Multi-user interactive visualization of asphalt paving operations

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ABSTRACT: The paving industry evolves with introduction new asphalt mixtures and working methods. The continuous communication between machine operators and paving experts is essential for the professionalization of the industry. Visualization is considered to be a means to support knowledge exchange between both groups. Nevertheless, currently there are no specialized visualization approaches to deliver information to machine operators according to their role in the compaction process. In this paper we propose a scheme for simultaneous multi-user interactive visualization of asphalt paving operations, based on analysis of knowledge intensive tasks of operators. This proposed approach focuses on providing different operators with the relevant information, related to their role in compaction process. The implementation of the scheme has a potential value to be used as an serious gaming environment to train machine operators during the professional education.

1 INTRODUCTION

The global road network is an important infrastructure asset with high social and economic value, indispensable for the modern society. As growth of the economy is accompanied by increasing travel demand (WSDOT 2011), there is a clear need to keep the road systems robust and reliable. Because of its value it is desirable to prolong periods between construction and re-construction activities and have the hindrance of the ongoing traffic flow as small as possible during construction activities. These factors boost the further development of road construction in whole and asphalt paving in particular.

Asphalt paving is a collaborative process, that depends on the temperature of the asphalt mat and conjoint work, performed by number of compactor operators. Operators (have to) continuously make decisions where to proceed with compaction according their understanding of the asphalt temperature and previous movements of themselves and the other operators. Though the process is highly individual for every machine operator, the quality of the final road surface depends on their joint performance.

Road construction companies are continuously interested in need to improve their work practice to construct high-quality road surface. This can be addressed through dissemination of best practices between paving teams. Knowledge dissemination is the major way to educate machine operators, involved in asphalt paving. Effective delivery of knowledge of paving experts how to proceed with compaction in relation to a particular asphalt mixture is important in educating compactor operators. Even more this applies to education of young and less-experienced operators, who attend professional education facilities. We assert that such a knowledge transfer - from paving experts towards machine operators - can be effectively supported by the means of visualization. As roles the machine operators on site are different, visualization should be oriented to a particular operator, according to his role and position in the overall compaction process. Nevertheless, currently there are no schemes to support knowledge transfer from paving experts to machine operators.

In this paper we present a user-oriented visualization scheme to deliver specific information to multiple users simultaneously. The scheme is designed to display operator-related information, according to their role in the compaction process. This visualization scheme has been developed based on analysis of tasks of machine operators and the information needed to fulfill those tasks. The proposed visualization scheme implementation is oriented to support professional learning, when the “students” simulate their behavior individually, while the result of collaborative efforts and individual decisions can be directly analyzed.

2 CHARACTERISTICS OF ASPHALT PAVING OPERATIONS

Asphalt paving is a unique type of construction activity because of the temperature-related behaviour of the asphalt mixture and the collaborative nature of rolling operations. The paving or finishing machine lays the hot-mix asphalt at temperatures between approximately 110°-150° C (MAPA 2011). Cooling of the deployed mixture depends on ambient weather conditions, including air temperature, wind speed and solar radiation (Bossemeyer 1966). Asphalt temperature directly influences operational decisions as when to start and when to stop compaction operations. If the mixture layer is too hot, then rolling can cause corrugations. If it is too cold - damages can occur (Bijleveld 2010). Therefore, compaction operations should be performed when the temperature of the mixture is within certain temperature limits (Wise & Lorio 2004). In this way, the asphalt layer temperature is a major factor for compactor operators' decisions.

In addition to the temperature-dependence, the operational behaviour is highly influenced by the collaborative nature of the compaction process. As compactors work in teams, every machine operator has to analyse not only his own current and previous positions, but also movements of previous compactors.

Combination of factors to analyze - asphalt temperature, ambient weather conditions, movements of previous machines and expected duration of the project - make operational decisions highly individual. By performing every-day work machine operators form their own tacit 'system of rules' based on their personal experiences, which evolve during their professional careers.

