Asphalt production, paving and compaction techniques

Pavement Information Modelling (PIM) – Dutch contractors develop a lifecycle pavement process and performance information system

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Abstract

The road construction industry is in a transition towards systematic and well-structured data and information management of the whole pavement lifecycle. Therefore, the information system PIM, Pavement Information Modelling, has been developed in the Netherlands. PIM is the core information system for contractors in the road construction industry and provides all stakeholders within the company access to relevant data and information of asphalt pavements, from its raw materials, pavement design and mix specifications, production information and georeferenced on-site construction data, including information about its foundation and the substructure. The development of PIM also aligns with ongoing developments at road agencies, such as functional specifications and contracts, need for BIM, data-exchange between contractors and agencies, digital project delivery (in COINS-containers), tangible fulfilment of the requirement (Systems Engineering). The most important goals of PIM are to manage and support the whole road construction lifecycle from raw materials via production and construction to project delivery. The application systematically documents information, specifications, requirements from material purchase until completion and delivery of the project. This leads to a reduction of failure costs, improved control of the companies desired strategy and policy, more efficient long term monitoring of constructed pavements for purposes of risk control, product development and reduction of the administrative pressure of construction processes. The information system PIM has been developed in a unique consortium of eight road construction companies together with an IT-partner using the scrum-methodology. The paper describes the modules and functionality of PIM, the data-structure and IT-architecture of the system. Also, the paper addresses the information exchange with information systems of road agencies and its relevance. Finally, an outlook and vision is provided on how the road construction industry could deal with information and how PIM anticipates on this future needs.

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1. CHANGE OF INFORMATION MANAGEMENT IN ROAD CONSTRUCTION NECESSARY

The road construction industry is changing. Examples are the transition towards performance contracting (varying from Design&Construct to Design Build Finance Maintain), often including long warranty periods (from 7 to over 20 years), the introduction of the CE-marking for asphalt and bitumen, and the functional route of laboratory testing (triaxial, stiffness, fatigue), 'new' construction materials resulting from circularity and biobased, the implementation of Systems Engineering (SE) and System-oriented Contract Management, efforts to record more information about the on-site asphalt paving process, i.e. intelligent compaction [1], many kinds of inspection techniques during the usage phase (e.g. LCMS), and GIS systems to record all this information geographically and visualise it clearly. In addition, the available craftsmanship (implicit knowledge) is increasingly difficult to implement due to the plethora of new asphalt mixtures.
As a result of all these changes, the road construction industry is in need of a completely new approach when it comes to the handling of data and information. Recording information systematically is essential for continuous learning and improvement, and to manage and make targeted decisions regarding risk management and product development. Together, this lead to the development of the software-tool PIM. PIM is short for Pavement Information Modelling and is the central company information system for Dutch contractors in the asphalt road industry providing a lifecycle pavement process and performance information system [2]. PIM is a system that provides all authorised stakeholders within the company access to the available information about asphalt roads, including foundation and substructure, from raw materials to the final completed asphalt road construction.

PIM is the successor of the currently available information systems Roadlab and AIS (Asphalt Information System) in the Netherlands and is somewhat comparable to Lastrada from Germany [3]. Roadlab is very outdated by now; support and further development has ceased, and it no longer meets the current demand for information. AIS for the production and construction of asphalt has now been used by four contractors for a number of years and was in need of an upgrade. In 2015 the decision was made to develop the PIM information system in a consortium of eight Dutch road construction companies. Naturally, this system will use the available knowledge and experiences from AIS and Roadlab, but it is to be an entirely new system that will go beyond Roadlab and AIS, for instance in terms of SE and BIM. PIM closes the entire information chain about asphalt roads throughout the entire life-cycle from building material to end of life, making it a stepping stone for asset management systems. PIM has been developed as an integrated system, so it can be used for asphalt materials and mixtures, foundations, and substructure.
The development of PIM also suits the ongoing changes at road agencies, such as the BIM developments in road construction, information exchange via Information Delivery Specifications (IDL), object identification through an Object-Type Library (OTL), and delivering road projects via COINS-containers.

