Functional Architecture of Toll Management and Supervision System – Case study Bosnia and Herzegovina

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Abstract

The aim of this paper is to describe functional architecture of Toll Management and Supervision System (TMSS) implemented at highway segment “Jošanica – Kakanj” on corridor A-1 in Bosnia and Herzegovina. Toll system consists of several hierarchical layers: lane, plaza and central levels. Central level, implemented by TMSS, is responsible for overall parameters and data management and processing of real-time tolling and technical data collected from hierarchically underlying layers of the system (plaza/lane levels). Wide spectrum of operational and business reports and analysis are obtained by such centralized data collection, archiving and processing. The TMSS is also responsible for coordination and management of communication and integration with both internal subsystems (lane/plaza levels) as well as with external partner systems (ERP/Back office, Banks, POSs, etc.). All information is stored and archived in Oracle database, while end-user applications and business services (integration) are implemented as web-based modules on Oracle Fusion Middleware 11g platform, including specifically Oracle Business Intelligence and Data warehousing. In this paper main functionalities and architecture of TMSS will be presented, along with logical and business rules of data processing, hierarchical communication with underlying layers, security model and overview of most important report and data analytics capabilities.

Keywords: Pay Toll System, System Architecture, Functional Architecture, Data Processing

1. Introduction

Toll Management and Supervision System (TMSS) is the central part of the toll system, which enables the collection and processing of data from the lower hierarchical levels and external systems, the distribution of system parameters and generation of a set of reports on the work of the entire toll system. The TMSS is responsible for communication and integration with internal subsystems (lower hierarchical levels, plaza/lane), and external users and partner systems.
The aim of this paper is to describe the functional architecture of the TMSS, which is designed and applied to the section of the highway "Jošanica – Kakanj" at corridor A-1 in Bosnia and Herzegovina. The TMSS is designed on the modern Oracle Fusion Middleware technology platform, which enables a high level of system scalability, reliability and data quality, compatibility with other systems and the evolutionary development of component functionalities.

The paper consists of five sections. Section 2 contains a brief description of the toll collection system. Section 3 describes the technical architecture of the TMSS. Section 4 describes the functional architecture of the TMSS with a description of all the major modules of the system. Section 5 contains the experience in the application of TMSS. Section 6 is the conclusion of the paper.

2. Toll System Description

The system of toll collection is a complex information system that includes hardware and software components. In organizational terms, the toll system includes three levels: the toll lanes, toll stations and the central level. The three levels of the system are in the on-line or off-line communication. Schematic organization of the system for toll collection is given in Figure 1.

![Figure 1. Hierarchical layers of Toll system](image)

The toll lane provides: the physical flow of vehicles (entry and exit of vehicles on the highway), the process of toll collection, recording all data on the vehicles and operations, control of peripheral equipment and communication with toll stations. Toll plaza is connected with all the toll lanes and it: provides communication with lanes, collects data from the lanes and generates a set of daily reports on the work. On the other hand, the toll plaza is in communication with the Central level where it sends information on the operation of all toll lanes.

The system on the Central level is the Toll Management and Supervision System (TMSS). The TMSS takes responsibility for entry and updating of all system configuration parameters of toll system, as well as all data on Toll Charging process collected from lower layers (plaza/lane). Different business and operational reports are generated by collecting, archiving and processing of all these data. These reports are used for support of decision making on both tactical and strategic levels of the Toll system (Dunkel et al, 2011). The TMSS is also responsible for communication and integration with both internal
subsystems (lower layers, plaza/lane) as well as with external users and partner systems (via Internet portal and number of external integration interfaces to third-party systems).

We will explain some basic terms used in describing the TMSS:

- **User** is a person who is a user or the owner of the vehicle using the highway.
- **Medium** is a magnetic card, OBU (On-Board Unit) or CC (Company cards) used as a means of passage and toll payment on the highway.
- **Client** is a legal or natural person holding an account for the OBU and CC whose vehicle is using the highway.

### 3. Technical architecture of the TMSS

The TMSS architecture is Multi-Dimensional, Event-Driven and Service-Composed (Hauser et al, 2010). Multi-dimensionality refers to horizontal and vertical scalability of the System in order to meet both technological and business requirements. Event-Driven aspect of the architecture originates from the principal behaviour of the lower layers of the System. Most of the data produced by underlying system layers are related to real-world events (communicated by messages, e.g. OBU/CC processing or equipment state / sensor detections etc.). The Service-Composition is required for provisioning of services (functions and data) to both internal and external consumers.

