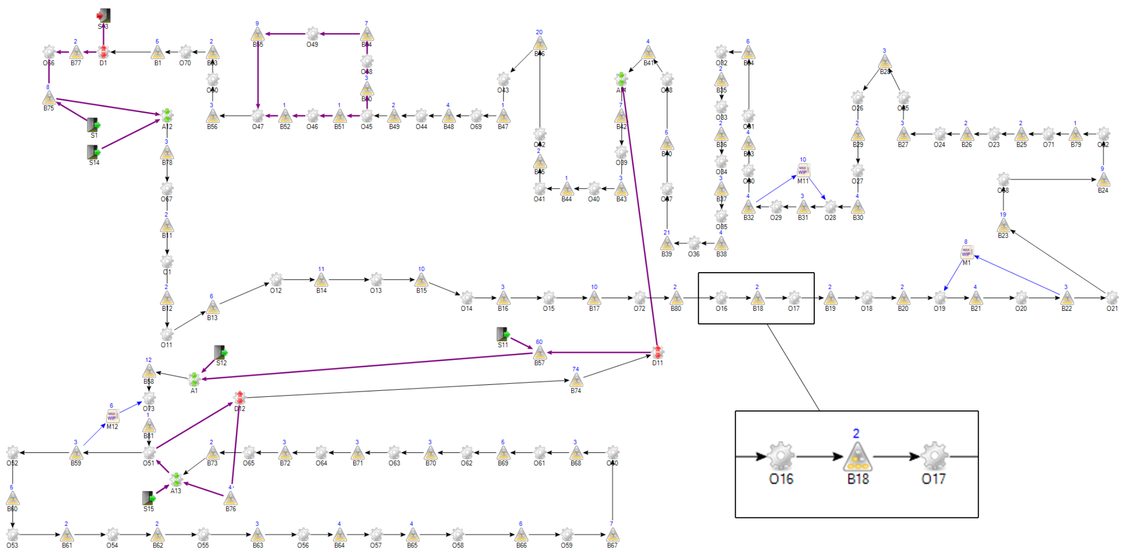


Figure 5: Simulation model of an production line.

The model is optimized using the SCORE method (Bernedixen et al. 2015) and the results are stored in the IDSS-AR database. The SCORE results are compiled on the basis of the most frequent improvements found among the best solutions generated by the optimization. The twenty most frequent improvements are presented to the user in a frequency diagram (Figure 6). Each bar in the frequency diagram represent a cause for a bottleneck and the text describes which station and what cause. For example, *imp_O16_AVB* shows that the availability of the operation O16 should be increased, see the zoomed in section of Figure 5. In this application study, only the top ten improvements will be displayed; however, this is a user option that can be adjusted according to the preferences of the users.

The IDSS-AR system can display the SCORE information directly in the simulation model, allowing the user to clearly identify the machines with one or more bottlenecks together with their priority. The cause of the bottlenecks with the highest frequency is ranked priority #1, the second highest cause is ranked #2, and so on.

The IDSS-AR client shows these ranks together with the bottleneck causes at each simulation object. Some objects may be marked with more than one cause and consequently different ranks. Figure 7 shows an operation where SCORE has detected two bottleneck causes, namely, process time and availability, which are ranked #2 and #9 respectively.

Figure 8 presents an overview of the simulation model. This image is what the user can see from a distance. The causes and ranks can be difficult to read from a distance, but each simulation object that has a SCORE bottleneck cause is highlighted with a colored circle beneath it. The tone of the colored circles range from red to yellow, where red is the highest rank (rank #1) and yellow the lowest. These markings