The purpose of the PIM software package is to have a systematic information tool about asphalt roads, including foundations and substructure. The goal of this paper is to communicate PIM's functionalities, how information will be used in the future from the perspective of contractors, and the possibility to more closely match other developments in the area of information management in the road construction industry.
In section 2, the paper describes the most important goals and principles of PIM. Section 3 covers the development process and section 4 describes the functionalities in more detail. Section 5 hones in on the IT-architecture of PIM and in section 6 we will discuss the information exchange opportunities with road client and agencies. Section 7 describes the most important conclusions and points for discussion. Finally, the paper will end with an outlook, describing a vision for the future regarding the way information should be used and how PIM will meet that need.

2. GOALS AND PRINCIPLES OF PIM

The main goals and principles of PIM are:

- PIM provides access for all stakeholders within a road construction company to relevant information about (all building materials in) asphalt roads in all phases from development, through production, construction and use, to demolition.
- PIM makes it possible to achieve central management of contracts, specifications, and material properties.
- PIM allows for central registration and management of production and construction information of asphalt pavements, for the purposes of:
  - An efficient Systems Engineering (SE) verification in projects;
  - An efficient exchange of information with the client and other construction partners;
  - The ability to control implementation processes and reduce failure costs;
  - The ability to generate management information for more directed control over desired policy.

- PIM provides more evidence that all requirements are fulfilled on a project-level towards agencies Also, it provides more measurable performance information and traceable quality control, also for analyses over projects.
- PIM provides a proper archive for discussion about unexpected damages and guarantee/warranty-issues.
- PIM supports efficient long-term monitoring of completed work. This facilitates continuous optimisation of risk management and product development (competitive positioning).
- PIM enables an efficient internal exchange of information between company departments, i.e. calculation, work preparation, mix design, etc.
- By means of maximally automated registration of information, PIM reduces the administrative pressure on on-site construction personnel and increases the reliability of process data.
- For the CE marking, the properties of each asphalt product have to be determined and recorded in specifications using a type test. The buyers (clients) choose the desired asphalt via a pavement design based on the specifications. It is the job of the asphalt plant to produce those specifications within narrow tolerances. PIM supports these processes.
- PIM can deliver information that shows that production took place according to the specifications.
- When the asphalt is being constructed on-site, PIM will supply information that the contractor can use to show that the supplied asphalt has the properties required by the specifications.
- PIM supports contractors when offering years-long warranties for the performance of the products they delivered.
- PIM provides information that can be used to prove that works are being completed or have been completed in accordance with requirements, plans, and (internal) procedures.
- PIM supports users when registering and managing information in the road construction process in a structured manner.
- PIM has extensive authorisation options, considering the large number of company departments, (semi-) external stakeholders, and users. This means there are both options to prevent information accidentally being available to parties without authorisation, and options to assign read, write, and administrator rights.
- PIM offers the possibility of providing KPIs (Key Performance Indicators) clear for analysis and management purposes.

3. THE DEVELOPMENT PROCESS

In 2015 the decision was made to develop the PIM information system in a consortium of eight road construction companies. Next, a global functional design was determined, including 10 usecases. These usecases were during the development process further detailed into user stories, which are small stories of the desired functionality from the perspective of the end-user.
PIM was developed in a Scrum-agile development strategy. This is a process framework to develop software in a iterative, short feedback-loop in close collaboration with end-users. It is designed for development teams of three to nine members, who break their work into actions that can be completed within timeboxed iterations, called sprints, then track progress and re-plan in 15-minute time-boxed stand-up meetings, called daily scrums. For the development of PIM, we worked in 35 sprints of 3 weeks (April 2016 – December 2018). In 2019, the focus is on implementing PIM into the daily practice of the eight contractors. During this development process, the contractors had their own product owner (daily project manager), key-users that wrote user stories and their own testers (testing after every sprint of 3 weeks). These people were physically working at the software developer in close collaboration with the development team.
The total input to develop PIM was approximately 50.000 hours, about 25.000 from the eight contractors writing user stories and testing the software and about 25.000 hours from the software development team. In total this equals approximately 4 million Euro.