System is composed of following main architectural tiers:

- Info-Structure foundation
- Core-Business applications
- Externalized sub-systems
- Third-party systems

Foundation (Info-Structure) provides technology frameworks and platform functionalities for deployment and execution of Core-Business components and applications. Service-Composition provides loose-coupling and enforces standardization (Common Information Model) among these components, and thus enables efficient development, implementation and maintenance of the TMSS, including easy reconfiguration and optimization in both physical (size/performance/quality/cost) and logical (provisioning/scope) sizing in order to meet different customer requirements (horizontal and vertical scalability). Such standardization also enables easy integration and flexible interoperability with third-party systems and optional components, with minimal changes to core components, and provides competitive sustainability for long-term market presence and standards and regulations compliance on different markets.

TMSS info-structure tier is implemented on Oracle Fusion Middleware 11g technology stack as set of J2EE web-based applications (using Oracle ADF Ajax UI components), SOAP web services and JCA integration adapters. Data layer is implemented on Oracle 11g R2 database, as mixed OLTP (transactional) and OLAP (analytical) model, with data warehouse for optimized analytical data structures utilized for both predefined and ad-hoc reporting implemented through Oracle BI platform (Oracle, 2011).
4. Functional architecture of the TMSS

TMSS Core-Business tier consists of number of high-level modules corresponding to main business and technical functional domains. Each high-level module is built by number of components. Each Component is implementing a logical group of functions (mostly exposed as Services) supporting the main role of corresponding module. While some system-wide functions may spread over several modules, the split of responsibilities and thus component functional scopes are based on logical correlations through business processes (important for development and maintenance as developers can focus on particular domain instead needing to learn and maintain global understanding). System-wide functions are performed by information flows integration and orchestration of services provided by modules / components.

Logical system architecture is focused on the TMSS, which is functional and integration core interconnecting lower layers of the system (plaza/lane) with number of external systems including Internet Portal, ERP, Banks, OBU and CC providers etc. (Figure 2).

The TMSS consists of following main modules:
1. Internal and external integration
2. System management
3. Toll charging
4. Customer Management
5. Data analytics and reporting

Figure 2. TMSS modules and integration with others systems

Detailed functional architecture of the TMSS components is presented on Figure 3 and further explained in following subsections.

Figure 3. Detailed functional architecture of the TMSS
4.1. Internal and external integration

**Internal integration** module implements communication and control of data exchange among Central and lower layer (plaza, lane) subsystems over proprietary transport protocol (utilizing binary data encoding).

Protocol adapter implements bilateral (inbound and outbound) messaging interface for receiving events data (inbound events) from lower layers, and delivery and distribution of configuration/control data and information to lower layers (outbound services). Adapter supports both on-line (over TCP network) and off-line (over transportable media e.g. USB flash disks or CD/DVDs) data delivery, and performs syntax validation and protocol integrity checking of message streams for detection of malfunctions (connectivity states of clients) and prevention of data loss (message chain integrity).

Communication audit log traces all inbound and/or outbound communication in raw format, for diagnostics and resolution of communication issues and problems as well as documenting of data interchange among TMSS and other subsystems. In Figure 4 is shown a monitoring screen for real-time control of internal communication adapter performances (connected clients and TCP sockets, average inbound message rate per minute and structure of inbound messages). Such monitoring and audit logging enables easy and prompt detection of malfunctions and provides means for diagnostics and resolution of problems so the system down time is minimal. Minimal downtime and fast recovery of communication is essential for near real-time information availability on Central level.

**Figure 4. Internal communication monitoring**
Message processor which is responsible for parallelized message pre-processing (semantic verification, basic in-memory processing for message-to-object deserialization etc.) and intelligent (based on configurable logic) routing for delivery to other system components in Service Oriented Architecture (SOA) for further processing and/or database storage as well as post-processing and generation of result feedbacks to clients (lower layers of the System, e.g. plaza/lane etc.). Message processor performs automatic detection of semantic and logical anomalies and errors (e.g. undefined lanes or road segments and other invalid data inconsistent to System logical and physical configuration and topology) which is used for additional indication of potential system miss-configurations or failures on lower layer equipment (plaza/lane) which could not be detected on equipment itself.

