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Principles and realization possibilities of the Intelligent Transport Systems

Summary of Doctoral Thesis

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Datums.......................

Promocijas darbs uzrakstīts latviešu valodā, satur 4 nodaļas, secinājumus, literatūras sarakstu, 85 zīmējumus un ilustrācijas, kopā 171 lappuses. Literatūras sarakstā ir 136 nosaukumu.

COMMON CHARACTERISTICS AND IMPORTANCE OF THE WORK

Congestion is the word that characterize condition of world transportation. Increase of income causes increased amount of cars in use. This lead to insufficient drive lane throughput and outcome is congestion. Already in y. 2003 US Federal Highway Administration announced, that each driver lose $384/y (Ls 200 approx regarding currency rates) due to forced stop during work time and fuel waste. This loss is added to significant amounts of expenses caused by loss of property, health threat and other cases when responsible services can not reach destination in short-as-possible time.

Simplest form of solution is just to expand the road, add a lane, where needed. This can be done, where space allow, but in such places are no traffic problems mainly. So there is only one way – search for solutions how to increase efficiency of lane usage. Modern countries are developing technologies rapidly and Latvia is trying to join. Here significant scientific work is in progress to develop technologies, that belong to ITS (Intelligent Transportation System) class. In general, all suggestions show how to improve efficiency of single form of transport.

Road traffic in general is extremely complex sequence of events and interactions. It seems like chaos but in fact that is a determined sequence of actions mixed with some coincidence. Well designed ITS is the element, that eliminate these coincidences.

Overview of accessible research clear – many traffic description models have been taken from world of computer networking. There is a core, while scientists, who create computable models, are familiar with related networks. But there is one general difference – regarding position traffic participants perform coincident activities. This is why for system learning anomaly detection rules are used. Meanwhile they are usable for post-factum analysis, but can not perform in real-time systems. After registration of conditions, it is easy to define a form of correlation, so linear regression methods also are in use.

Development of techniques demonstrate creation of ad-hoc wireless network between traffic elements. Prediction of faulty or unstable link causes usage of linear regression models that covers lack of data. While solution technologically is simple, this can not exist in autonomous version, but can give valuable input as cooperative element.

Traditionally, traffic engineers are operating with determined flow-density diagrams avoiding stochastic changes. In fact, such diagrams has to be used as graphical interpretation of the flow only. Flow-speed diagrams sometimes are presented in square form. Flow physicists propose to use fundamental expressions that are common for liquids, but they can not hold values generated by coincident.

There is a common problem that computable models can cover only fixed length road sections with limited amount of variable parameters. In the same time, some of parameters have random-like values. It seem to be impossible to create a model, that can predict situations caused by joined events and spread over a large area, so even worlds most powerful supercomputers can not operate true real-time ITS with acceptable parameters. It is important to separate elements that are some how autonomous and show the way to structure the task.

Traffic today is observed by numerous sensors – inductive loop, sound or optical sensors. These elements can fill a system with immeasurable amount of information, but it is still representation of a conditions in a spot. As a rule, data are collected locally and transmitted to processing center in a timely manner, from 5 to 30 min or hour. Sensors with link to surveillance cameras are effective when observation of actual situation is required or incidents are under investigation, but they can not make a significant impact to performance of a ITS. It is observed a tendency, that mainstream manufacturers are offering certain limited range ITS. That mean – a crossing or some are covered with controlling equipment but interaction with neighbor is limited.

Sensors mentioned before are local and can not provide information about any place of a road. In general a traffic flow is attempted to describe as sequence of events that correlate only partially, so in creation of a model any uncertainty or coincidence is strongly unwanted. Even previously mentioned systems carry “real-time” label, due to deviation of measurements and uncertainty, they have high inertia. Cause of a problem is, how to operate in environment, when from uncertain input values system must provide determined response, that is acceptable for neighbor systems. From here it is to conclude, that stochastic considerations holds main position in creation of ITS core models.

All solutions and methods mentioned before does not permit to create simple and common description of traffic participants, that can be used in structured ITS, where computer is used for control environment. Result is a set of **localized** ITS like structures for traffic management that are not inter-operation capable.

GOAL OF THE WORK

Goal of the Dissertation is to create a new descriptive form of traffic participant, that can be easy implemented in computing environment, suitable for true real-time operation, and is a backbone for high accuracy models. To reach the goal regarding numeric description, it is necessary to design a fast operating environment that contain elements of modern ITS, that while integrated in complex system are self sufficient. It is necessary to determine level of activities for each and demonstrate connections. Description of the connections it is mandatory to show redundancy and alternative algorithms. Created structure and elements must comply to terms:

- responsiveness – ITS based on proposed model must provide necessary information to rescue service;
- robust – coordination personnel are not interfering traffic in case of normal operation and there is no congestion;
- directly joined with actual situation.