Nevertheless, it is not enough only to perfect existing set of rules as a set of invariable working methods. New suggestions on how to perform compaction operations - in relation to a particular asphalt mixture - can be developed by mix designers. For example, new recommendations can include sequence of compactors and their working areas with respect to asphalt mat temperature (Sullivan & De Bondt 2009). Thus, introduction of new mixtures may require adoption of working methods that differ from the gathered personal experience of compactor operators (Huerne 2004). To apply the best working practices in practice the compactor operators should continuously adopt new knowledge – how to proceed with compaction according to the ambient conditions, such as wind speed and air temperature.

To support asphalt teams in acquisition of new knowledge contractors seek for opportunities to facilitate the information exchange between paving teams and experts in the paving domain. The need to support knowledge is in particularly evident for the needs of initial professional education, where the trainees in addition to the formal knowledge of asphalt paving industry have to study concurrent construction methods.

In summary, during the asphalt paving process the machine operators have to apply their personal knowledge how to proceed with compaction operations in relation to asphalt temperature and previous movements of machinery on site. Nevertheless, this knowledge is a subject to evolving. In particular, with introduction of new asphalt mixtures machine operators should continuously adopt new working methods during both professional education and their later working practice. The existing and new working methods can be represented using a domain-specific visualization.

3 TRANSFER OF KNOWLEDGE IN PAVING INDUSTRY USING VISUALIZATION

According to recently conducted research (Miller 2010), visualization of asphalt paving operations is an effective method to supports communication between road construction teams and paving experts. Consequently, it is possible to distinguish two directions of information transfer between the named groups: from machine operators to experts, and from experts to operators (Fig. 1).

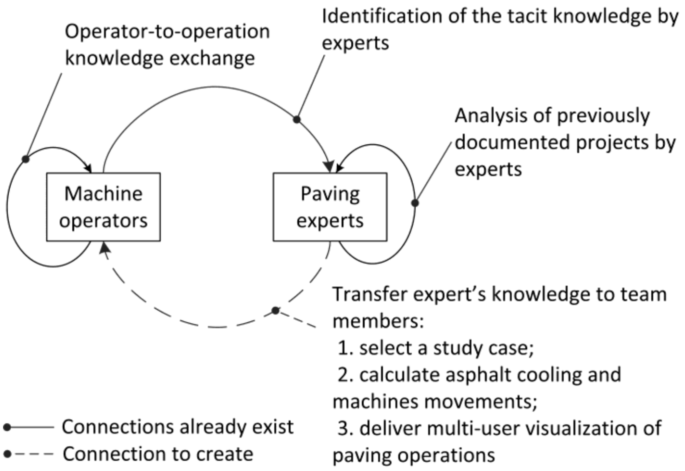

Figure 1. Scheme of the knowledge transfer within the paving domain

The communication between machine operators and paving experts is a two-directional knowledge exchange process, where each direction has specific characteristics according to the nature of the groups' knowledge. On one side, knowledge of machine operators have a tacit form, where operators 'feel' what is the right thing to do, but can hardly put this tacit knowledge into words. To identify best paving practices the experts should analyze documented operational behavior on site in the context of the paving process. This requires documentation of characteristics of a particular construction project – ambient weather conditions, asphalt cooling rate and machinery movement on site. On the other side, knowledge of paving experts, that include best practices and new compaction strategies, should be represented as instructions to machine operators to be adopted by them. For the both directions of knowledge transfer the visualization can be considered as an effective means of communication.

To support identification of tacit operators' knowledge by experts currently there are specialized visualizations approaches available. The existing solutions include both commercial software to analyse the projects and experts-related visualizations, developed by academic institutions.

The available commercial solutions mainly support compactor operators in their daily work to maximize compaction efficiency (Woof 2012). At the same time, because of the documenting options they can be used to study operational behaviour on site. For example, the commercial system to record and visualize the asphalt temperatures during paving (PAVE-IR) developed by MOBA (Swaner 2010) and a compaction control system (CCS900) for a single compactor was created by Trimble (Trimble 2012). More advanced system to monitor compaction of the road by a number of compactors, was introduced by the HAMM (2012) manufacturer. These visualization methods do document machine movements, but do not consider other factors of the paving process, such as asphalt cooling and ambient weather conditions. In other words, the named commercial visualizations are well-suited to support operators in their operational decisions on site, but are not oriented for knowledge exchange between machine operators and paving experts. Moreover, because of a lack of documenting external parameters of the paving process – ambient weather conditions, temperature of the deployed asphalt mixture – it is hard to analyse the performed paving process in context.