External integration implements number of interfaces and protocols for data exchange with external (third-party) systems like banks, OBU and CC providers, etc. External integration is realized utilizing different mechanisms of communicating and data provisioning from/to other systems, depending on technical requirements and business agreements with external partners (e.g. supported are SOAP web services, with palette of WS-* policies, FTP/HTTP interfaces or other type of on-line and off-line data provisioning - import of file received via Email or form flash/USB stick).

4.2. System management

This module is responsible for overall system monitoring and physical configuration for production operation as well as test mode of operation on parts or system as whole. Overall toll system technical monitoring and supervision of real-time operation of complex equipment and hardware/software subsystems has significant similarities with systems in
other industrial fields, like SCADA or power control systems etc. (Pradeep et al., 2011).

Also, for purposes of collection and dissemination of information, this component implements logic for scheduling and reliable delivery of meta-data configurations and other data to lower layers (plaza/lane) via internal integration which is responsible for communication only. As part of system configuration, the security and user management functionalities are provided for provisioning of user access rights and also for audit logging of relevant activities on all system applications and layers.

**System monitoring and supervision** in (near) real-time (overall system state, drill-down view on state of equipment and subsystems on lower layers, alarms, etc.), including:
- Display of last/current event on every lane,
- Display of equipment functional and operational state by plaza/lane,
- Display of staff/collectors logs and operations by plaza/lane,
- Display of different alarms, etc.

All information is presented graphically as well as textually (Figure 5).

**Maintenance management** is supported through add-on module which is based on Issue-tracking subsystem for registration and lifecycle data collection on equipment service requests, diagnostics and service operations performed.

**System configuration management** implements:
- Physical and logical configuration management (setup of system topological and other technical configurations e.g. road/plaza/lane configurations, equipment types etc.)
- Management and scheduling of both physical and logical configuration sets distribution from Central to lower layers and subsystems. While Internal Integration is responsible for technical delivery mechanism, this component is responsible for organization and scheduling management of distribution of configuration data in accordance to business and organization rules.

**Figure 5.** TMSS monitoring and overview screen
Security and access management and auditing implements:
- User management for all System layers (including role management for the TMSS).
- Access control (role-based application access control) and monitoring of user activities (audit logging of user access to applications and workstations) – Workstation access logging, Application access logging, and Report access logging.

Test management, including management of test data usage and control of test mode of operation for different system components and on different layers (plaza/lane/equipment etc.) supports:
- Creation of standard test definitions per application functionality/use-case
- Test results data storage management (distinction and separation from “real” production data)
- Possibility of work with test data in different application use-cases (at any moment)
- Test data reporting (dynamic inclusion/exclusion from production data for testing / verification of report templates etc.).

4.3. Toll charging

This module is responsible for automation of core business process related to processing of toll charging events, generated automatically by equipment and/or staff (Toll Collectors, Supervisors etc.) on lower system layers (plaza/lane), and generation of financial charges for customer accounts (further processed by Financials and Accounting module).

Toll context management, implements logical configuration management with parameterized configuration of business and processing logic rules:
- Context data management, including creation and editing of different metadata models and business/logical configurations used in all system components, like: tariffs, exchange rates, exemption lists, etc.
- Management of configurable parameters and variables used in all business processes in the System, like VAT rate, Discount rates, etc.

Toll Charge Transaction processing implements receipt and collection of event messages from lower layers (plaza/lane), identification of related messages and creation of Toll Transaction Record in central database (chaining of related messages/events), logical validation and checking of messages (consistency and business rules validation and identification of irregularities etc.). More specifically, following activities are performed:
- Logical checking and correlation of related event messages per logical Toll Transaction;
- Logical validation toward business rules and identification of irregularities and non-compliances (which are then marked and distinguished from regular cases for further processing);
- Receipt and processing of Incident data records;
- Receipt and processing of Runaway reports;
- Reconciliation and resolution (decision making by authorized users) on all special cases (irregularities, incidents etc.);
Creation of financial records for charging of Customer account (automatically for regular transactions and semi-automated, after manual reconciliation and resolution, for special cases).

