Regional Module of Intelligent Transportation System: Algorithms and Information Infrastructure

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Abstract: Due to the increasing number of personal transportation vehicles and cargo transportation it is reasonable to implement intelligent transportation systems based on adaptive algorithms to deliver the effective control of traffic flows within the highspeed transportation corridors connecting different countries. The presented paper proposed the concept of the regional intelligent transportation system module which could be extented into regions taking into account its specific features. Presented approaches are considered on the data on real-time traffic flow parameters collected from different heterogeneous data sources. The nature of the data and its structure underlie the data warehouse model.

1 INTRODUCTION

1.1 Relevance and Motivation

Creating the regional module of intelligent transportation system and a great interest devoted to similar projects could be explained by many reasons. But, first of all, it is an ability to connect the heterogeneous transportation monitoring and control systems together. This idea prevails in the road map of AutoNet market of Russian National Technological Initiative (NTI) (NTI, 2011).

NTI is the program to support perspective developing Russia economics sectors which can be the basis of the world's economy in the next 20 years. The collection of its road maps is the main document containing a list of priority trends and tasks in different spheres. They are also based on studying the sphere of economy modernization and innovative development and include the results analysis of each implementation step. According to the road maps the Russian Government confirmed participation on 7 world economy's markets, among which is the AutoNet market.

Road maps are regulatory instruments and plans of action connected with creating new products, business models and performing lots of tasks. For example the regulatory legal framework, intelligent transport and unmanned driving system development providing. The current project could be referred to AutoNet market, the main development ways of which are unmanned vehicles and intelligent transportation systems.

The organizations developing intelligent transportation systems actively implement projects to forecast traffic volumes and flow-control. They actively work in Japan, America, European Union, Australia, Brazil, China, Canada, Chile, Korea, Malaysia, New Zealand, Singapore, Taiwan, the UK. In India, Thailand and some countries of South Africa such scientific schools and organizations are just beginning to develop the concept of smart roads ((Hasegawa, 2014), (ITS-America, 2019), (LTA and ITSS, 2014)).

Nowadays, the most advanced technologies in the field of intelliget transportation control are designed in Japan, the USA, Singapore and South Korea. The main directions of developing intelligent systems in these countries are connected vehicle technologies, connected corridors, well-managed and resilient traffic flows, Smart Roads and integration these technologies into Smart City Systems and Internet of Things.

Taking into account the Russian Federation geographical location the propoced intelligent transportation system has to connect both European and Asian transportation systems with its specifical features (e.g., right or left driving and connected questions, normative documents and regulating laws, personal data protection, etc.).