Another approach, that allows to analyse paving operations in the context, was recently developed in the academia sector. The proposed solutions include real-time analysis of compaction process on site (Vasenev 2011) and off-site examination of working methods of the asphalt teams (Miller 2011). To support analysis of paving projects Miller (2010) introduced framework of utilization of contemporary technologies (GPS, temperature laser linescanner and infrared camera). The framework describes the following activities: documentation of the paving process, data analysis and communicating results with the paving team during analytical session. In particular, a number of sensors measure surface and in-asphalt temperatures, density progression, weather conditions and machinery movements during compaction operations at the construction site. By documenting movements of every machine the paving experts can later analyse the final result of collaborative work in relation to individual effort of operators. The described framework was originally proposed to analyse paving activities. In this way, there is no specialized visualization to disseminate experts knowledge towards machine operators. In other words, the described framework as well as the existing commercial visualizations, do support knowledge transfer from machine operators to the paving experts by analysing compaction process, but they are not oriented to disseminate knowledge of experts towards operators.

The specialized visualization to support knowledge transfer from paving experts towards machine operators should take into account the special characteristics of the paving process - collaborative work and temperature-driven operations. As the machine operators work in a particular sequence and have different roles within an asphalt team, it is essential to differentiate information according to the user needs. Also, the information, describing the paving process, should be delivered to all operators at the same moment of time. Therefore, we see a simultaneous representation of information to a number of operators as a key to effectively deliver user-oriented visualization. In the available visualization practices (Turkiyyah 2007; Miller 2011) these aspects were not yet addressed.

In summary, to increase professionalization of the paving industry there is a need for a two-way knowledge exchange between machine operators and experts. The dialog can be effectively supported by specialized visualization approaches. Nevertheless, there are no specialized visualization approaches available to deliver information to machine operators according to their tasks in the compaction process. To develop specialized visualization approach which delivers relevant information to machine operators it is necessary to identify information relevant to a particular operator during compaction operations.

4 KNOWLEDGE INTENSIVE TASKS AND INFORMATION DISTRIBUTION

To identify knowledge-intensive tasks of compactor operators and the origin of the required data to proceed with the tasks, the authors of this paper combined both literature review and monitored five road construction project in the Netherlands during year of 2011. With the identified information sources we developed a multi-user visualization scheme to support knowledge exchange in paving domain with respect to operators' roles during the compaction process.

The operational decisions where and when to compact are made by machine operators at the road construction site based on a number of factors. In particular, a compactor operator takes into consideration the (estimated) temperature of the asphalt mix, his own previous movements, and movements of other operators on site. The information, relevant for every machine operator, is directly related to the role of the compactor during the working process.

In the paving practice, the amount of specific construction machinery on site is directly dependent on the scale of the project. For example, if the constructed pavement should be wider than the width of the paver, then two or more paving machine and extra compactors could be used. Nevertheless, to analyze tasks of compactor operators it is possible to examine a generic paving project, illustrated in Figure 2 with one paver and two compactors, similar to analyzed by Halpin & Riggs (1992). Each role of the compactors, shown in Figure 2, may be performed by one or several machines in parallel.

