Developing a real-time process control system for asphalt paving and compaction

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Abstract

Asphalt construction is a complex process filled with variables that influence asphalt quality significantly. Process parameters such as the temperature of the asphalt mat and compaction consistency need to be measured and observed using high accuracy sensors. Analysis of the sensor-derived temperature contour plots (TCPs) and compaction contour plots (CCPs) (available for the last decade) has suggested asphalt quality also linked to operator's behaviour, where his decisions mainly based on tacit knowledge. To eliminate 'blindness' of asphalt team about construction process itself, we consider to provide operators with essential data in appropriate way in real-time. This paper presents the solution of developing a real-time process control system for asphalt paving and compaction.

We explore current solutions, which are utilized in hot-mix asphalt pavement, and estimate the main set of drawbacks and benefits of them. Our analysis further revealed the strong need in real-time system. Providing data and visuals to the asphalt team in real-time is a complex task, demanding great effort in terms of system and software development. The results of such development need to be considered in future studies of monitoring systems for asphalt pavements.Tekst (Times New Roman 12)

Keywords - asphalt; construction; real-time; quality control; development; prototyping

1. Introduction

The road construction industry progresses with help of new high-tech solutions, which are offered for the daily tasks of asphalt teams. The machine manufacturers and asphalt companies along with researchers from academia try to improve current solutions, which are used by contractors. Nevertheless their efforts are focused on improving design of the machines or testing around features of asphalt mixtures, leaving beyond of the research scope the process variables. In addition, current solutions provide either the overview of the paving process or that of asphalt compaction. Each solution has its own drawbacks. From a communication perspective, each machine (paver or roller) is mostly being considered as a fully independent block. The data between machines is mostly not being transmitted resulting in variability since the effect of each machine's behaviour is not being taken into account. From the perspective of time, many solutions provide the data with high latencies that may lead to inappropriate operator's behaviour. The other critical aspect is the data visualization where current solutions present data in a complex format, sometimes too difficult for operators to understand. It appears that current real-time solutions, although promising, do not as yet fully meet the needs of operators. All in all, despite strong demand of industry to implement novel methods and techniques, we are witnesses of the trend, when operators reject to utilize some technologies.
In response we propose to develop a real-time process control system for asphalt paving and compaction through the design of a system prototype. The process of system development will be operator-centered, to match the operator's needs and eliminate possible refusal of system usage in future. The development of a prototype will consist of three basic phases: design of a paver module, design of a roller module and design of a communication module. This separation provides for flexible elimination of development mistakes, without the necessity of essential changes in software and hardware architecture. To mitigate the disadvantages of current solutions and to provide the asphalt teams with reliable data, we will incorporate the latest sensor technology to measure the essential process parameters for paving and compaction. Data transmission between components of the system will be based on wireless networks with sufficient bandwidth to reduce the latencies. We will also study appropriate machine to machine communication options, where the data transition algorithm will be developed.
This paper describes the background to the real-time challenge, a review of current solutions, the methodology to develop a prototype and discuss the elements focused on. In closing we discuss the lessons which could be learnt from the development of such a prototype for creating more complex industrial solutions, integration between different systems and data representation.

2. Related work

2.1 Systems

Since the beginning of the two thousandth, along with incredible growth of new technologies, researchers all over the world have started to propose different solutions for hot-mix asphalt monitoring and control. One of the earliest works, which suggests to use on-line tools for asphalt monitoring is [2]. Authors focus on gathering data about construction projects, to be able to offer related information in a structured way of database, which could be acquired on-