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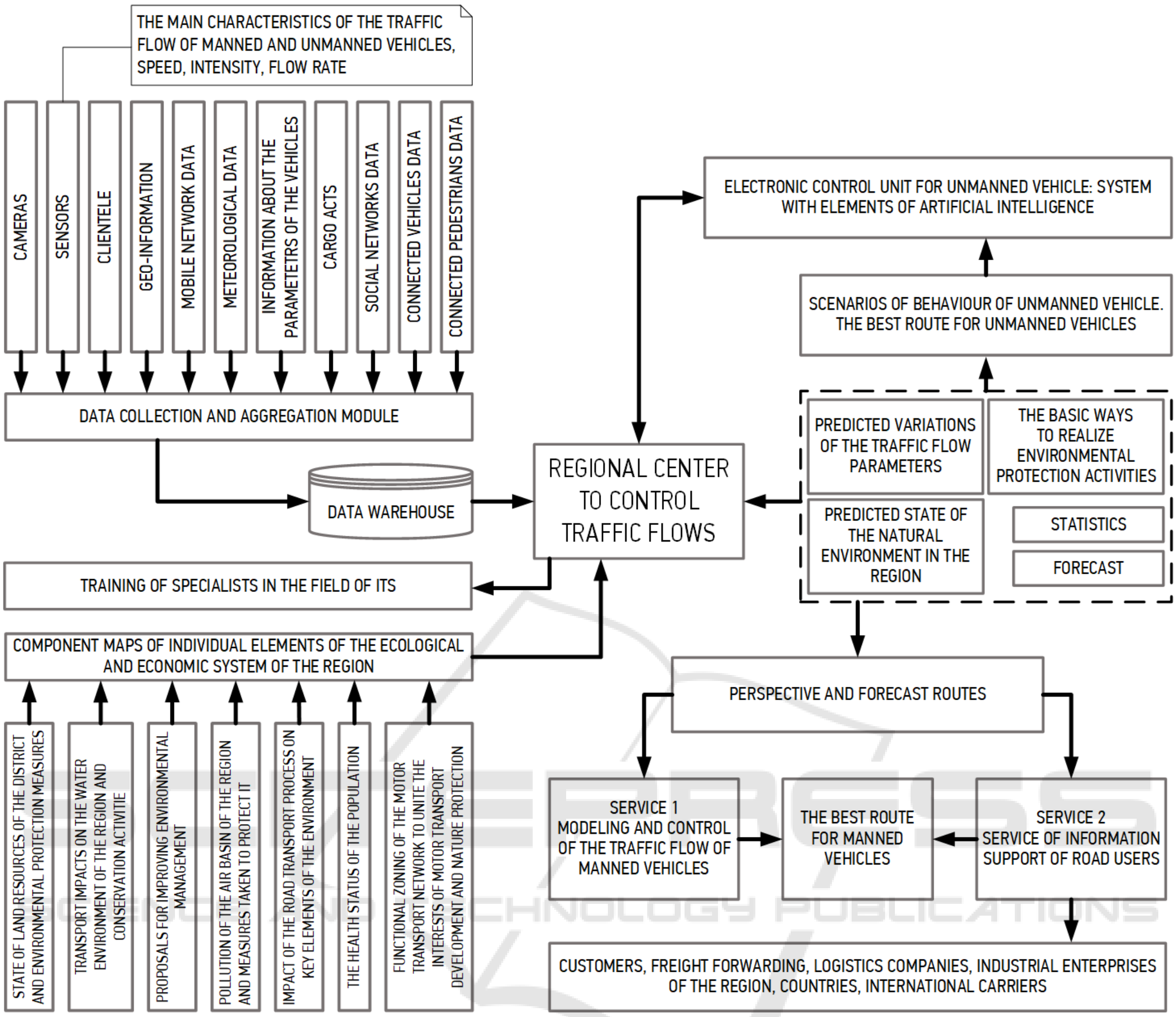

Figure 1: Conceptual Scheme of Regional Intelligent Transportation System Module.

1.2 Conceptual Scheme of Regional Intelligent Transportation System Module

Based on long-term studies in Lipetsk State Technical University it is proposed the following structural scheme to organize the regional module for the intelligent transportation and logistics system (cf. Figure 1).

Regional Center to Control Traffic Flows (Korchagin et al., 2011) consisting of manned and unmanned vehicles delivers following functions: collecting information about traffic conditions and cargo acts; processing, analyzing and storing big data; as well as the training of specialists in the field of intelligent transportation systems. This center is an academic, scientific-educational institution aimed at solving transportation problems using the achievements on intelligent transportation control. The proposed structure is a platform to implement regional modules of the intelligent transportation and logistics system of the Russian Federation.

Based on the detected traffic flow characteristics deviations and predefined quality criteria, the control system (which is a part of the regional control centre) changes traffic signaling modes and / or variable traffic signs (including adaptive control) to achieve the optimal values of the observed criteria. Depending on the task to be solved, it is possible to use various system quality criteria (system security criteria, just-in-time and other logistic principles) (Galkin and Sysoev, 2019). It is assumed to use a system of traffic controllers switching traffic signals and variable traffic signs. In addition the necessary information for road users has to be constantly placed on the real-time information boards.

The main goal of the current study is to present the usage of the advanced algorithms to control traffic situation within the highspeed transportation corridors and to construct the data warehouse model to collect and to store aggregated from heterogeneous sources data efficiently.

2 CONTROL OF TRAFFIC SITUATION WITHIN THE HIGHSPEED TRANSPORTATION CORRIDORS

2.1 Modeling Transportation Corridor

It is reasonable to consider a highspeed transportation corridor to be modeled as a freeway with a ramp metering system controlling the access to the corridor from all entry ramps. Depending on the traffic volumes and other factors, the ramp metering system can be either active or not. Therefore, activation parameters are defined and set for the corridor based on its traffic characteristics and geometry, the weather conditions, and other factors. For detecting optimal metering rates from the global point of view, it is proposed to use the solution of a mathematical optimization problem, which determines the minimal travel time (including delays on the entry ramps) for traversing the whole analyzed transportation corridor segment.