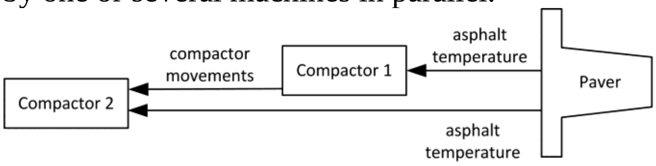

Figure 2. Illustration of the compactor-related information distribution during paving operations

During the paving project compactors follow each other. The first machine acts as a "breakdown" compactor that affects the mat density more than any other machine in the sequence (TxDOT 2011). The next machine(s), that can be an intermediate or finish compactor, is used afterwards. Both operators have to consider asphalt mat temperature in connection to compaction patterns, as developed by asphalt designers. In general, the first compactor should avoid starting operations when the temperature is still too hot, while the second one should not proceed with compaction if the layer is relatively cold. In addition to the temperature information, the second operator should consider movements of the previous machine to aim for the homogeneous pavement as a collaborative work result. The tasks of machine operators can be described in a form of knowledge intensive tasks, corresponding information and information sources (Table 1).

Table 1. Knowledge intensive tasks of machine operators

	Operator 1	Operator2
Task of the operator	start to compact when temperature cools down to a certain degree; provide initial compaction	continue compaction while mixture is warm enough; create a uniform compaction as a result of work of both operators
Information needed	asphalt temperature	asphalt temperature; compactor 1 movements
Type of the information	temperature readings	temperature readings; GPS sensors
Origin of the information	sensors on the paver	sensors on the paver and on the compactor

The analysed tasks of the machine operators clearly shows that different machine operators require different information to effectively conduct their work. This insight should be considered during development of the specialized visualization of paving operations that aims to effectively support knowledge transfer from paving experts towards machine operators. In other words, it is necessary to deliver information on temperature and previous machinery movement related to the role of an operator on site. With respect to this fact in the next section we will propose the scheme to support multi-user visualization for education of compactors' operators.

5 PROPOSED SCHEME OF MULTI-USER VISUALIZATION OF ASPHALT PAVING OPERATIONS

To support transfer of knowledge from experts to machine operators it is required to deliver information according to operators' tasks. With respect to the tasks and the information distribution on site, described above, we propose the scheme for simultaneous multi-user visualization (Fig. 3). The individual screens are utilized for compactor operators and an additional one displays the combined information, available for analysis. To support visualizations of previously documented projects as well as the simulations proposed by experts, the proposed scheme incorporate following modules: documented sensors reading, simulated sensors reading and data fusion block.

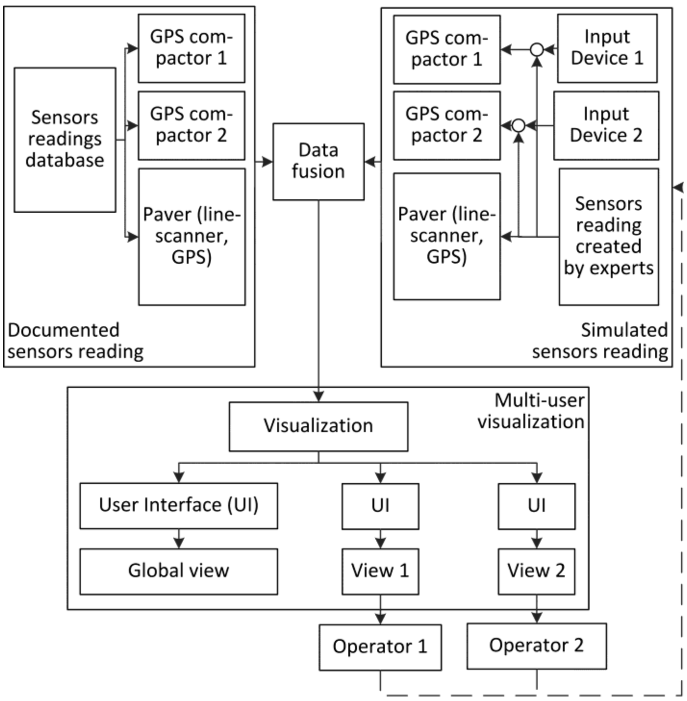

Figure 3. Proposed scheme of the multi-user visualization of asphalt paving operations

The documented sensors readings are stored in a sensors readings database and include temperature laydown information and compactors movements, collected during a real construction project. The documented readings can be used to create the visualization oriented for operator 1 and operator 2, that represents previously documented paving projects. In this way using documented sensors reading it is possible to analyze best and poor working practices, with respect to movements of every particular machine during the project.