line and in real-time. Despite the practicality and usefulness of such solution, its main drawback is that the data is given for post-processing, where the mistakes of construction could be revealed but not eliminated.
Differently, authors in [3] introduce an intelligent compaction (IC), system which controls different compaction parameters for the roller such as: drum vibration, amplitude, frequency and working roller speed (impact distance). The advantages of the proposed solution are explicit - an instantaneous and complete evaluation of the zone being compacted. Nevertheless, the high cost of the used equipment makes the system more expensive than ordinary rollers. The more important factor is that the roller is considered separately from the whole construction team, without taking into account positions of other machines on site, their compaction strategies and acquired data about state of the asphalt mat. The visuals provided by the system are complex for understanding by common roller's operator, where many of the parameters given in graphs. Examples of practical implementation of intelligent compaction are shown in [10]. More extensive intelligent compaction field validations put as a base for quality control (QC) and quality assurance (QA) specifications in [11], where authors observe qualifying IC equipment, specifying GPS equipment and requirements, validating IC systems and GPS operations on site and other aspects. In [4], authors argue that the time for intelligent compaction is right now. On the other hand, they point out, that it may be premature to fully engaging this technology, due to set of drawbacks: system requires sophisticated and rugged equipment in a harsh environment, some operator training and calibration of the equipment using auxiliary lab and field tests. In addition, the compaction cost increases in the short term.
In [6] the ODMS is proposed. The model of measuring system focuses on a density measurements in real time. Developers implemented extensive research, where questions about choosing hardware and software for system modeling along with mounting and communication aspects were considered. Although, the system shows high accuracy in comparison with nuclear density gauge, still, there is an uncertainty of its usability for roller's operator in terms of data presenting. The similar solution (CMS) is presented in [17].
A detailed study of possibility to utilize neural network-based approach to predict the density of the asphalt mat is presented in [7][8][9]. The Intelligent Asphalt Compaction Analyzer (IACA), proposed by authors, shows estimated density which correlates well with the density measured from compacted cores. Furthermore, authors claim that the output of IACA is continuously available to the operator in real time and can serve as a useful guide during the compaction process. One key aspect missing in these works is the consideration of combining of obtained information to the operator when he is working in a team.

2.2 Communication and sensors

One of the examples of using wireless data communication for purposes of connecting the trucks, asphalt pavers and the asphalt plant is presented in [5]. The conducted tests showed the reasonability of using such technique for further system development.
With respect to control the temperature of the asphalt mat, some work has considered ability to develop real time system with sensors based on Fiber Bragg grating (FBG) [12], where the feasibility of such sensors for monitoring asphalt pavement structures was shown.

2.3 Main drawbacks and other initiatives

In spite of the numerous researches in an area, with consideration of different approaches and solutions to extract and monitor set of the parameters about state and quality of the asphalt mat, still, there are questions, which are challenging for further research. Among them the

data representation for the machines' operators, data exchange between machines, working collaboratively in real time.
The manufacturers of the construction machines, continuously present their own solutions in an area. BOMAG, AMMANN, GEODYNAMIK [3], and others offer for contractors different systems, which are already installed on the machines. The major drawback of these solutions is that they are 'black'-boxes for the end user, where the customer has no any chance to improve the system or change it, to be able to use it from his own perspective. In response, the asphalt construction companies have their own initiatives. Ballast Nedam, Heijmans and BAM work closely with academia [1], and independently, trying to explore and define the most appropriate development strategy and further implement it for their own needs.

2.4 Rejection of technology

The last but not least question, which is usually beyond of the developer's consideration, is the mismatch between the technology which has been developed and that one which has been adopted by industry. The possible reason of that is a gap between the technology and knowledge of the system's user, which leads to rejection of the new technology. There is a bunch of researches about rejection of new technologies [18][19], where authors claim that in general the acceptance of technology is well studied, but technology rejection requires careful examination for each particular case. Among factors determining technology rejection, authors mention its complexity, associated fatigue, level of flexibility offered, user-base, and associated switching cost.

3. Solution overview

3.1 Operator-centered solution

Developing of a real-time process control system for asphalt paving and compaction aims to achieve better acceptance among the construction teams, shifts the development model to the operator centered perspective.
For the asphalt construction projects we can define three main perspectives, which could be applied during design of the system. These are: operator perspective, manager perspective and strategy perspective. Putting each of the perspective as a base for the system development, software programmer or design engineer implicitly chooses the information that would be given to the end user. It is quite often, that the developer picks a wrong strategy, reducing the possibilities for further success of the system. For instance, it is planned to pave 600 tons of hot-mix asphalt, this is obviously the information which the manager on site is interested in. For the strategic manager, the data about target density of the asphalt mat which should be equal 2100 kg/m3 is a significant data for planning and for the organization of the process. Although, in general, this information is about the construction process itself, at the same time it is far from the needs of the roller's and paver's operators. Thus, providing the operator on site with insufficient information would lead to system failure for further adoption.

