IWiRoM: An Intelligent Winter Road Maintenance Information System

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Abstract

This paper introduces a joint applied research project between Riga Technical University and software consulting company ZZ Dats "IWiRoM: an Intelligent Winter Road Maintenance Information System" sponsored by European Regional Development Fund. The objective of the project is to increase the efficiency of winter road maintenance processes by developing an open and modular intelligent winter road maintenance support information system and a corresponding Enterprise Resource Planning (ERP) integration module. The main innovative features of the proposed project are usage of non-conventional data sources and exchange of data and knowledge in the winter road maintenance ecosystem among the stakeholders. Currently, the ecosystem analysis and platform design activities have been completed and elaboration of analytical and machine learning models for winter road maintenance is the ongoing activity.

Keywords

Intelligent transportation system, winter road maintenance, sensing, data analytics

1. Introduction

Internet of Things (IoT) and big data technologies have enabled development of a new type of data driven intelligent information systems. Winter Road Maintenance (WRM) is one of the application areas greatly benefiting from these technologies. The problem is characterized by a high degree of complexity due to information processing and decision-making challenges. Perrier et al. (2006) provides an extensive review of decision-making algorithms used in winter road maintenance [1]. That includes design of ploughing and removing operations, vehicle routing, depot location and resource allocation. From the information processing perspective, variety of factors need to be considered for planning and execution of winter road maintenance operations. Hinkka et al. (2016) analyse existing information systems for winter road maintenance and calls for integrated solutions with emphasis on collaboration among various actors involved in winter road maintenance [2]. They point out that the current systems focus on the centralized data processing model what leads to local optimization of maintenance decisions. The work effort, material consumption and work results should be booked in the resources planning system for the winter road maintenance case. Various data sources are needed to record and to analyse this information [3]. The centralized data management is complicated because the winter road maintenance problem tends to involve variety of actors [4] and the data sources are temporal and geographically dispersed. Therefore, users of the resource planning system cannot be sure about available data sources and there might be complex data interdependences. The ecosystem approach has been suggested for tackling these issues though without providing formal means for analysis [5].

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In order to address, these issues Riga Technical University and software consulting company ZZ Dats are jointly working of the applied research project "IWiRoM: an Intelligent Winter Road Maintenance Information System" sponsored by European Regional Development Fund. The project started on January 2021 and will continue till November 2023. The project results are expected to supplement ZZ Dats portfolio of information systems supporting variety pf business processes at Latvian municipalities.

The objective of the project is to increase the efficiency of winter road maintenance processes by developing an *open and modular intelligent winter road maintenance support information system and a corresponding enterprise resource planning (ERP) integration module*, which are based on the latest scientific knowledge and provide road managers with data-driven resource usage reporting and proactive decision-making, minimizing response time for performing optimal road maintenance actions, thus promoting safe driving conditions for road users, as well as establishing an ecosystem for other intelligent transport and public safety services.

The IWiRoM system developed as a result of the project will be open to third-party developers. In comparison with currently available solutions in the WRM market, IWiRoM will be able to collect and retrieve more qualitative data from different standard and non-standard real-time data sources, thus combined with the included standardised and efficient integration with the ERP systems it will provide a data-driven and transparent solution for WRM process management and a competitive advantage against other similar service providers.

The ERP integration module developed as part of the Project is expected to be integrated with ERP systems from different vendors, ensuring high quality service for users of these systems and ensuring full integration with other business processes provided by the ERP. The IWiRoM system will be able to provide efficient and easily customizable solutions for addition of data sources and decision-support modules and delivery of decisions to external systems, thereby creating an attractive ecosystem and demand from other developers of smart services aimed at road infrastructure. The ERP integration solution developed within the project will be integrated into the ERP system GVEDIS managed by the consulting company.

2. Challenges

High citizen mobility has led to increased traffic intensity of road traffic, which in turn has led to increased load on road infrastructure, energy consumption and has contributed to escalation of transport related environmental and social risks. In order to address these challenges implementation of Intelligent Transportation Systems (ITS) has become one of Europe's priorities. ITS are based on Information and communication technology (ICT), provide innovative traffic management, information sharing services and contribute to cross-sectoral synergy.