4. PIM FUNCTIONS

4.1. General functions

PIM is a system that provides all stakeholders in the road construction company access to all relevant information about asphalt pavements, from raw material to completed road, including foundations and substructure.

In order to accomplish this, the global structure of PIM is shown in Figure 1, consisting of:

- A section with all materials and building materials with their properties (the difference between a material and a building material are that for a material not all specifications and properties are known yet);
- A library of requirements, standards, tests, etc. related to the materials and building materials;
- A tab with mixtures (both asphalt and foundation), mixture design requirements, mixture designs, CE-markings, and mixture properties that can be viewed and managed;
- A production section with mix recipes, entry checks, production checks (Factory production control, FPC) and deliveries, material stock management plus supply and price information per building material per production location;
- A project section (road works), containing projects, constructions, asphalt requests, calculation mixtures, and quality control (both in-situ and in the laboratory) can be managed;
- A production scheduling section in which the asphalt production schedule can be managed on a planboard from the road construction company perspective (overview various plants) and from the asphalt plant perspective (overview various clients for one plant);
- A management section that contains departments and authorisations, but the building material descriptions, grain size groups, sieves, quality control and inspection sets, and the asphalt teams.

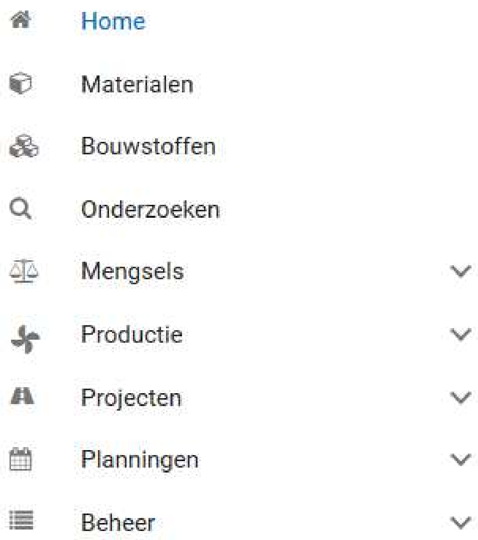

Figure 1: PIM general structure (in English from top to bottom: home, materials, building materials, research tasks, mixtures, production, projects, schedules, management).

4.2. Information structure: decomposition layers

Within PIM, we chose to create a physical object decomposition and an spatial decomposition to record information at different information levels. Information can be attributed to a certain decomposition layer. We distinguish a physical object decomposition, so that information about the physical construction will be recorded (determining which materials are used in a road object) and a spatial decomposition to explicitly record spatial information, such as where specific production batches are located on a project. It is important to keep the physical and spatial decomposition separate to ensure flexibility in analysing, visualising and exchanging data. For instance, from a road object the daily productions or the GPS locations from cores taken from the road object can be shown.

In order to record and systematically store all information regarding a physical road object, we distinguish five physical decomposition levels (see Figure 2). These decomposition levels vary from the whole road object to the smallest construction unit (each smallest construction layer). Next, each smallest construction layer consists of a building material or mix of building materials.

With this decomposition, each decomposition level of the road, for which requirements are possible for information exchange, is recognised in the system. By also recording the right relationships between levels, it becomes possible to analyse the desired object information, both administratively and graphically, in any desired form throughout the life cycle of a completed pavement. For instance, if a pavement shows early unexpected damage in the fourth year of the warranty period, using PIM it can be shown which asphalt batch it was, if that batch was produced at the right temperature, what building materials were used, and whether those were supplied within the desired specifications. The revolution in pavement information management is that all pavement data is object-oriented and can be georeferenced, so PIM fully aligns with the newest BIM developments in the construction industry.