All collected data on each toll transaction (entrance and/or exits of vehicles from toll-road) are searchable using number of parameters and every transaction event is accompanied with OCR (Optical character recognition) and video surveillance (VS) images for enforcement control (Figures 6 and 7).

Figure 6. Centralized enforcement control through detailed transaction inspection including images from OCR and VS

Toll Collectors monitoring and logging enables automatic and manual data collection on work shift reports (one work shift may contain several work sessions on same or different lanes, and system automatically collects and merges these data in single work shift report per Collector).
Pre-magnetized cards management enables support for supervision and control in limited working mode of the System (when automatic card distributors are not in function etc.).

4.4. Financial and Customer Management

This component is responsible for management of customers and their accounts, including wide range of supported account types, payment methods, special tariff packages (discount groups, services) etc. Also, support for financial transaction pre-processing (for booking into external General Ledger or integration with external ERP and accounting systems) is implemented.

Financial Accounting including Customer accounts management for different account types (pre-paid, post-paid, and retroactive) as well as financial processing implements:
- Accounts management (opening / suspending / closing / transferring of accounts, account / service type management etc.)
- Accounting and Bookkeeping (receipt and processing of transaction from Toll Charge module, gray/black list enlisting etc.)
- Financial integration (data import/export and interchange) – receipt and processing of bank statements (payments / receivables) for different payments (debit/credit cards, transfers etc.); integration with OBU and CC providers (or Sales Points); and different reports generation and delivery to partners (e.g. invalid payments etc.).

Customer management enables support for creation and update of customer data and provision of customer related services through internal business procedures or via external subsystems including Point-of-Sale and Internet portal:
- Import/Export customer data and/or sales point data (via on-line or off-line data exchange),
- Complaints management – entry and processing of reversal financial transaction data for accepted (positively resolved) complaints etc.

Point-of-Sales (PoS) externalized application provides a set of functions related to OBU and CC sales and cash-up services to customers. PoS application is integrated with a system via business services, relying to business functions provided by TMSS Financial & Customer management module, and includes a specialized OBU and CC personalization/test module option as well as other optional equipment for other payment modalities.

4.5. Data analytics and reporting

Analytics and Reporting module allows production of different sets of reports based on which it is possible to supervise and manage entire toll system operation. Given the complexity of the tolling system, this module can show reports on all aspects of work on different levels of detail.

Analytics is based on the DWH architecture, which allows optimal performance in near real-time for the statistical and historical analysis of large amounts of data (Linden et al, 2010). Reporting in near real-time is enabled on several levels of granularity (hour, shift, day, period ...). Reporting is based
on the optimized data structures, allowing the generation of standardized ad-hoc and dynamic reports using the modern BI technology. Using the Oracle BI platform enables users to define new ad-hoc dynamic reports through an intuitive web-based application module.

Analytics and Reporting include the following groups of reports:

- **Toll Charging – Financial and Traffic Report** – Financial reports include data on all vehicle traffic on the highway, vehicles paying cash, OBU and CC, financial reports on the work, surpluses and deficits of the treasurers. Traffic statements are on entry, exit and circulation of vehicles on the highway, reports on the re-categorization and image of the vehicle traffic on the highway.
- **OBU and CC – Reports on** the OBU and CC include sale, amendment and pass OBU and CC, and can be obtained on individual clients and media.
- **Financial & Customer Management – Reports on** account balances of OBU, CC and clients, and various synthetic and analytical reports.
- **System Management – Reports on** the system operations are reports on the current state of equipment, work of users and import and export of data with internal and external systems.

All these reports are available at different levels of detail, depending on the set of input parameters: time, station, collector, period, medium, clients, and others.

### 4.6. External / Internet portal

Internet portal is optional module which enables public relations with both general public (anonymous users) and customers (through secured user access for registered users):

- Public information (Content Management System) about Toll Charging (different documents, information, instructions, pricing lists, discount information etc.) as well as selected survey reports (e.g. traffic flow statistics etc.).
- Customer services, including registration and update of customer data and generation of different customer reports on demand (e.g. history of Toll Transactions, account reports etc.).