The segment of the highspeed transportation corridor could be divided into sections of two types. This division is characterized by the location of the entry ramps (cf. Figure 2).

(I) Sections of the first type consist of an exit ramp and the following segment up to the next entry ramp. The traffic volume in this case can be calculated as the difference between the volume upstream of the exit ramp and the volume of the exiting traffic.

(II) Sections of the second type, which start where vehicles from the ramp enter the main roadway and end at the next exit, are more important in terms of optimization, because the traffic volume depends on the calculated ramp metering parameters.

Sections of both types have a total travel time which must be calculated in an on-line regime according to the current traffic conditions. Delays in the entry ramps, which are caused by the ramp metering system, are referred to sections of type II.

To quantify the total travel time, the travel time within the corridor and the delay on the entry ramps have to be summed up. The volumes measured at the entry ramps and detected within the corridor serve as input data for the optimization model.

Total travel time could be found as

$$t = \begin{cases} \dfrac{L}{v(q)} \cdot q \cdot \Delta & \text{for free traffic,} \\ \dfrac{L}{v_{crit}} \cdot q \cdot \Delta + t_{loss} & \text{for congested traffic,} \end{cases} \tag{1}$$

$$v(q) = \frac{v_0}{1 + \dfrac{v_0}{L_0 \cdot (C_0 - q)}},$$

$$t_{loss}(q,c) = A \cdot \left(\frac{q}{c} - 0.9\right)^B,$$

where t is the total travel time (veh·h), L is the segment length (km), $v(q)$ is the speed (km/h), q is the traffic volume (veh/h), Δ is the interval duration (h), v_{crit} is the critical speed at capacity (km/h), t_{loss} is the congestion-related travel time losses (veh·h), v_0, L_0, C_0, A, B are model parameters.

On approaches to entry ramps appears another type of the delay which could be estimated as a traffic delay on non-regulated (when ramp metering system is turned off) or regulated (when the system is turned on) intersection. Calculations of this delay times are based on volume-to-capacity ratio. The freeway segment capacity was estimated based on the mathematical remodeling approach [(Sysoev et al., 2019), (Sysoev and Voronin, 2019)]. In this paper the following model from Highway Capacity Manual 2010 (TRB, 2010) was used:

$$d(q) = \frac{0.5 \cdot C \cdot \left(1 - \frac{g}{C}\right)^2}{1 - \min\left(1, \frac{q}{c}\right) \cdot \frac{g}{C}} + 900 \times \\ \times T \cdot \left(\frac{q}{c} - 1 + \sqrt{\left(\frac{q}{c} - 1\right)^2 + \frac{8 \cdot k \cdot I \cdot \frac{q}{c}}{c \cdot T}}\right), \tag{2}$$

where $d(q)$ is the average delay time (s), C is the phase cycle time (s), g is the green time within the cycle time (s), (always equal to a fixed time interval), q is the traffic volume (veh/h), c is the capacity (veh/h), T is the duration of analysis period (h), k is the incremental delay factor that is dependent on controller settings, I is the upstream filtering/metering adjustment factor.

For each analyzed time interval, both travel time components are calculated with the models (1) and (2), respectively. In contrast to the classical stochastic approach based on a Poisson distribution for the arriving process and some stochastic distribution for the explanation of the service time, the deterministic (systematic) mechanism assumes using a constant fixed arriving time for every request (vehicle) in a system and constant times for the service process. The