SCIENTIFIC NOVELTY

Scientific novelty of this dissertation is

- description of the vehicle and motion with coordinate and direction vector method;
- description of true real-time ITS structure and functional division;
- definition of real-time ITS element interconnection and interactions;
- creation and description of algorithms capable to operate in real-time;
- definition of technical principles and means for creation of real-time ITS.
- development of adaptive street crossing with application of balance rule definition.

PRACTICAL VALUE

Practical value is in fact, that all proposed theoretical solutions have been tested on-field and design prototypes are demonstrated.

FOR DEFENSE IT’S PRESENTED SUCH TOPICS

1. Mathematical base model of real-time ITS and its definition.
2. Structure of real-time ITS.
3. Algorithms for prediction of vehicle location.
4. Crossing management regarding balance rule.
5. Methods dedicated to system continuity and integrity.

CONTENT OF THE WORK

Promotion work include introduction, four chapters, conclusions and reference list. It contains 162 pages, 85 figures, 5 tables and 136 entries in reference list.

APPROBATION AND PUBLICATIONS

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Content

Chapter 1

ITS as standalone traffic management structures

Overview of current ITS regarding disadvantages, tasks and possibilities of integration in real time systems is given.

Common type of ITS are single processor systems, that perform specific task. Most complicated are flow control systems. Most of those systems “believe” in their model, that drivers of a sequential vehicles can follow the speed in the lane with fine accuracy. There is also an assumption in place, that changes of the speed for one vehicle have immediate reflection on sequential. Such assumptions are blunting the running algorithm and cause reduction of efficiency. In fact it is observed, that age of the driver, non-driving activities, other factors are affecting reaction speed to situation changes. In set with another factors this dramatically reduce performance of a system. It is clear, that question, which approach is better – to measure parameters of each traffic participant or evaluate the flow as one, is just logical.

Mathematical models and subordinated processes are named as disaster avoidance algorithms. In fact, today it will be correct to talk about evolution of those algorithms while they evolve from GHR model defined in year 1961. That describe a three traffic participant sequence (Fig.1), where two are named as leading (Vad1, Vad2) and one is tailing.

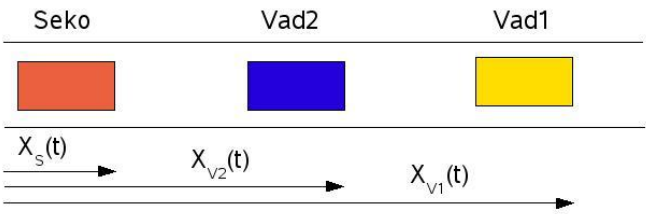


Fig.1. Sequence of two leading and one tailing vehicle

This sequence is expressed in a form with changes listed in table1. Descriptions used in expressions:

t – total time of process cycle;
Δt – time of single iteration;
$X_S(t)$, $X_{V1}(t)$, $X_{V2}(t)$ – position of a vehicle in a time moment t;
$V_S(t)$, $V_{V1}(t)$, $V_{V2}(t)$ – speed of a vehicle at time moment t;
α, β, m, l, W_1, W_2 – variable parameters of a model;
G – empiric definition of the link between acceleration and distance to the next vehicle;
$a_{V2}(t)$ – acceleration of the second leading vehicle at time moment t;
$a_S(t+\Delta t)$ – acceleration of the tailing vehicle at time moment t.

Table 1.

Evolution of the GHR model expressions

$$a_F(t+\Delta t) = \alpha\,[V_{V2}(t) - V_S(t)]$$

$$a_F(t+\Delta t) = \alpha\left[\frac{1}{X_{V2}(t) - X_S(t)}\right](V_{V2}(t) - V_S(t))$$

$$a_F(t+\Delta t) = \alpha\left[\frac{V_s(t)}{(X_{V2}(t) - X_S(t))^2}\right](V_{V2}(t) - V_S(t))$$

$$a_F(t+\Delta t) = G_n\,[X_{V2}(t) - X_S(t)]$$

$$a_F(t+\Delta t) = \alpha\left[\frac{(V_S(t))^m}{[X_{V2}(t) - X_S(t)]^l}\right](V_{V2}(t) - V_S(t))$$

$$a_F(t+\Delta t) = \alpha\,[V_{V2}(t) - V_S(t)] + \beta\,[X_{V2}(t) - X_S(t)]$$

$$a_F(t+\Delta t) = \alpha V_S(t)\left[\frac{W_1\,[V_{V2}(t) - V_S(t)]}{(X_{V2}(t) - X_S(t))^2} + \frac{W_2\,[V_{V1}(t) - V_S(t)]}{(X_{V1}(t) - X_S(t))^2}\right]$$

$$a_F(t+\Delta t) = \alpha\,[V_{V2}(t) - V_S(t)] + \beta\,[V_{V2}(t) - V_S(t)]$$

$$a_F(t+\Delta t) = \alpha\,[V_{V2}(t) - V_S(t)] + \beta a_{V2}(t)$$

Idea, when a selection of three vehicles (triplet) is observed is correct in general, while this describe any place on the road, except cases, when due to lack of flow only two vehicles are close enough to be observed. In this case models, that are excluding impact of second driver ahead activities to tailing, appear to be sufficient and correct.