The simulated sensors reading module is oriented to allow using simulated scenarios and opportunity to control machinery using input devices. For example, experts can develop an example of the construction project including geometry of the road (road curves, intersections, and roundabouts) and the proposed compaction strategy to illustrate the a particular operational practice. Also, students can use input devices to 'test' different collaborative strategies. In other words, the simulated sensors reading module makes it possible not only to visualize previously documented projects, but also offer to paving experts to create particular cases. This tactic to visualization aims to support transfer of knowledge in the educational process from paving experts towards machine operators.

The data fusion module is dedicated to combine both documented and simulated readings of the different sensors. This combination may include, for example, documented temperature of the asphalt mat and simulated compactors movements over a paved surface. The combined information is delivered to the visualization block, which represents it according to the role of the machine operator in the sequence of compactors - breakdown or the finishing roller.

Visualization of the paving operation is simultaneously displayed on three screens. The combination of screens with the proposed information is represented in Figure 4. The combination includes two computer displays and a large (projected) screen with combined visualization. The latter screen displays a larger view of the working area, while the smaller screens show operational areas closer to position of the compactors. Every operators' screen displays information, relevant to the operator's tasks, as described in Table 1. In particular, the asphalt temperature and movement information of the first operator is shown on the first screen. On the screen of the second operator temperature and movements of both compactors are displayed. And, finally, the temperature and the result of collaborative compaction activities are displayed on a large screen. Optionally, in the proposed implementation of the multi-user visualization both operators have an opportunity to display their movements using the interactive component, available on screen.