### 5. Experience with application of the TMSS

The TMSS is designed for the highway section "Jošanica – Kakanj" Corridor A-1 in Bosnia and Herzegovina. This section is 37 km long and has six toll plazas with 30 toll lanes. The TMSS is implemented in less than 6 months, and started routine operation from 14. June 2012, with plans to expand it to other sections of highways in Bosnia and Herzegovina (Mihajlo Pupin Institute, 2012). So far, the operation experience of the TMSS has proven the efficiency, good functionality and high operational reliability.

The TMSS working online receives messages from the lower levels of the system. Communication Statistics is shown in Figure 8, and refers to the period of 24 hours. The figure shows the average message inflow (per
minute), the structure of messages by type and structure of messages per plaza from which they originate. The most frequent event messages (daka	extsuperscript{1}, daps, dakau, daenp, OCR/VS images) are generated with each entry and exit of vehicles on the highway.

**Figure 8.** TMSS Communication Statistics

Based on analysis of data different indicators may be derived on the operations of the TMSS. Table 1 shows some indicators of TMSS for a 24-hour period.

**Table 1.** Some indicators of the TMSS operations

<table>
<thead>
<tr>
<th>The total number of messages</th>
<th>Average messages inflow (msg/s)</th>
<th>The average time of processing the most frequent messages (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125,955</td>
<td>1.46</td>
<td>daka 8.2, daps 2.7, dakau 8, daenp 19.1, image 2.5</td>
</tr>
</tbody>
</table>

With this performance of the system it is possible to provide support for the peak period of approximately 80-100 simultaneous entries and exits of vehicles on the highway. Although this is the peak load significantly above the average, it is important in order to support the recovery of the system where individual plazas are operating in the off-line mode of communication. That is when the messages are stored on the local plaza servers, and after re-establishing on-line communications they are submitted in the "bursting" mode to central level i.e. TMSS. Therefore, peak performance is important for shortening delivery time of delayed messages and synchronizing data on the central level with the data at lower levels. The experience in TMSS testing period shows that the recovery time for the system after e.g. one-hour outage of a station is about 5 minutes.

As explained in technical architecture section, TMSS is designed to be scaled – the database servers and application servers can be added, to strengthen the performance of critical processing bottlenecks. It should be noted that the total system load is also made out of transaction processing of messages that are received from lower levels (plaza) in parallel with the execution of the requests and operations of end-users via application web user interface. Depending on the number of end-users, the system can be

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1 Daka, daps, dakau, daenp... are internal message names representing events corresponding to vehicle entrance/exit passages using magnetic card and OBU/CC (and thus representing the main data volume generated by lower layers of the system).
scaled and adapted to the needs of the expected traffic flow and the total number of application end-users (if integrated with external systems e.g. Internet portal, the total number of end-users should account for all of them). Such scalability allows fine optimization of the total cost of investment (by optimal selection of hardware and software licenses minimizing the costs) and long-term expandability of the system (by enabling further acquisition of hardware and software licenses in small chunks and only when needed). Specifically, the system owner in Bosnia and Herzegovina is planning to scale the system in line with the increasing volume of traffic as well as to expand the TMSS to cover other sections of the highway when they are completed in the future.

6. Conclusion

In this paper we presented the new Toll Management and Supervision System – TMSS, which is a central level of the toll charging system developed and deployed by Institute Mihajlo Pupin at highway segment “Jošanica – Kakanj” on corridor A-1 in Bosnia and Herzegovina from 14 June 2012. TMSS is designed and developed on modern Oracle Fusion Middleware 11g technology platform, providing scalability and high-reliability needed for 24/365 near real-time operation.

TMSS functional architecture is covering both technical and business processes of the tolling system. Such and convergent architecture, where both technical and business functions are combined and integrated into single application, offers number of benefits to both end-users and system administrators. Also, development and change management of system functionalities, in response to new requirements and regulatory demands, is much improved in such converged architecture compared to heterogeneous systems with number of autonomous components that need to be adapted and synchronized independently. Together with scalability which offers possibility for optimal hardware and software investments for needed performances, ease of change management and maintenance enables economic efficiency of the TMSS in production rollouts.

Experiences of two months of production operation of the TMSS have proved good performances and reliability. It is noticed that modern and intuitive web based user interface is well accepted by end-users, allowing easy and fast self-learning. Combined Event-Driven and Service-Oriented architecture provided very good data analytics and reporting capabilities and performances, which enables near real-time system monitoring and supervision on all levels of decision making (operational, tactical and strategic).

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