Flow control systems are very important, while they collect information about drivers habit in observed location. They permit to plan evolution of the process in the section of a road and react accordingly. **But still** methods of traffic description are inaccurate and can not bring exact information about traffic condition. All ITS and traffic participants are standalone and not connected with open and common inter-operation standards. To improve performance and eficiency of the system, borders must be removed and a choice must be done, which direction to keep when developing new systems. Build one, highly integrated, centralized system or keep simplified and dedicated form of a system with open data exchange protocols and formats. Common data structures for operation data must be created.

If today ITS are for detection of a fact and proactive reaction to, then task of a really modern ITS is to predict the evolution of the situation and act regarding prediction while keeping “fine eye” what is really happening and how prediction fulfill.

One of prediction type is meteorological system. 17% of accidents around the world happen due to bad weather. So meteorological systems are robust structures that provide information for drivers in form they can read for section of a road ahead. Meteorological ITS contain several elements – surface sensors, surveillance cameras, communication network, traffic analysts, GIS, GPS, satellites. This is next level after “sensor – message board” type systems.

There are five types of meteorological ITS:

- **dynamic road signs**;
- **telematics of a vehicle;**
- **dedicated information sites;**
- **road surface sensor grid;**
- **traffic accident control system.**

Sensors used by meteorological ITS are, air temperature, air humidity, wind speed, precipitation, solar, visibility, road temperature, road surface condition (wet, dry, icy).

Meteorological systems have common standard WMO1995 and all of them generate 7 base alarm signals: road or air temperature is +3 and due to wind, extrapolated temperature is less or equal to +1; air temperature is lower or equal to 0; road temperature is less or equal to +1 and extrapolated is less or equal to 0; temperature 5cm below surface is less or equal to 0, temperature 10cm below equals -1, temperature 20cm below is -2 plus, road surface is humid or precipitation detected in last hour, or relative humidity is equal or more to 95%; temperature of the surface of the road is below 0 degrees and “black ice” is detected; a snow or blizzard detected when air temperature is +2 or less and temperature of the surface of the road is 0 or less; average wind velocity is more than 11 m/s and direction differs from road azimuth more than 45 degrees; visibility is less than 200m.

Meteorological systems are quite well developed, their product is not implemented in street section and lights management, mean while meteorological obstacles are directly impressing traffic conditions.

Street light management systems are directly connected to traffic management system and can operate as standalone for one crossing or combined for whole city. First group is pedestrian way crossing control systems, second – vehicle motion control system. This system differ to flow control system while observe only a crossing, while other observe driver habit away from it. A crossing control system can privilege a pedestrian or treat them as equal to vehicle. Improvement of light management systems in general link to monitoring elements, that must detect a position of a pedestrian and report about safety conditions.

Those systems are well known and is developed by famous companies. During evolution, reaction time is improved and is presented in table 2 as recovery interval. These systems has not only a reaction time improvement but also an updated algorithm and extra functionality.

Table 2.

Characteristics	1. generation	2. generation	3. generation
Recovery int.	15 min	5 – 10 min	3 – 5 min
Optimization of the control plan	Optimization to stored data for current type of day. React to changes of flow or manual intervention	On-line optimization regarding actual state	On-line optimization regarding actual state
Traffic prediction	No	Regarding previous facts	Regarding last measurements
Determination of cycle length	Fixed for each lights section	Fixed with flow improvement for sequential street light sections	Fixed within one recovery time period. Can change regarding situation

Actually, each streetlight system, even it is fully functional, is just a micro ITS, that needs a common ideology. How it is for others systems, these also lacks connection between traffic participants and management infrastructure. Network of interconnected micro ITS can deliver several important traffic improvements:

- Merging previously autonomous micro ITS and using common light-time diagrams time in transit can be reduced by 10 to 20%;
- If comparing time in transit for sections equipped with adaptive systems (3rd gen.) to fixed time (1st gen.), latest can give up to 20% reduction;
- Centralization with analysis of flow characteristics can provide 10-16% shorter time in transit if compared with autonomous, but well tuned micro ITS;
- Regarding quality of models, time in transit can vary from 8 to 10 %.

While in territory of a city systems from various vendors may persist, interconnection is problematic for large ones. This makes mandatory to divide traffic management into cells, that are supervised by central module. Division in cells is required also by amount of data, generated by each element of complex ITS, that can not be transferred to and processed in central element.