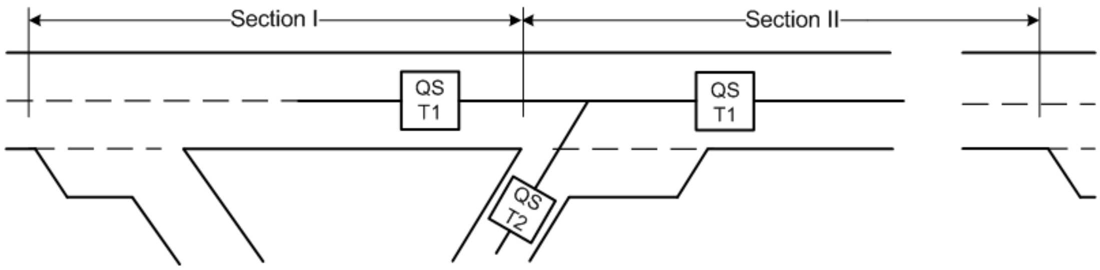

Figure 2: Queueing Systems as a Basis of Freeway Segment.

assumed deterministic queueing system is a *D*/*D*/1 queue with deterministic arrivals and deterministic service times at 1 server.

Figure 2 also illustrates how deterministic queueing systems are applied to model the different segment types of highway transportation corridor. The following two types of queueing systems are defined.

QS T1: *D*/*D*/1 queueing system used to model the traffic flow within the corridor, where main traffic flow characteristics (traffic volume etc.) are taken as input parameters.

QS T2: *D*/*D*/1 queueing system used to model the traffic flow on the entry ramps. Delays on the entry ramp arise because of a high volume within the corridor and/or ramp metering. By varying the ramp metering control parameters, it is possible to minimize the service time.

The aim of formulating the problem is to find optimal regulation parameters for the Type 2 queuing systems to provide a higher level of quality for the whole freeway facility.

2.2 Finding Optimal Control Parameters

The problem described below can be considered as a non-linear multidimensional constrained global optimization problem and formulated as:

$$\min_{x \in \mathbb{R}^n} \sum_{j=1}^{n} (t_j(x) + d_j(x)) \tag{3}$$

with constraints:

$$\begin{cases} x^{\min} \le x \le x^{\max}, \\ g(x) \le 0, \\ h(x) = 0, \end{cases} \tag{4}$$

where $t_j(x)$ is the total travel time within the segment j (veh·h), $d_j(x)$ is the average delay time on the approach within the segment j (veh·h) , x is the vector of optimal cycle times for the investigated part of freeway (s), $x^{\min}$, $x^{\max}$ are the minimum and maximum limitations of the cycle times respectively (s), $h(x)$, $g(x)$ are equality and inequality constraints functions respectively.

Such formulation (3)–(4) is a general one and in every particular case different additional equality and inequality constraints functions could be taken into account. To find the solution of the stated problem algorithms of both types analytical and numerical may be applied. The only limitation for using analytical approach is non-differentiability of the function estimating delay on approaches to entry ramps in case of congestion. Before the volume-to-capacity ratio equals 1, the problem could be solved with traditional methods such as Lagrange multipliers approach.

It should be mentioned, that the propoced approach to find an optimal parameters to deliver the minimum total travel time was implemented on A40 German Autobahn and has demonstrated results better than existing local ramp-metering approaches (like ALINEA algorithm, cf. (Sysoev et al., 2017)).

3 INFORMATION INFRASTRUCTURE OF INTELLIGENT TRANSPORTATION SYSTEM

The solution of the tasks which are posed to the regional intelligent transportation system module is possible with a complex analysis of relevant data. According to studies (Khabibullina et al., 2019b), (Khabibullina et al., 2019a), (Khabibullina and Pogodaev, 2019) such information can be obtained from sources with heterogeneous nature and format. The presented organizational and technological model (cf. Figure 3) allows collecting information from heterogeneous data sources, data pre-processing and distributed aggregation.

Data obtained from heterogeneous sources can be divided into the following types according to the possible representation form:

- Well-structured data (e.g. knowledge base for expert system; information on high-speed corridors