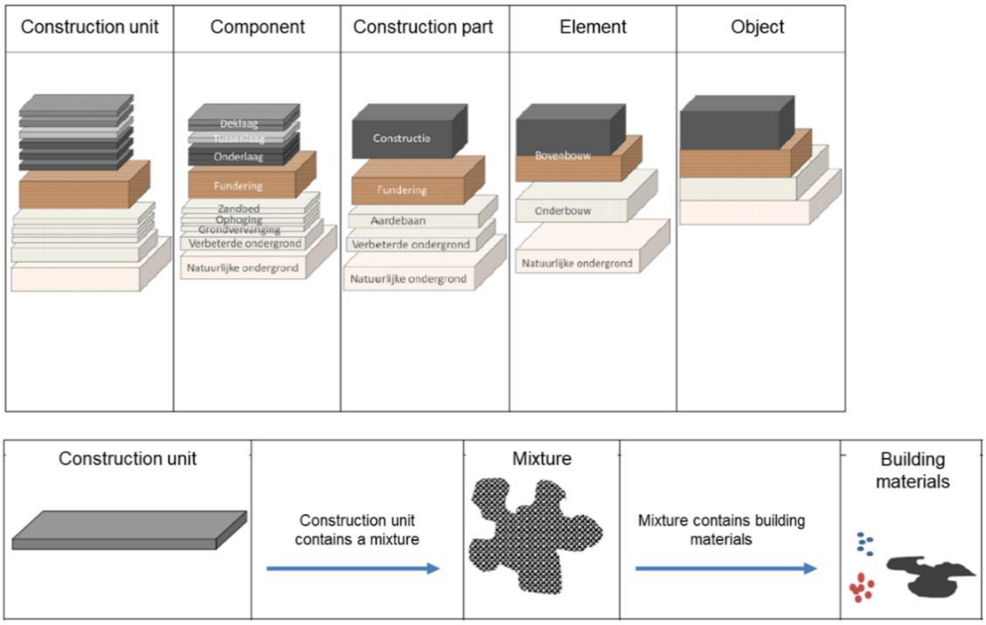

Figure 2: Physical object decomposition

Figure 3 shows an example how the object decomposition has been visualised in PIM. At these various construction layers different requirements can be attributed. For example, there can be a requirement for the density of a specific asphalt layer, but there can also a requirement for the thickness of all asphalt layers together.

Figure 3: Example of an object decomposition in PIM with requirements at various levels

A different decomposition is the spatial decomposition. This means that information can be attributed to specific GPS-locations. Some examples are visualised in Figure 4, in the left figure some cores drilled from the road and in the right figure specific surfaces that are constructed on a specific day.

Figure 4: Spatial decomposition in PIM

4.3 Constructions and traceable quality control

In PIM it is possible to add different constructions (as shown in Figure 3) and attribute a certain quality control set to that construction for a specific project. Firstly, so-called construction blueprints with identical structure can be entered. Based on the blueprints, constructions at multiple locations, with different areas and with functionally equal mixtures, can be distinguished. That is because the entered blueprint construction is not a representation of the space, but of the physical object that can be created at multiple locations. A construction will only change when the functional properties, leading to changed functional performance of the construction, changes. An example is a road with a crossing in between can have the same construction before and after the crossing – these construction will then have the same blueprint and are only different in its spatial decomposition.
The application of a continuous layer of the same type of asphalt (or every other building material) is called an construction unit. This is the lowest physical decomposition level and also the level (e.g. asphalt layers) on which the construction is actually completed. Quality control is conducted on this construction unit. All results of quality control, inspections, and examinations will also be linked to the pavement construction at this level. For instance, if two layers have been drilled, the right construction unit will have to be chosen for each layer in order to record the results. This means that the construction units and the constructions are specifically distinguished from each other as a result. We no longer work based on constructions, but based on application units that belong to a construction layer. A construction may therefore be made up of layers that may contain multiple construction units. An construction unit itself may in turn be part of multiple constructions, as long as the building material/mixture and the layer thickness are the same.

4.4 Support of the primary process

PIM is also essential to support the main processes of the contractor. For the road construction industry and particularly the contractors, PIM is an important step forward to standardisation and mutual information exchange between various departments of the company. Examples of this standardisation are, for instance, the same descriptions for building materials, the same specification, the same design parameters, typetest-reports and QC-reports, etc. This also leads to unambiguity in the demonstrability of quality control and inspections to clients. This standardisation also helps to connect and link to asset/road management.

