Asphalt paving is a specific type of construction work: the machines and materials constantly move while the asphalt mixture constantly cools down. The machine operators do have a clear goal – to provide an equally distributed and uniformly compacted asphalt layer - in time-restricted conditions. But what does it mean in particular? In reality, the asphalt should be compacted to a certain degree while the asphalt is warm enough: if the mixture temperature during the compaction is outside a specific range, for example 85 - 120°C, then machine movements can result in damaging the asphalt layer. Such work requires adequate operational decisions, which can be effectively supported by specialized information systems. Progress in developing such systems is a challenge we strive for.

The operational decisions are ultimately driven by the (implicit) question “how to proceed with road construction in relation to the current state of the asphalt layer?” Compacting - in close collaboration with other machines – within temperature/time limits is the characteristic of operators’ tasks. Therefore, machine operators have to monitor movements of a number of machines in conjunction to changing asphalt temperatures. Clearly, contemporarily technology, such as GPS equipment and temperature sensors, should be able to support operators in their daily work.

Until now, to assist machine operators in the field, a number of specially designed information systems were developed by large international machine producers - such as Trimble, Hamm, and Moba. Those systems normally consist of a number of specific components: sensors to document temperature changes and machine movements; processing units for a single or a group of sensors; communication lines and visualization clients to represent processed data to an operator. Nevertheless, while being
useful for machine operators, the existing solutions do not consider the multifaceted context of asphalt paving processes. In particular, the transfer of location and temperature information between different types of machines is still a weak point. As the road construction process requires a number of specialized machines, addressing the inter-machine communication is of utmost importance. This motivated us and the road building contractors to develop better systems.

Centralized processing – the core of the information systems

To find the effective way to deal with communicating between different types of machines, the Construction Management and Engineering (CME) group at the Department of University of Twente works in close collaboration with the Pioneering Foundation (www.pioneering.nl/) and Dutch road building contractors, via the professional network named ASPARi (“Asphalt Paving Research & Innovation” – www.aspari.nl).

Together with ASPARi members we push for improved support of the paving processes by analyzing machine operators’ tasks in depth. Then, with respect to the identified tasks, we experiment with infrastructures of the system to support operators in the field. In addition to the primary function – support operators in making decisions - the developed information systems document and transmit sensor readings to a central storage, where it stays available to managers and quality control personnel.

To adequately process sensor readings the information systems should comply with two requirements: (1) support data transmission from a number of sensors to multiple clients, and (2) support real-time computations. How can we fulfill these requirements when the amount of sensors or users is continually increasing? Luckily, the named requirements can be addressed with the current trend in computer science – cloud computing.

Cloud computing allows (us) to utilize multiple servers connected via a network as if they were one processing unit. Such a cloud shares resources, processing power and is accessible on-demand from any location. Therefore, a central processing unit, connected via a network to all sensors and final users, can be employed as a core of the sensor-based infrastructure. By using cloud computing it becomes possible to receive readings from de-centralized sensors and immediately process them at specialized processing units. Then, the visualization is to be immediately delivered to distant users.

We consider the flexibility of cloud computing as the asset of the user-oriented information systems. In this way, the information system can benefit from the following advantages:
- Firstly, origins of information are not limited to a particular construction site. Users have access to the processed data independent of their geographic location as the communication lines exist there. Any kind of data transfer would work, such as broadband, 3G/GPRS connections. In fact, only a reliable connection to the Internet is required.
- Second, there is no limitation in the number of sensors. For example, a large-scale construction project can utilize a lot of sensors or the same infrastructure can be used to control multiple projects at the same time.
- Finally, all calculations can be done within the computation center, thus reducing the need for IT support on site.

All together, the given advantages allow us to approach the development of paving process information systems from a new perspective. In particular, new opportunities become feasible for centralized
processing of sensor readings: sensor readings can be collected, processed, and disseminated as easy as never before. To investigate the opportunities we developed specialized information systems for paving operations to support machine operations in making well-founded decisions during the paving process. The development process incorporated two major steps. Firstly, we followed machine operators in their daily work. Then, we developed and implemented information systems with centralized processing of multiple sensor readings to support them in their typical tasks. As a result, we developed two infrastructures to support paver and roller operators by tracking both off-site and on-site machine movements. The infrastructures are extendable, as new modules can be seamlessly added in case of need. In this article we will describe the particular examples and, then, conclude with advantages of such an approach.