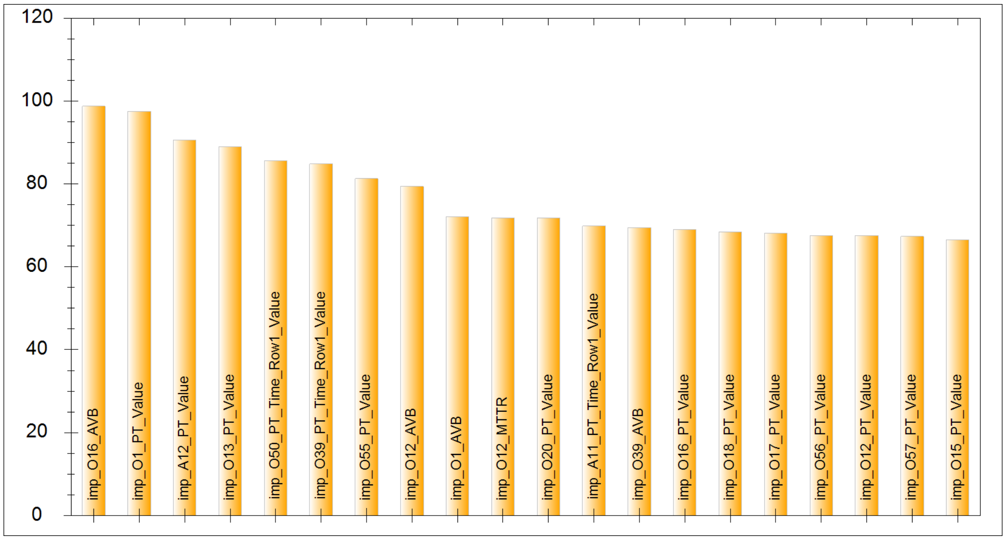


Figure 6: SCORE results showing top twenty causes of bottlenecks ordered by frequency.

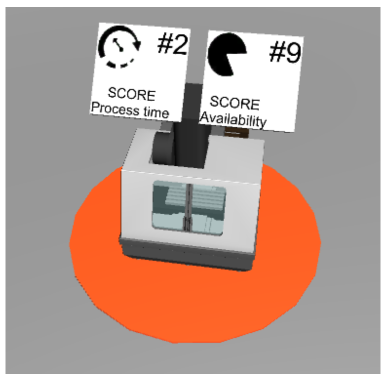


Figure 7: Operation simulation model object with SCORE information.

allow the user to identify the location of the bottlenecks and their ranks, in a fast and comprehensible manner. The type of bottleneck cause can be seen on the sign of each marked object.

A section of the model is shown in Figure 9; the signs with the bottleneck causes are clearly visible.

4.3 Evaluation

The IDSS-AR prototype with the previously described simulation model and SCORE test case has been evaluated by a simulation expert with a good understanding of SCORE and other bottleneck detection methods.

The true strength of the SCORE method lies in its ability to not only detect the location of a bottleneck, but also its cause, the amount of improvement required to remove it as a bottleneck and, not least, its ability to do this for all bottlenecks in the system. This enables the creation of a plan of action involving not only the primary bottleneck, but also secondary and tertiary bottlenecks, and so on. In turn, such a plan could potentially reduce investment costs, if improvements can address several bottlenecks at once, rather than the cost of tailored improvements carried out for each bottleneck in sequence. The frequency diagram of the SCORE method visualizes the sequence of the improvements needed, but does not clearly indicate the connection to where they should be made; only indirect connections are revealed through the clever naming of the improvements. If this connection can be clearly shown, as with IDSS-AR, the possibility