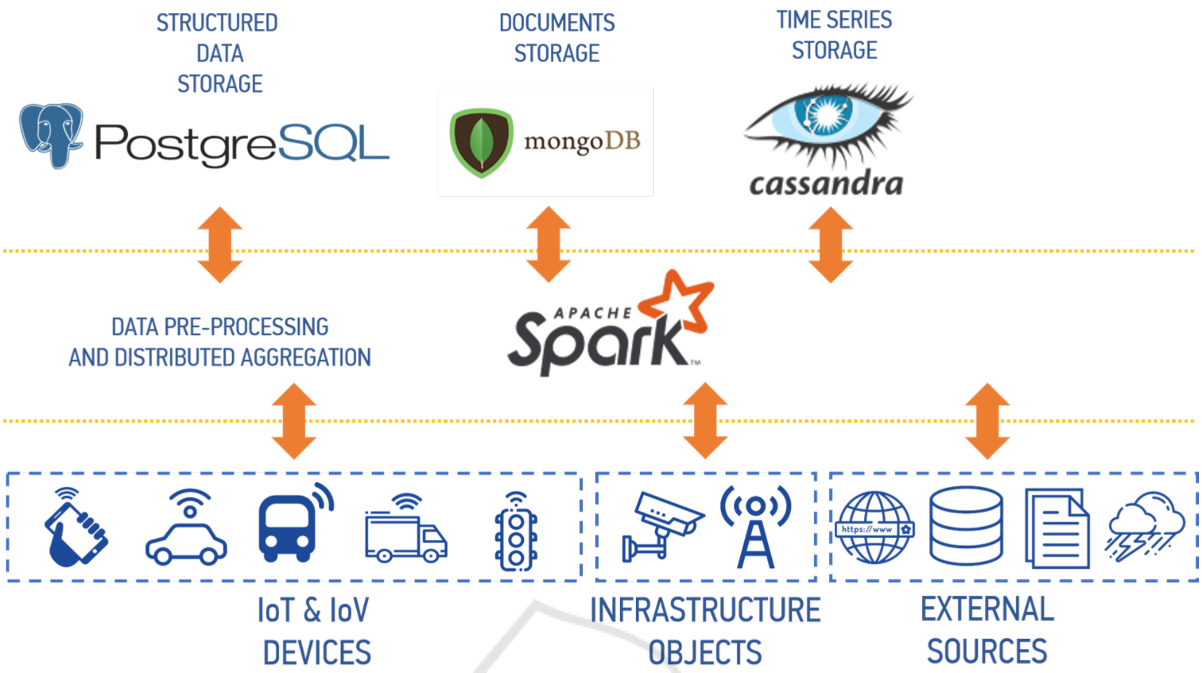

Figure 3: Organizational and Technological Model of Data Warehouse.

(area, grade, work zone layout, number of lanes in one direction, lane widths, availability of acceleration lane, speed limits); information on traffic accidents; information on public transport traffic patterns; catalogue of large companies in the region; cargo transportation data in the region; passively collected information (news, social media posts, information about major events that can cause heavy traffic));

- Data in the form of time series (data collected from road infrastructure sensors or received as a result of processing of data from road cameras or passively collected information, for example, averaged speed of vehicles on lanes, percentage of heavy vehicles, predicted freeway capacity; meteorological data; mobile devices data; connected vehicles data);
- Data stored in the document form (data obtained from CCTV cameras, unmanned vehicles cameras, audio content from mobile devices, etc.).

It is proposed to use a data warehouse model combining the following data models:

- The relational model for well-structured data;
- NoSQL model for storing and processing data in documentary form (data for determining transport flow parameters are analogue in origin and other data from heterogeneous data sources, which are more convenient to store and process efficiently in the JSON-format);
- NoSQL model for storing and processing time series (relational DBMS can be used for storing and processing such data, but specialized databases provide scalability for working with large amounts of data and provide special functions for processing time series).

Apache Spark will be used to implement distributed pre-processing (filtering and aggregation) of unstructured and semi-structured data coming from heterogeneous sources in different formats. PostgreSQL was chosen as a relational DBMS, MongoDB allows storing data effectively in JSON-format documents obtained from heterogeneous data sources, Cassandra was chosen as NoSQL DBMS to work with data in time series format.

3.1 Relational Data Model Description in ITS

The relational data model due to the specificity of data sources is used mainly for the storage and analysis of actual and reference data. Each source has its own relational model (an example of a relational model for storing and processing traffic accident information is given in (Khabibullina and Pogodaev, 2019).