**An information system to track off-site machinery movements**

The paving process requires continuous delivery of the asphalt mixture to a construction site. This continuity depends on the number of trucks transporting the mixture and on the traffic, which may influence the timely delivery of the asphalt mixture to the construction site. As a consequence, the paver operator cannot be sure when the next truck will arrive and the paver frequently has to stop and wait for the next truck. Such stop-start moving patterns should be avoided because they weaken the surface quality. With additional information about the trucks' estimated time of arrival an operator can adjust the paver's speed to avoid complete stops according to the expected time of the trucks' arrivals. To provide paver operators with information about the arrival of trucks we developed and tested an infrastructure to document and visualize positions of the asphalt trucks during asphalt paving operations (figure 1). The core of the infrastructure is a universally available computing unit, which execute code to process data from multiple devices.

In particular, we developed a specialized Java application, running on a smartphone with the Android operations system, to track machine movements. The following sensor readings are documented: GPS location, azimuth (compass) and acceleration data. The readings are stored in the memory of the smartphone and, then, are transmitted to a server for storage and processing. Then, the server creates web-pages with visualization of current trucks’ positions by using a combination of PHP, MySQL and Google Maps API technologies. Finally, the corresponding web-pages can be accessed from any mobile device on- and away from the construction site.
With the developed information system the paver operator can make better-informed decisions how to proceed with his tasks, based on additional information of trucks location and expected arrival time. The developed infrastructure has no artificial limitation to a number of sensors and final users. As a result, by utilizing the remote storage and processing units it became possible to reap the benefits of multiple sources of information and deliver the final visualization to a number of users, who are located at distance from each other.

In short, the described system infrastructure can support a paver operator in his tasks. Still, at the moment the asphalt layer is constructed by the paver, the next, possibly even more important, process starts. The roller operators start to compact the layer. To support roller operators in their work and to track paving process on-site we developed a specific information system.
An information system to track asphalt paving process

The roller operators are mainly interested in knowing the asphalt temperature at different locations of the construction site. Such information is a basis for operational decisions: choosing the number and type of rollers, determining when to start rolling, and when the last roller pass should be executed. To support operators in their daily work we developed a specialized information system to forecast/predict the asphalt temperature distribution over the road surface.

To provide additional information about asphalt temperature to roller operators the information system measures the surface temperature of the mixture during the asphalt paving process by utilizing high-precision GPS equipment and a temperature linescanner. The linescanner – a device to remotely measure temperature along a single line - is mounted behind the paver at the height of approximately three meters. As the paver moves, the linescanner continuously measure the temperature at the time the asphalt is paved. In addition to the temperature information, to document machine movements we use Trimble SPS851 base station and two receivers, located on both paver and roller.

After the sensor readings are collected, we sent it via WiFi network to a server with a database and a specialized software (Figure 2). The data processing and visualization routines are implemented in Matlab code. Combination of location and temperature information relates temperature data to a particular position: the software continuously generates a mesh, while every node corresponds to a single temperature measurement point. Later, the temperature plot is combined with the location of a roller. Finally, the obtained visualization can be displayed on a client’s computer, located distantly (figure 3).

Figure 2. System infrastructure to track asphalt temperature of the paved road
Characteristics of the developed systems

One can say that cloud computing is a game-changer today. Indeed, with the reliable communication channels the developed infrastructure components – both processing and storage solutions – can be located distantly, in so called public or private clouds in the Internet. In this way, new possibilities to collect and process sensor readings are coming: the sensors’ locations are no longer limited to a single project and it becomes possible to track a number of simultaneously conducted projects.

Scalability and software control opportunities, provided by cloud computing, are additional advantages. In case additional computation power is needed to process multiple projects at the same time, it is possible to easily upgrade the remote infrastructure. From the software perspective, the advantages include the centralized control over versioning, simplified software installation and infrastructure maintenance. Thus, the tasks, related to updating and licensing the software, can be switched to dedicated specialists.

To investigate the coming opportunities of utilizing centralized processing systems, we developed specialized information systems to support machine operators in their daily work. The described information systems illustrated the applicability of centralized processing of multiple sensor readings.

Figure 3. Visualizing temperature of the placed asphalt along with machine’s location
The benefits become particularly visible, if many sensors are to be utilized, or when additional data processing per sensor are needed. All together, the described information systems can naturally support machine operators in constructing high quality road pavements.

PS: Interested in doing BSc or MSc projects in visualization and simulation? Check the list of proposed topics at the UT/VISICO website: “http://www.utwente.nl/ctw/visico/Possible%20Student%20Projects/”