Another process that PIM supports is the production scheduling at the asphalt plant. Figure 5 shows an example of the planboard of an asphalt plant. Various contractors can send their asphalt requests via PIM to the planner of plant and via PIM the asphalt request can be accepted or declined. So, PIM provides a real-time insight into the production schedule for contractors and asphalt plants.

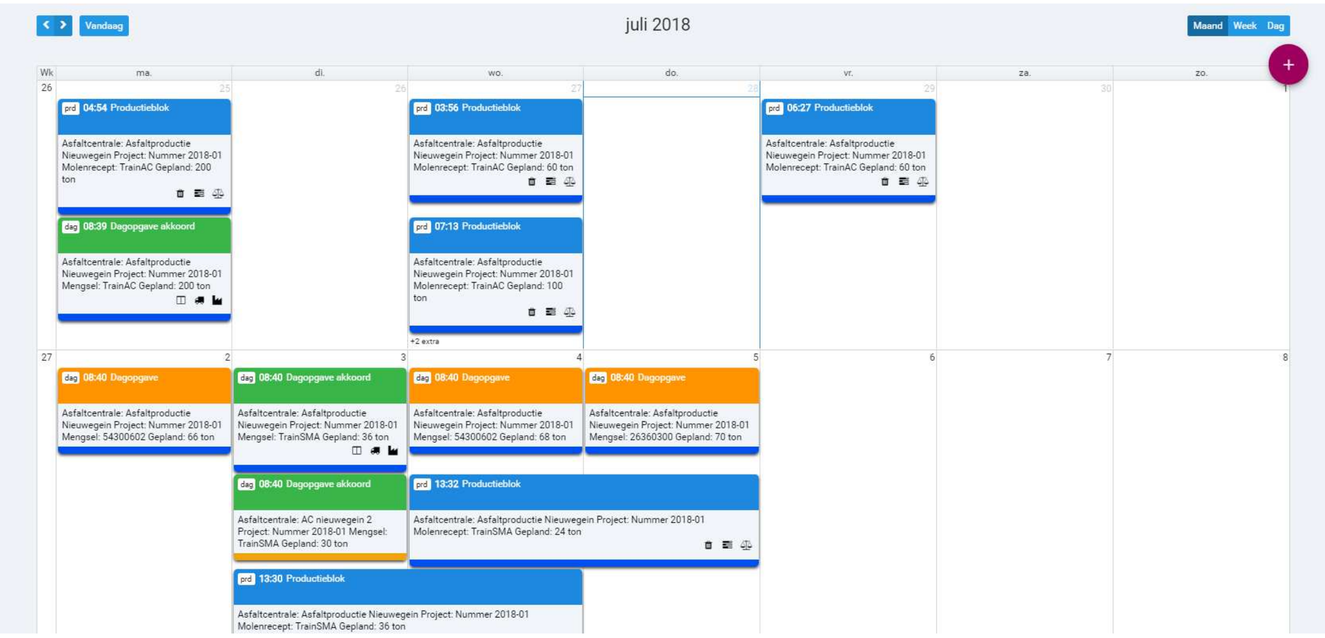

Figure 5: Example of a planboard for the production scheduling in PIM

4.4 Management information and KPIs

The combined information in PIM is vital management information. A management dashboard has been developed with various KPIs (key performance indicators) to analyse the performance of the construction company (analyses over multiple projects and multiple production plants) in order to target and implement the intended company vision, strategy and policy.

Some examples of KPIs that have been developed in PIM (also see the visualisation in Figure 6) are:

- Building materials:
  - Used building materials per application area per period (per year, for example);
  - Amount of recycled asphalt, incoming and outgoing material stream (in tonnes).
- Type examination:
  - Number of tonnes produced per typetest.
- Production preparation:
  - Price at quote and calculation vs. actual price upon delivery;
  - Planned quantities vs used quantities;
  - Average time between asphalt request and delivery per asphalt plant.
- Production-in-plant:
  - Amount of production outside desired temperature range per asphalt plant;
  - Factory production control, number of non-conformities;
  - Quality control and inspection frequency per delivered tonne of asphalt (per mixture type);
  - Overview of product control results for asphalt mixtures at an asphalt plant.
- Construction:
  - Deviations per layer (quality parameters, i.e. density, void content, etc.);
  - Overview of the results of all analysed asphalt cores drilled from the road.
  - Difference in desired density as determined in the laboratory (type test) vs. density immediately after production vs. density level realised in the road.