3.2 Data for gathering and presenting

During the construction project the asphalt team mostly rely on tacit knowledge and gut feeling [20], do not take into account many parameters, which could significantly increase the variability of the process and as a consequence the quality of the asphalt mat. Among these parameters: temperature of the asphalt layer, number of roller passes and the existence of the truck with asphalt mix or time of asphalt mix delivery. These values are implicit due to the fact that they could not be observed without special tools and sensors. Providing these data in real-time to the asphalt team is a complicated task, demanding great effort in terms of system and software development.

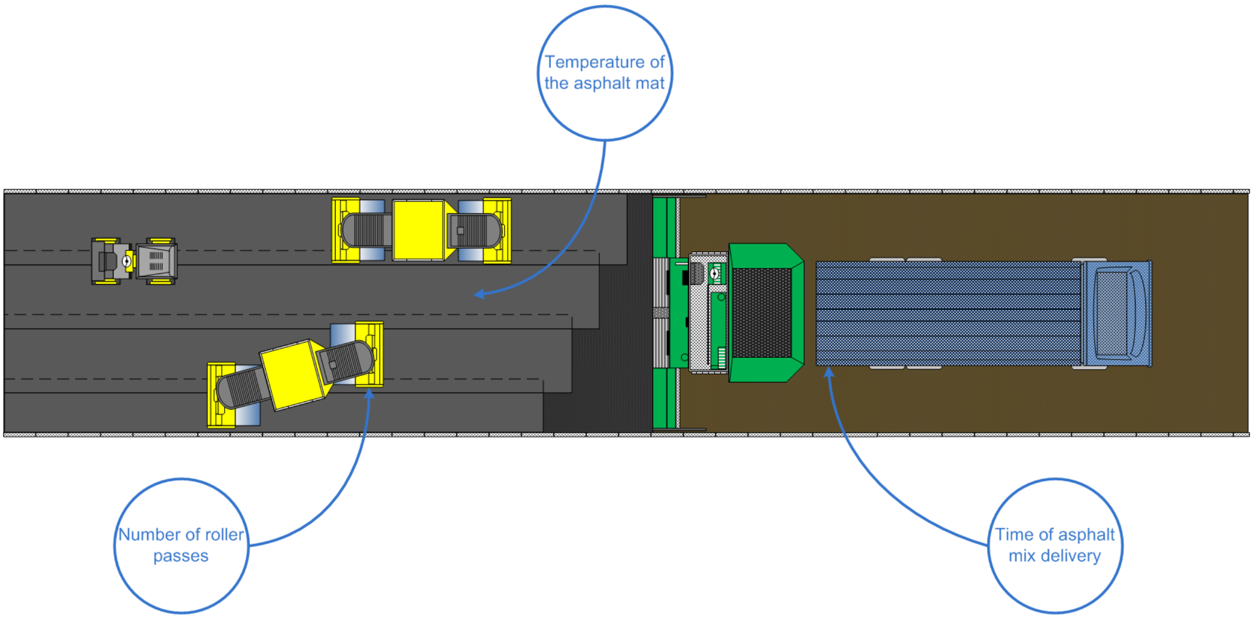

Figure 1. Implicit variables of the asphalt compaction process

Because of the reasons mentioned above, in our system development, we are going to concentrate on operator-centered approach. Due to necessity to achieve the temperature homogeneity and compaction consistency during the asphalt construction project we will supply the operators with reliable data and visualizations in real-time, about the temperature of the asphalt mat, pressure, which has been produced by rollers, and time of mix delivery. This data is relevant because it might impact on work strategy of operators during compaction and as a result quality of the asphalt mat.