Winter road maintenance (WRM) is one of the ITS' key application areas and it includes seasonal activities (snow removal, de-icing etc.), which aim to ensure adequate road condition during winter. The global WRM challenges are:

- **Efficiency** – USA government and local agencies spend 2.3 billion USD (approximately 20% of road maintenance budget) on WRM annually. Unlike other road maintenance work, which can be planned in advance, WRM strongly depends on varying meteorological conditions and resulting road state changes. The effect or WRM activities is transient In the United Kingdom WRM operations cost more than 140 million £ annually and damages made to vehicles and road structure cost an additional 100 million £. It is necessary to balance the amount of resources consumed, environmental impact and road safety.
- **Delayed WRM operations lead to hazardous driving conditions and pose significant threats to the society.** The death of a single person causes economical loss of up to 1.9 million € in other European countries. Icy or snowy conditions caused 24% of weather-related accidents in USA and lead to 116 800 injuries and 1 300 deaths. Research confirms correlation between road conditions in winter and the number of accidents. It has been confirmed that successfully performed WRM significantly reduce the number of traffic accidents (reduction in traffic accidents with injured by 88%, cost of accidents by 85%).

- **Individual vendors, providing full range of service with closed proprietary systems, have obtained a dominant position in the market of WRM support systems.** Recently one of the leading vendors of WRM systems Vaisala acquired its competitor Forecca. If current tendencies remain, market entrance for start-ups and companies providing specific services such as computer vision will be more complex due to seclusion of the WRM market. On the long term this could lead to licencing cost increase (for municipalities and road maintenance companies) and decreased level of innovation in WRM products.
- **Global warming increases the importance of WRM** since temperature fluctuations and forming of black ice have become more frequent. Climate change tendencies and increasing mobility requirements have made traditional reactive WRM approaches obsolete and require proactive de-icing strategies.

The challenges can be addressed using a suitable ITS. The proposed IWiRoM platform addresses several technical problems:

- **Inadequate exchange of data and knowledge between the ecosystem members** – the IWiRoM system provides the WRM ecosystem members (road maintenance companies, road managers, road users – private and public transport, etc., developers of new innovative smart traffic services) with opportunity to open their data and share their knowledge with other ecosystem members. The project promotes interaction and creation new knowledge by organizing joint workshops, as a result of which an ecosystem is established.
- **Insufficient coverage because RWS do not provide full picture of the road conditions on regional and national scale** – unconventional data sources are used, such as a free mobile application evaluating road condition, which brings the advantages of using crowdsourcing, and video analysis module, which determines road condition by using images from traffic cameras.
- **Road maintenance company workers are unable to access video streams from several stationary cameras since they might contain personally identifiable information** – video stream is processed using deep learning neural network, which retrieves the derived information about road state (e.g., the road is wet or covered in snow). As a result, workers gain access to larger number of annotated video data sources that are free from personally identifiable information.
- **Traditional analytical models are unable to use unconventional data sources such as Waze alerts or information about detected snowy road** – a deep learning neural network is trained; it uses data from all available sources for evaluating road state and recommending the most appropriate road maintenance operations.
- **Available WRM systems are closed systems** – IWiRoM platform is developed as an open system which can be extended with modules created by third-party vendors.
- **It is complicated to measure the effectiveness of WRM operations and rationality of decisions** – during the IWiRoM project execution the platform is adapted according to regional specificities and legislation, unconventional data sources are integrated, rules and management dashboards are defined for graphically showing the WRM efficiency (road maintenance according to legislation, used material, average road state and other parameters which will be identified during WRM ecosystem modelling). An ERP module will be implemented, which will use the information provided by IWiRoM regarding the road maintenance work and the road condition for establishing full-fledged control over the performed road maintenance operations and corresponding key performance indicators.
- **WRM support systems are not adapted to regional specificities and legislation** – regulations are formalized in a form of rules and integrated into the IWiRoM Rules engine together with rules and best practices defined by the experts of the road maintenance area.

3. Solution

A new product will be created to address the identified challenges – open modular IWiRoM information system, which is based on collaboration and use of artificial intelligence (Figure 1). It will consist of the WRM ecosystem and IWiRoM technological platform. The WRM ecosystem is a network of all parties involved in road maintenance and data processing. It includes road users, entities

responsible for road maintenance (e.g., municipalities), road maintenance companies, owners of road maintenance related data and third parties, which depend on the quality of road maintenance or provide additional services. The IWiRoM is based on data and information exchange among ecosystem members to provide other parties with the missing information. Core functions of the platform are data retrieval from heterogeneous real-time data sources, road state evaluation and decision making regarding the necessary road maintenance operations, as well as passing resulting decision-making information to external system (e.g., Waze, ERP systems, municipality mobile applications). To enable functioning of the ecosystem, the platform is open and provides effective and simple means of adding new data sources, decision making modules and passing information about decisions made to external systems. IWiRoM also provides a standardized ERP integration service, and its applicability will be demonstrated by providing integration with enterprise resource planning system GVEDIS developed by ZZDATS and implementing a specialized IWiRoM module in GVEDIS.