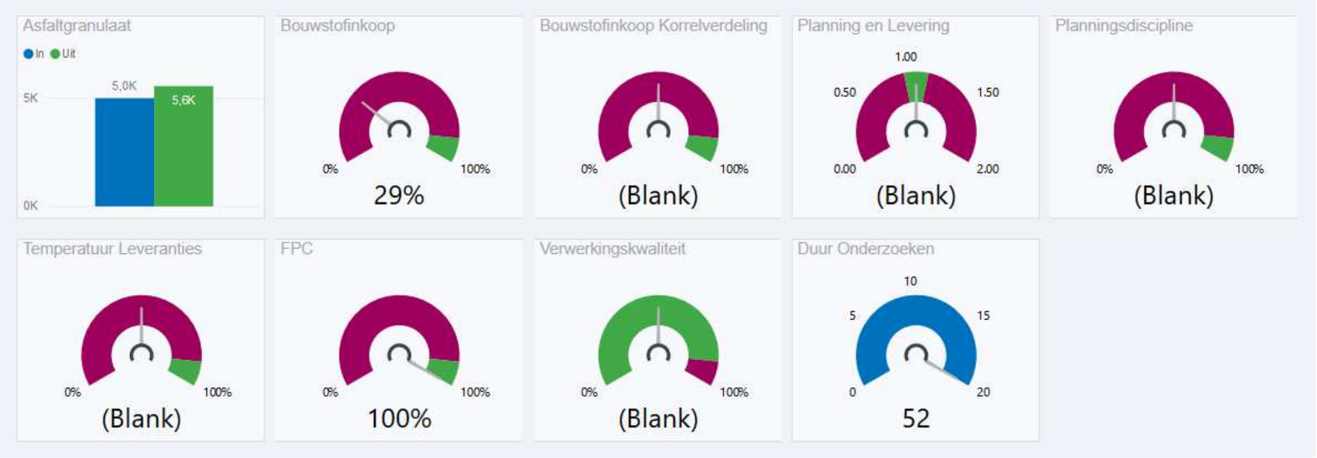

Figure 6: Example of the management dashboard with different KPIs in PIM

5. IT-ARCHITECTURE AND INFORMATION EXCHANGE

The IT-architecture of PIM is based on a Software-as-a-service model and consists of three layers:

- A database-layer with different databases of all information (raw information databases, a datawarehouse for analyses, and a document store);
- A layer of business logics containing all PIM-logics which are accessible via various APIs (Application Programming Interfaces);
- The user interface layer, including screens and reports that the PIM-user can see.

Beside these information layers, there is separate authentication and authorisation applied over all three layers. The whole PIM IT-architecture is based on a multi-tenant (the use of one physical PIM-system) and multi-instance (each contractor uses their own physical instance of PIM). Multi-tenant provides an easy maintenance of the software, whereas multi-instance creates enough flexibility and configuration possibilities for each contractor.

Besides, PIM has to be integrated into the company IT-architecture. Therefore, a separate interface layer has been developed in order to exchange information with other software packages. Examples are ERP-software (e.g. Metacom, Navision) to exchange financial and project/client information, GIS-software (ArcGIS) for all georeferenced information, transport and intelligent compaction software (e.g. BPO Asphalt, WITOS) to exchange transportation and compaction information, SE-software (e.g. Relatics) for all requirements of a project, document management (e.g. Sharepoint), etc.