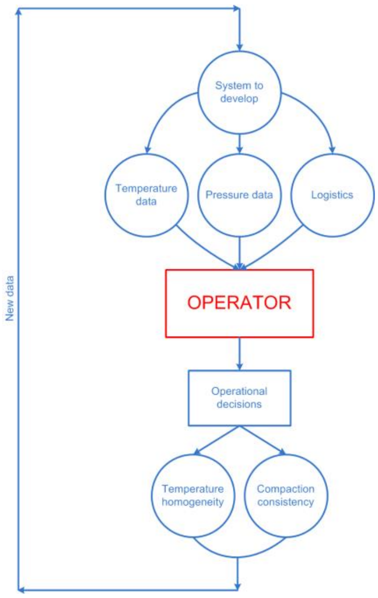

Figure 2. Operator-centered scheme

3.3 Functional requirements

To be able to match the expectations of the contractors, and the end users in particular, the developed system should satisfy with the following functional requirements:

- The solution should be non-invasive - that means that the process of mounting/dismounting of the system and of using the system during the road construction, has to be non-disturbing for the main paving and compaction responsibilities of an asphalt team; or the developed system should be easily placed on current construction machines, without any additional disturbance for the construction team;
- Simple to use - means simple process of mounting/dismounting, without any significant time costs;
- Real-time data representation - due to the speed of work (for paver ~5 m/min, for roller ~80 m/min), it is necessary to provide the operators with data with low latencies, otherwise the mismatch between operator's behaviour and real situation on site will occur;
- 'Simple' data visualization - it is planned to develop '2D' top and back views of the construction process, which could be comprehensible for the machines' operators;
- Ability for integration - the developed solution should be able to integrate with other systems by predefined interfaces;
- Solution should be robust - because of the aggressive environment, where it is planned to use developed system (high temperature, vibration, weather conditions, etc.), the system should meet the robustness criteria;
- Solution should be redundant - the system should be able to work in case of failures of sensors, controllers, data storages, etc. (it is necessary to consider redundant blocks and elements of the system);
- Standalone system - the system itself and its components should be able to work continuously up to 12 working hours, thus battery capacity of each element should meet this requirement.

3.4 Tools and technologies

To obtain the information about location of the paver on the construction site, we are planning to equip it with the GPS receiver, as the most reliable tool for positioning. In case of gathering information about the temperature of the asphalt mat, it is considered to use infra-red cameras, which could replace expensive and invasive temperature line-scanner, widely used in current projects [1]. For the purposes of presenting collected data to machine's operator, we are going to utilize appropriate tablet with sufficient robustness and readability in both direct sun light and shade. For the rollers, the set of equipment almost the same as for the paver, with additional modules for machine-to-machine communication. As we are considering to assess the influence of the whole team of the construction machines during compaction on the asphalt mat, we have to transfer data between the machines. For this goal, machine to machine communication technology (M2M) seems to be the most promising, as it provides abilities to transmit megabytes of data with low latencies among several parties on site. In addition, this technology could be a base to support the other task of creating compaction zones on the construction area.

3.5 Development methodology - prototypes

For the development methodology, it is being considered to divide the system on the several main modules: for paver, for roller and communication, where each module will be designed through its own prototype. On the one hand we will make the system more flexible for testing and detecting 'weak' points of the solution. On the other hand we will get an ability to combine several modules or use them separately.
Prototype for the paver module should be able to collect data from the GPS receiver and infra-red camera to construct the temperature view of the asphalt mat or temperature counter plots (TCPs).
Development challenges which are related to this prototype are the following:

- Selecting suitable devices (GPS receiver, infra-red camera, tablet);
- Creating a software model with appropriate algorithms for data collection, filtering / processing, visualization, transmission and storage;
- Selecting data format and upload rates;
- Testing places for mounting on a real machine.

Prototype for the roller module should be able to collect data from the GPS receiver and in the case of using additional temperature sensors to control the data from the paver, also collect data from these sensors. All challenging questions for the paver module prototype are also valid for the roller module prototype.