3.2 NoSQL Data Models Description in ITS. Documents Storage

Data is stored and processed as documents which are described in JSON format in a document-based database. This type of database allows working with data using the same document model that is used in the regional intelligent transportation system module. The flexible, semi-structured, hierarchical nature of documents and document-based databases allow development according to the needs of the system. The proposed model allows flexible indexing, standard queries and document collections analytics.

Such data can be described in the following terms:

- Location (coordinates system, latitude and longitude) of the transmitting device or reported action;
- Time of data transmission or reported action;
- Data category (location-based mobile phone data, GPS data, road cameras data);
- Data format (single value, matrix, vector, text, image, etc.)
- Data representation (e.g. measurement unit).
- Semantics of the data (e.g. tracking vehicle or mobile phone).

Thus, based on the above, the document database model can be defined as follows.

```
{"definitions": {
   "Element": {
      "type": "object",
      "additionalProperties": false,
      "properties": {
        "time": {
           "type": "string",
           "format": "date-time"
        },
        "location": {
           "$ref": "#/definitions/
               Location"
        },
        "data_category": {
           "type": "string"
        },
        "data_format": {
           "type": "string"
        },
        "data_represantation": {
           "type": "string"
        },
        "data_semantics": {
           "type": "string"
        },
        "file_path": {
          "type": "string"
        }
      },
      "required": [
         "data_category",
         "data_format",
         "data_represantation",
         "data_semantics",
         "file_path",
         "location",
         "time"
      ],
      "title": "Element"
   },
   "Location": {
      "type": "object",
      "additionalProperties": false,
      "properties": {
         "coordinates_system": {
         "type": "string"
      },
      "coordinates": {
         "type": "array",
         "items": {
            "type": "number"
         }
      }
   },
   "required": [
      "coordinates",
      "coordinates_system"
   ],
   "title": "Location"
   }
}
}
```

3.3 NoSQL Data Models Description in ITS. Time Series Storage

Using relational databases to store and analyze time series in the knowledge domain with a pronounced Big data problem is not possible ((Chowdhury et al., 2017)). In general, the time series model for ITS can be represented as Figure 4.

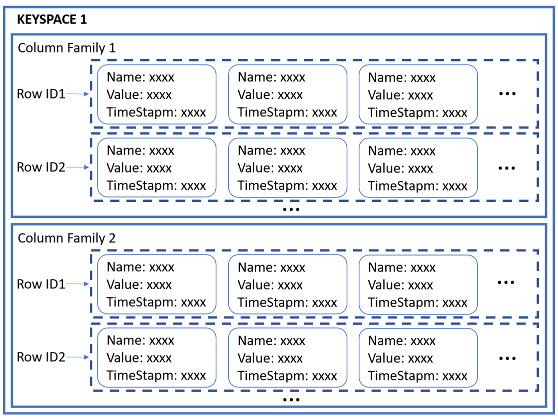

Figure 4: ITS Time Series Data Model in General.

For easy understanding, it can be drawn an analogy with the terms of relational databases: a key space corresponds to the concept database schema in a relational model. This key space can contain multiple column families, which corresponds to the concept of a relational table. In turn, column families contain columns, which are combined using the row key in the row. A column consists of three parts: a column name, a timestamp, and a value. The columns within the record are ordered. Unlike a relational database, there are no restrictions on the fact that records (and in terms of database these are rows) contain columns with the same names as in other records.

This generalized model description should be specialized for each type of data source by changing column names and reorganizing column families.

4 CONCLUSION

In this paper the complex study on the regional intelligent transportation system module is presented. The conceptual scheme and algorithms which are used to control traffic flows in high-speed transport corridors are described. To solve the module's tasks it is necessary to collect and aggregate information from heterogeneous data sources.

The information infrastructure of intelligent transportation system is considered. It allows aggregation, storage and receiving information from a data warehouse effectively. The presented model is based on the decomposition of the information data warehouse model into data models corresponding to the degree of data structuring and amount of data.

An important question on traffic safety has to be implemented in the ITS regional module. In case of car accidents the total travel time increases significantly, that's why there should be a developed system to recognize accidents immediately and to manage road servises for eliminating consequences of accidents. Based on on-line video streams from highway corridors and approaches to them the pre-trained reccurent neural network could identify accident with a high accuracy and send to emergency services GPS cam location to find out the fastest way to the scene of the car accident.

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