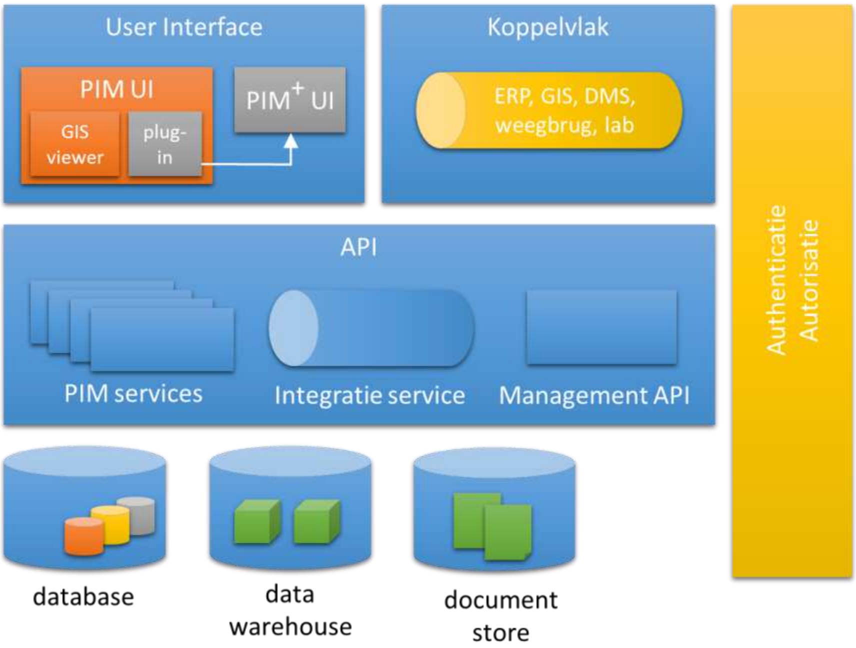

Figure 7: IT-architecture of PIM

6. INFORMATION EXCHANGE WITH ROAD AGENCIES

As with all information systems, the ability to exchange information with other stakeholders and other software systems is essential. For example, road agencies are also working on up-to-date, reliable, and complete information for the maintenance of their roads. Therefore, it becomes increasingly important to systematically store and deliver all relevant information of a road project to the road agency. Important facets in this information exchange are ‘information delivery specifications’, a uniform ‘object type library (OTL)’, and a COINS-container to digitally exchange the information.

6.1 Information delivery specifications

The information delivery specifications (IDS) are part of the contract between a road client and a contractor, which specifies the transfer of data. This contract document ensures a uniform exchange of information about road projects. The document contains agreements about the delivery processes, the responsibilities of contractor and client regarding information, the way in which the information should be transferred (COINS), the frequency of the transfer, and the (open) standards to be applied. By using an IDS, the information about the composition and conditions of their roads will be available in the agencies’ systems immediately after the data have been transferred. PIM has been set up in such a way that the contractors can easily provide information in accordance with the delivery specifications.

6.2 Object-Type Library (OTL)

Efficient exchange of digital information between road agencies and contractors is only possible if everyone speaks the same language. The development and the use of an OTL contributes to chain partners along the entire life cycle of a construction speaking the same language. The OTL is based on the principle of one-time gathering and multiple use of data. The OTL contains definitions of relevant road object types and makes information about road objects available.
In order to achieve that, a PIM-OTL has been developed, which means that all eight contractors use the same language for the same building materials. Road agencies have not standardised this in the Netherlands, which means that each road agency has their own OTL. At a national level, it has been arranged that all organisation-specific OTLs can be linked to the Dutch concept libraries to link and exchange OTLs in an accurate and unambiguous way. The PIM-OTL is a first stepping stone towards BIM-standardisation.

6.3 COINS

COINS is used to exchange data between the contractors and road agencies. COINS is a flexible standard for the exchange of (BIM) information making use of existing multiple ISO-IEC standards and semantic web technology. It provides a data exchange and storage mechanism by means of a container or envelope for (BIM related) data/information. The standard provides a semantic model comprising a small core information model which can be extended with reference information models and object libraries for specific domains. It provides functionality to integrate data structures which are a combination of RDF formatted, non-geometric data structures and standardised data structures like IFC and GML, object type libraries and non-structured documents. It is an answer to the needs of practice in which information delivery often consist of combinations of various data structures. It also enables a data drop as one information package with multiple data formats. PIM has been developed in such a way that it can easily fill the COINS containers with information regarding the asphalt road construction and can exchange information according to the standard exchange format.