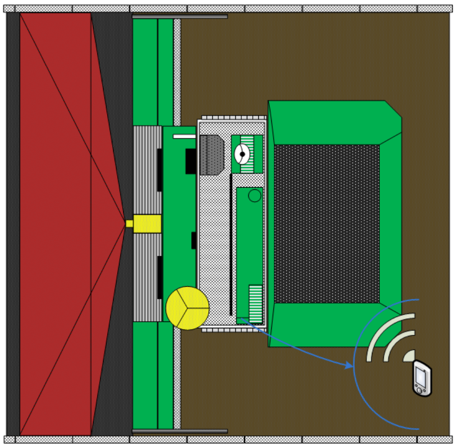

Figure 3. Prototype for paver module

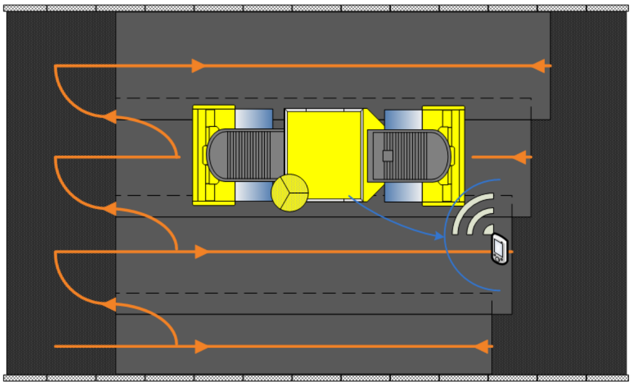

Figure 4. Prototype for roller module

Prototype for communication module should be able to collect the data about the temperature of the asphalt mat behind the paver. When the data will be obtained, there will be the possibility to create an algorithm for calculating current temperature (T_{curr}) from initial temperature (T_{init}), that gives an ability to create temperature zones. This data will be sent to the roller and in combination with roller passes, compaction zones will be generated.
Development challenges which are related to this prototype are the following:

- Applying wireless machine-to-machine communication;
- Integrating cooling curve data;
- Developing an algorithm for temperature prediction.

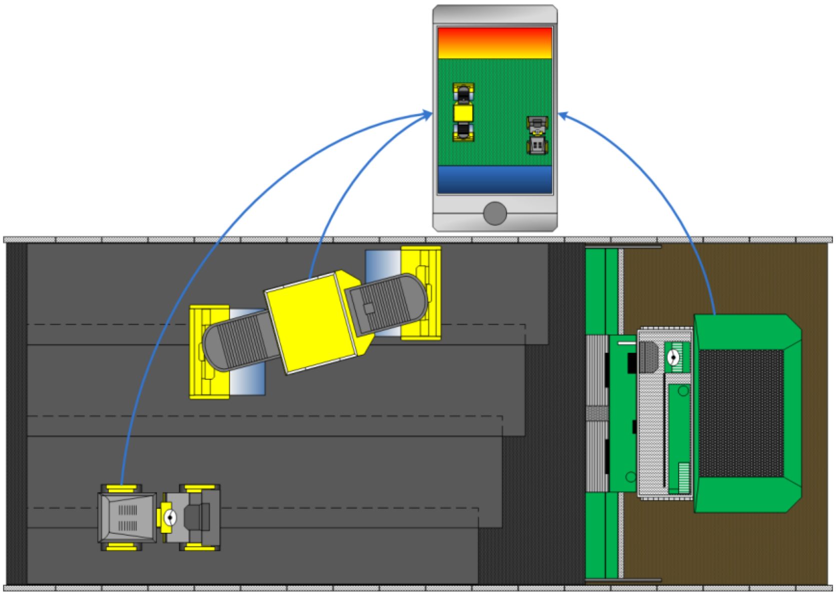

Figure 5. Prototype for communication module

3.6 Visualizations

The other essential part of the system development is the way of data representation. As a first step we are going to supply the paver's and roller's operators with 'top' views of approximate models of the corresponding machines, where roller's operator will be provided with the information about his location on the construction site and the number of passes, which has been produced. At the same time operator of the paver will obtain information about his location on construction site and information about the temperature of the asphalt mat behind the paver. During further development roller's operator will get the plot of the temperature zones on the construction area. Paver's operator will derive logistics about the asphalt mix delivery and the mix temperature inside the hopper.