A data ingest framework provides decision support and data interpretation modules with the necessary data. Machine learning algorithms will be used for video data pre-processing. Numeric data for each prediction point (i.e., road section) in time and space will be prepared by applying filtering. Adjusting analytical models to new context and input data is time consuming, which is why automatically adjustable machine learning models will be used. The developed machine learning models will be integrated into the IWiRoM platform in a standardized way and the platform will provide means for their execution and adaptation.

Within the project, a unified ERP integration service corresponding to the IWiRoM system will be developed and a single use case will be implemented by connecting the enterprise resource planning system GVEDIS developed by ZZDATS to the IWiRoM's ERP integration service. This integration will provide availability of IWiRoM's generated road maintenance related information flow withing the ERP systems in a standardized way and will facilitate better control over road maintenance operations and their key performance indicators. It is expected that the ERP integration service developed within the Project will enable integration with ERP systems from various vendors, ensuring the availability of high-quality service to the users of these systems and full-fledged integration of WRM business process with other company processes.

This allows the IWiRoM to provide a full cycle of data and information processing for all ecosystem members, improves the availability of information in time and space and creates opportunities for building new types of services through extending IWiRoM platform with innovative third-party modules (such as road condition forecasting using deep learning networks).

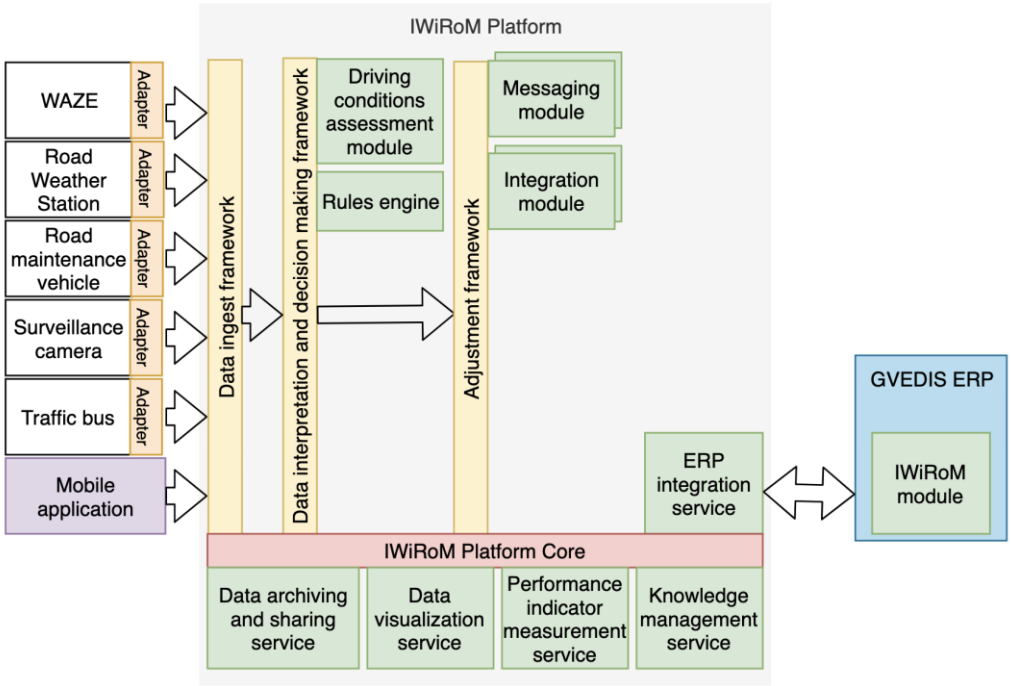

Figure 1: The key components of the IWiRoM platform

The **IWiRoM** platform consists of:

- IWiRoM platform core, which is responsible for data and information exchange between other components, consists of data ingest framework, core services – data archiving and sharing service, data visualization service, performance indicator management service, knowledge management service, ERP integration service (IWiRoM platform integration with ERP systems in a unified way) frameworks – data interpretation and decision making framework, adjustment framework;
- Data ingest framework – receiving data from different data sources in a standardized manner;
- Data source adapters – provides data source data pre-processing, transformation and feeding data into data ingest framework;
- Mobile application – evaluates road condition by using mobile phone sensors and feeds data into the data ingest framework;
- Data interpretation and decision-making framework - unified extension of the platform by using third party developed solutions, which provide road and driving condition evaluation and decision making in regard to necessary actions;
- Driving conditions assessment module – retrieves information about road condition from stationary video cameras (e.g., traffic cameras) and combines it with other data (Waze alerts, measurements from road weather stations, work performed by road maintenance vehicles, road condition evaluation sensors installed on public buses), thus enabling effective use of all available data for evaluation of driving conditions in wide geographic area;
- WRM decision support best practices formalized by industry experts in form of rules – rules engine containing expert defined rules corresponding to local regulations;
- Adjustment framework - provides standardized platform extendibility with modules, which receive data from the data interpretation and decision-making framework and uses it to perform the necessary adaptive actions;
- GVEDIS ERP integration module - provides GVEDIS ERP integration with the IWiRoM system by using the ERP integration service included in the platform core, provides availability of information generated by the IWiRoM to ERP systems;
- Adjustment framework modules – distribution of alerts via e-mail, SMS, posting alerts in Waze, integration with APIs of enterprise systems owned by WRM ecosystem members.

4. Research Plan

The project is executed following the Design science methodology and it is primarily aimed towards creation of a new artefact – the IWiRoM platform. The chosen methodology fits the project since it emphasizes practical relevance and theoretical foundations of the research, allows to evaluate different design alternatives during iterative development and supports combination of multiple research methods, as well as promotes dissemination of the scientific results. The project consists of four activities:

- Activity 1 – Development of the WRM ecosystem model;
- Activity 2 – Design of IWiRoM and ERP integration solution;
- Activity 3 – Elaboration of analytical and machine learning models;
- Activity 4 – Implementation and validation of the IWiRoM platform;

According to Design science these activities form the theoretical motivation and justify practical importance (Activity 1), design the platform (Activity 2), implement and evaluate the platform and included solutions (Activities 3 and 4). Design, implementation and evaluation are performed iteratively, supplementing the development with evaluation results.

Currently the first two activities have been completed. The WRM ecosystem model has been developed by using enterprise modelling methods. The modelling was performed during interactive sessions involving road maintenance companies, service users (municipalities and Latvian State Roads), traffic information operators, national weather service (LEGMC) and interested ICT companies. The

ecosystem modelling results have been reported in two scientific publications [6, 7]. The design of the IWiRoM platform has been developed. Open source technologies such as Kafka, Spark, Cassandra, TensorFlow and Docker are used to implement the platform. The technology evaluation results are report in [8].

The third activity on elaboration of analytical and machine learning models is currently ongoing. Deep learning and convolutional neural networks, that are suitable for image and various data processing, will be used in implementing road condition prediction models. Input data will be retrieved from different data sources (road weather stations, Waze, weather predictions, mobile devices, traffic cameras etc.) and will use data integration technology, which will be based on Lambda architecture. Historical data from "Latvian Road maintainer" and weather service (LEGMC) in combination with newly acquired data will be used for neural network training. Analytical models will be developed by using numeric models from transport engineering and operations management.

Incremental and iterative software development methods will be used for implementing the IWiRoM in Activity 4. The development will be divided into stages with periodic validations and demonstrations for estimating progress and providing feedback. Ecosystem members will participate in the presentations. The development process will be organised and coordinated by using Kanban approach. The analytical models developed during Activity 3 are integrated with the IWiRoM technological framework. The models will be validated in laboratory environment with historical data provided by ecosystem members and simulated data. Experiments are designed using factorial design methods. The main experimental factor will be the available data types. Validation will be performed on different type of roads with varying data availability – all data sources (primarily, road weather stations), partial data and only a single data source (except for road weather stations). The measure of evaluation will be the precision of the road state evaluation. The number and amount of valid and invalid road maintenance events will be evaluated in cooperation with WRM ecosystem members. Estimates will be statistically compared to the current situation and hypotheses about the statistical significance of improved evaluation accuracy will be tested. Validation results will be used for improving algorithms by performing neural network pruning, using dropout method, which will allow to use the networks for wider range of problems.

The main risk factors to success of the IWiRoM platform are viability of the WRM ecosystem, availability of training data and lack of suitable benchmarks to evaluate efficiency. The evaluation of efficiency of the WRM operations highly depends on varying weather conditions and valuation of the impact of road accidents. Occasionally favourable weather conditions could lead to reduced incentives to contribute to the WRM ecosystem. Supervised learning techniques are mainly used to classify road conditions what requires preparation of training data.

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