7. CONCLUSION

Various changes in the road construction industry, such as the transition towards performance contracting including longer warranty periods, the introduction of performance-based CE-marking, the introduction of BIM, and the introduction of a plethora of sensors and technologies, together lead to necessity of professional information management. In order to meet that demand, eight Dutch contractors have developed PIM, a central company information system for asphalt pavements (incl. foundations and substructure) to provide a lifecycle pavement process and performance information system. The development of PIM has taken place from 2016 to 2018. In 2019 the software tool PIM will be fully implemented into the daily practice of asphalt road testing, asphalt road design, production and on-site construction of asphalt roads.

The system includes the construction materials, the production, the processing, and various laboratory tests and characteristics of asphalt mixtures, bound and unbound foundations, and substructure. In addition, the system is able to record information per object level (object decomposition) and per area (spatial decomposition).
PIM will also be compatible with information systems and supporting instruments that are being developed by clients, such as Information Delivery Specifications, Object-type-library, COINS-container. PIM is being set up in such a way that PIM and these systems can easily and efficiently exchange information. Together, PIM makes information exchange with road agencies much easier. Also, PIM is a stepping stone of standardisation towards a BIM-standard (in terms of a PIM-OTL) for roads.

In conclusion, PIM can be seen as the birth certificate of the road. Each realised road has a birth certificate with which building materials are used, how it is produced and how it was constructed. PIM helps to work in accordance with the regulation (European standards, national standards, CE, FPC, etc.) and to work according the requirements on a project-level. Also, it provides more evidence and traceable quality control, also for analyses over projects. Direct savings from PIM are: (1) less time required to make delivery files and reports, (2) less time required for data collection and analyses, (3) less failure costs: Right people have access to the correct data. Indirect savings from PIM are: more insight in (1) production quality, (2) on-site construction quality, (3) better project and product choices. Together, this leads to a more uniform and more efficient road construction process providing further professionalisation of the industry regarding information management.

8. INFORMATION MANGEMENT IN ROAD CONSTRUCTION IN THE FUTURE

The demand for information in road construction will continue to change considerably in the future. The main challenge will not be any more to collect data, but much more to transform the data into useful information and link that information to information from different sources in order to make better product and project choices in fulfilling the desired company vision and strategy.

We included, for instance, a full link to GIS, asphalt logistics, process registration, and road management systems (e.g. Horizons), so that long-term monitoring of road pavements in a very effective and efficient ways becomes possible. With the opportunity of this long-term monitoring, the risk of undesired premature failures can be quantified, so that it will be possible to anticipate it during the design stage and to base product development and innovation on reliable and quantitative data.

Further, the systematic storage of data in PIM also makes it possible to take the step towards functional verification of realised road work [8]. After ten years of experience with performance-based specification of asphalt, it is time to take the next step and switch to functional, end-result verification and functional delivery [8]. Functional, end-result verification means that asphalt constructed in the field is also tested using performance tests and related to the functional tests in the laboratory design phase [4,5]. This allows directly comparing field properties with properties promised in the pavement design and declared on the CE-mark. After all, the CE marking determines the potential properties of the asphalt mixture, which does not automatically mean that the same performance will be achieved in the field.

A lot of information about road construction will be recorded systematically in the next few years, with the help of software systems such as PIM. When more data will be stored in PIM (all projects from eight contractors), more insight into the performance of building materials and asphalt mixtures can be analysed. Also, in the future quality control and inspection of roads will be based on big data analyses and dynamic inspection frequencies, making it possible to effectively use developments in data registration and monitoring for the verification and validation of completed projects [6,7]. Together, this enables big data analyses in the future. We plan to create a data lake for combining these datasets with i.e. traffic intensities, maintenance schedules, etc. This means a big step forward towards further professionalisation of the road construction industry regarding information management.

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