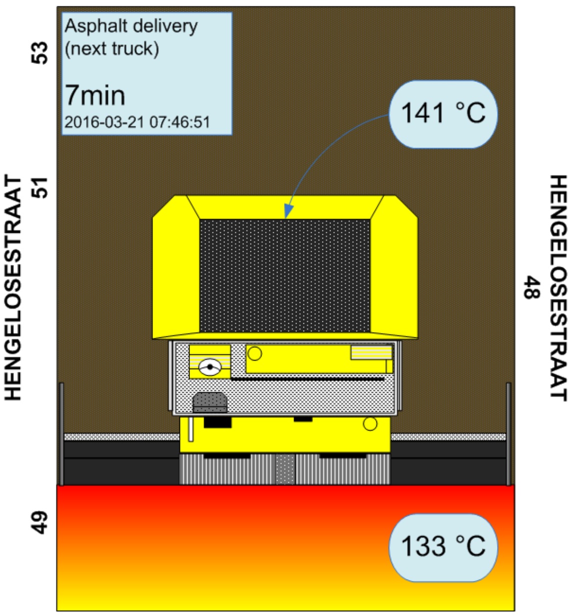

Figure 6. Draft of the data representation for paver operator

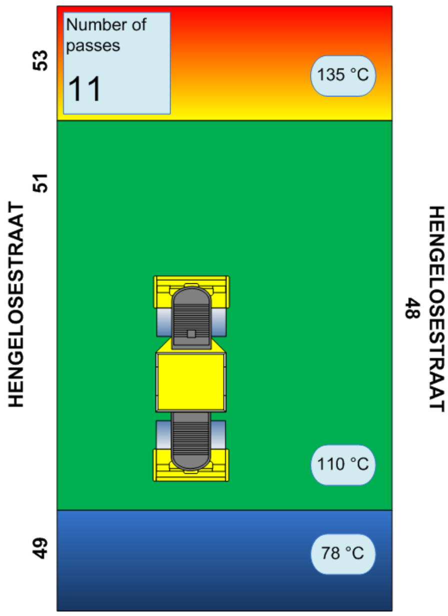

Figure 7. Draft of the data representation for roller operator

4. Possible results of the developed solution - Challenges, constrains and lessons to learn

The first challenge of developing such system, where broad data gathering is used, is to find the suitable temperature and pressure sensors. Back to the mentioned functional requirements, system have to be non-invasive. Thus it impose extra constrains to the sensors, where mechanisms of mounting on a construction area, with minimum additional labour work have to be proposed.

One of the other focal parts of the system is machine-to-machine communication. There are no doubts that the data flows should be organized between all machines which are involved in the paving and compaction project, as well as with the different stakeholders inside and outside of the construction area. This part of the project will reveal many constrains, and lessons to learn for data processing, transmission and storage, where we have to pay attention for developing the communication protocols, network bandwidth, storage capacities of the used equipment.

Regarding data visualization, we have to validate our views through the test trials with end users of the system, where their eligibility have to be checked. There is high possibility that the operators will share their own ideas about the ways of data presenting with notes about their relevance.

The other essential challenge is integration of different parts of the system with each other, as well as with the third parties hardware and software which is used on the construction machines. And if in cases where the machine is equipped with high-tech systems, the main problem is to coordinate between different protocols and interfaces. Then for the 3-drum roller, the question is even more challenging and it is about how to equip the machine, which doesn't have any high-tech solutions on board.

To conclude, through the development, it is possible to gain insights which may be useful for further work. Among them are:

- Prove or refute the methodology of development (usage of prototypes);
- Reliability of chosen equipment / tools - tablets, infrared cameras, sensors;
- Which software model is better to utilize;
- Data processing, transmission, storage;
- Visualization - views, colours, usage of additional signals - sounds;
- Interfaces for integration;
- Necessity of redundant elements;
- Places for mounting elements of the system;

5. Conclusions and future work

Referring to the state of art we have defined the common lacks in many of the researches and initiatives, such as absence of data sharing between different machines on site, latencies in data presenting from sensors, complexity of form in which information is provided to the operators. Based on that we are planning to prove our concept of development with elimination of mentioned drawbacks through chosen elements and technologies. All mentioned intentions in area of modeling the parts of the system, data collecting and presenting, establishing usability of chosen equipment, will be checked in several phases: through the laboratory testing and testing on real construction projects.

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