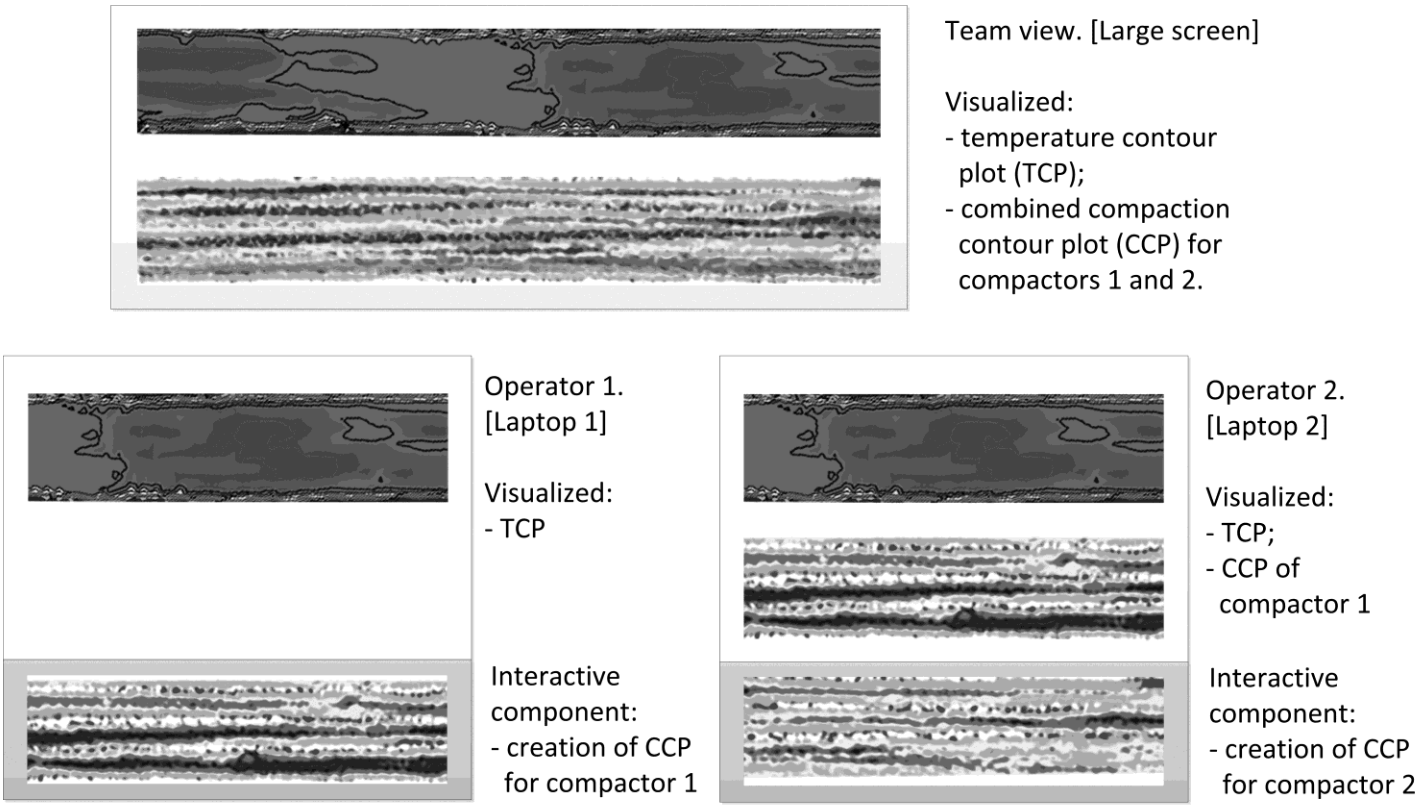

Figure 4. The proposed on-screen information organization of multi-user visualization scheme

6 DISCUSSION

To support knowledge transfer from paving experts towards compactor operators we developed a scheme for multi-user visualization based on machine operators task analysis. We see this approach as a way to support communication between paving experts and machine operators in a form of user-oriented visualization. We believe, that as science and technology have become increasingly visual in their intrinsic nature, every medium has its strengths and weakness (Greenfield 2009). Therefore, we see such visualization as an additional tool to support explication and transfer of knowledge in addition to printed or oral instruction. From a knowledge transfer viewpoint we see interaction as a potentially valuable part of the system, aimed to support students' understanding of individual influence on the overall result.

From the perspective of developing interactive visualization based on the tasks of operators the procedure was close to development of other educational collaborative games, where the cooperative pattern directly influence the development process (El-Nasr 2010). Therefore, we see similarities in the development process of interactive multi-user visualization and designing serious games for education. In this way, the further build-up of the interactive visualization can be similar to serious games development.

7 CONCLUSIONS

Road construction operations require collaborative work from a number of construction machine operators. The particular task of a sequence of compactors is to achieve uniformly compacted asphalt layer as a team. Introduction of new asphalt mixtures and their specifics for asphalt compaction requires a continuous dialog between paving experts and machine operators to improve knowledge of operators. Such experts' knowledge include best practices, expressed in recommendations for the operators how to process with compaction in relation with respect to a particular asphalt mix. Although visualization can enhance knowledge transfer currently there are no specialized user-oriented environments to support transfer of knowledge from paving experts towards machine operators.

We see simultaneous user-oriented visualization as a possible way to support dialogue between operators and experts. To identify the required information to support machine operators in their work we studied knowledge intensive tasks of the operators. Based on the identified information distribution on site we developed a multi-user visualization scheme to support knowledge transfer from paving experts towards machine operators. Finally, we proposed organization of simultaneous visualization, suitable for the knowledge transfer and, in particular, to professional education of machine operators. The proposed scheme incorporate three displays: two operators' screens to represent compactors individual movements on site along with the temperature data, and a third large screen that shows combined temperature and machine paths visualization.

The described way of visualization is oriented to deliver operator-related information, according to the operators role. Also, the proposed system implementation allows students to simulate their behavior individually. The scholar's decisions can be analyzed in relation with performance of other operators.

It should be noted that the described project is a work in progress, and as such, the proposed scheme is a subject of ongoing testing. The prototype of the visualization approach, based on the described multi-user visualization scheme, is currently under development. Based on the prototype testing and analysis of users' perception the proposed multi-user visualization will be further investigated.

8 ACKNOWLEDGEMENTS

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