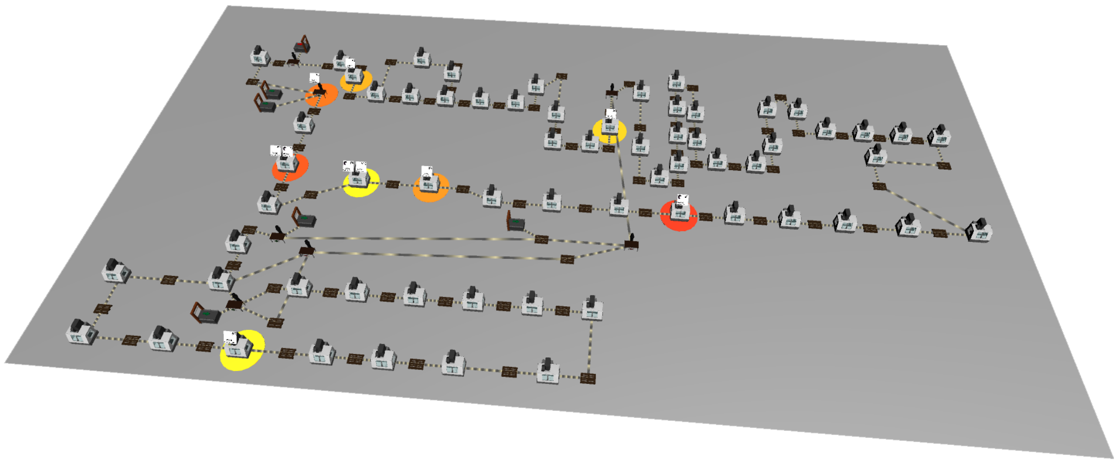


Figure 8: Overview of 3D simulation model in IDSS-AR.

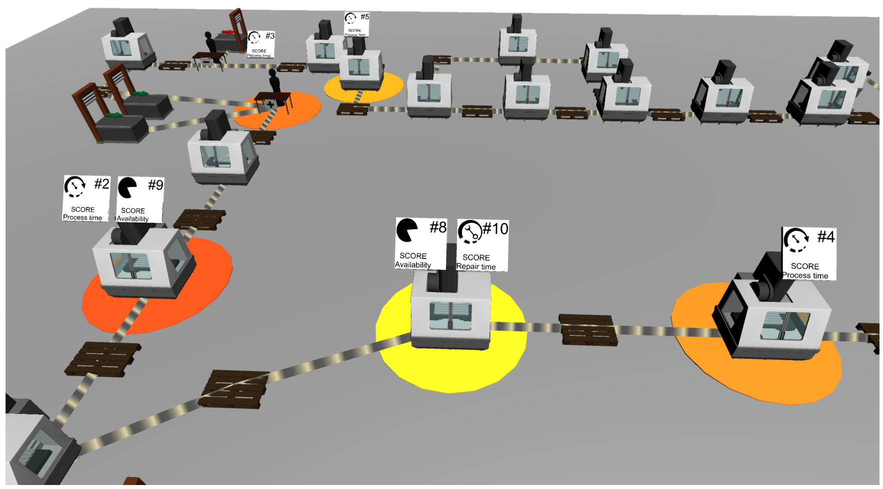


Figure 9: Section of 3D simulation model in IDSS-AR showing SCORE information.

of realizing commonalities and interactions between bottlenecks increases drastically and opens up for smarter solutions to address the various bottlenecks.

5 CONCLUSIONS AND FUTURE WORK

This paper discusses and shows how Augmented Reality can be used together with a decision support system based on simulation-based optimization. Since simulation models and the information they generate can be complex, Augmented Reality provides new and improved ways of displaying this information, compared to traditional screens. For instance, presenting bottleneck information on a 3D model or a real world production system compared to in a bar chart.

A decision support system with Augmented Reality support, IDSS-AR, is proposed in this work to illustrate how knowledge from simulation-based optimization can be shown to the user through an Augmented Reality system. The IDSS-AR support system can present a clear visualization of a simulation model in 3D to a user, together with information about the model.

IDSS-AR uses Microsoft HoloLens, which is a head-worn hardware for Augmented Reality. The HoloLens hardware can map a user's surroundings and, through IDSS-AR, place a simulation model visualization in 3D on a table. This gives users of IDSS-AR the ability to study the model and its results in a completely new way, providing great potential for increasing knowledge of the studied system. IDSS-AR also supports more than one user at the same time, which opens up possibilities of using Augmented Reality for meetings and training sessions.

In this work, an application study of a real manufacturing system has been used to show bottleneck information above the simulation model. This allows users to clearly identify which objects are bottlenecks. The IDSS-AR prototype has been evaluated by a simulation expert with knowledge of bottleneck detection methods. The simulation expert states that the clear visualization of the bottleneck information drastically increases the possibility of realizing commonalities and interactions between bottlenecks.

The next step is to let decision makers evaluate the decision support system in a real-world manufacturing problem and compare their performance to a control group. The system can be expanded so that simulation and optimization results can be displayed directly on the manufacturing equipment, i.e., machines, instead of a table. A decision maker could then walk around on the shop floor and receive immediate feedback regarding any changes proposed by the decision support system. Other simulation results, e.g., machine utilization, throughput, etc., could also be shown.

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