So a public safety ITS can be designed – in fact a group of systems, that are dedicated to care about safety of every person within transportation infrastructure. Public safety systems are divided to several classes.

First are driver assistants. Main task of those systems is to watch out activities of a driver and deliver support like warnings.
Second class are access control systems – separate group of systems, that in general are standalone and do not affect traffic, but can interfere with other systems. Access control systems are divided into two large groups – public and private.
Third class are Rescue systems. These system like meteorological can act as triggers for traffic accident control systems. Difference is in fact, that meteorological systems warn about risk of accident, while rescue system confirms accident and transmits location coordinates.
Fourth class are diagnostic systems. These systems are very important for complex ITS to function. They do not affect traffic regulation, but control elements that does. Functionality of a diagnostic system is to extract data from various elements and lookup for certain correlations. Are needed ones in their place or vice versa.

Task for a routing system is to find a best route to desired destination. Task sounds to be simple, but still it contains several unknown variables, that are ambiguous at the moment of planning. It will be wrong to select a route only by one parameter like top speed or shortest path. As a result, routing systems are solving an optimization task detecting best route by parameter weight. In modern design decision is taken by artificial neuron network with multi-criteria principle , but instead of a result, a response stability issue is obtained.

Disclosure of the problem is a fact, that not in all cases decision is correct. For example, request for path with shortest time in transit, driver get stuck in a congestion. While planning a route, several aspect should be considered, like probability, that driver will turn away from planned route. This probability is caused by several issues like:

- Suggestion of unsuitable roads;
- Use of unsafe routes;
- Use of obsolete maps;
- Conflict between road markings, signs and ITS instructions.

For routing systems several quality requirements must be defined:

- Detection of the location must be so accurate, that ITS is delivering only correct instructions;
- Maps must be precise regarding road net;

- System does not suggest a route that does not suit by width, load or speed.
- System must take in account and act accordingly to short term traffic reorganization, administratively forbidden maneuvers, speeding etc;
- Creation of the route must prioritize larger motorways with higher speed and / or throughput;
- System must react properly to dynamic part of information, Dynamic part must be available immediately and in form for easy implementation;
- System must be capable to adapt to inadequate driver activities. This mean, for example, if driver miss a turn or take wrong, reroute operation must bet performed in acceptable time interval.

Individual ITS is separate class of systems, that can provide important information (if collected), but are designed to service traffic participant exclusively.

Fixed location individual ITS are traffic signs activated by a vehicle. Normally they are invisible and information they carry depend on vehicle parameters.

In-car ITS are devices like night vision, distance control, lane control, sign recognition, pseudo-virtual signs, driver condition detectors, individual routing system, driver assistants like braking or parking robots.

From overview in the 1st chapter it is possible to define some **conclusions**, that must be improved and taken into account while designing a real time ITS.

- One of general problems is insufficient precision of vehicle location measurement technology;
- All ITS are autonomous and **do not follow common** and **open** information exchange standards;
- To improve efficiency of an ITS, a border in between must be removed, and direction of technology development must be considered. To create one single-point centralized ITS or keep specialties and agree to information exchange protocols and standards;
- Structures for data collection and consolidation must be installed;
- A single and accurate source of time must be used, or there are no other ways to find correlations between events supervised by system;
- A data validity period must be defined. While recording mathematical description of the traffic generate tremendous amounts of data, storing all of it is useless and only several events should be extracted and saved for later investigation.
- Mathematical apparatus used in ITS, is not always superb. So idea, how to do one or another functionality, are welcome. If today's ITS in general are designed for detection of a fact and proactive reaction, then future systems must capable to predict evolution of measured situation and control, how prediction fulfill;
- While centralized systems are extremely complex structures, to keep necessary functionality and reduce amount of calculations to be performed in single place, a cell principle must be used, like in cellular phone networks, where one hardware setup serve certain area. Neighbor cell contain the same hardware setup but minor changes in operating software configuration. As a result, a centralized and homogeneous ITS can be built, that in the same time use advantages of distributed computing.
- Question about data reliability is also a case, while a faulty transmission channel can be detected, but to detect a part time functional sensor is quite difficult. Even a self test procedures solve the problem partially;
- While operation can bet disturbed in various levels, parallel data channels must be used to discover faulty state of an element. It is mandatory to keep system synchronized while several algorithms with common goal demand different time for action.

- Very important is to connect traffic management ITS with Drive-by-wire technologies implemented in the vehicle, while this permit to create direct interaction between decisions of the ITS and maneuvers on the road.

Chapter 2

Mathematical models for ITS realization

Today most of the Systems use mathematical description of the flow regarding vehicle distribution within the lane. There are several models known and simplest is well known Gaussian or normal distribution model (fig.2) with derivatives known as condition auto-regression model and Gaussian tree cluster. All these models are describing observed spot and increase of variables count reduce accuracy.

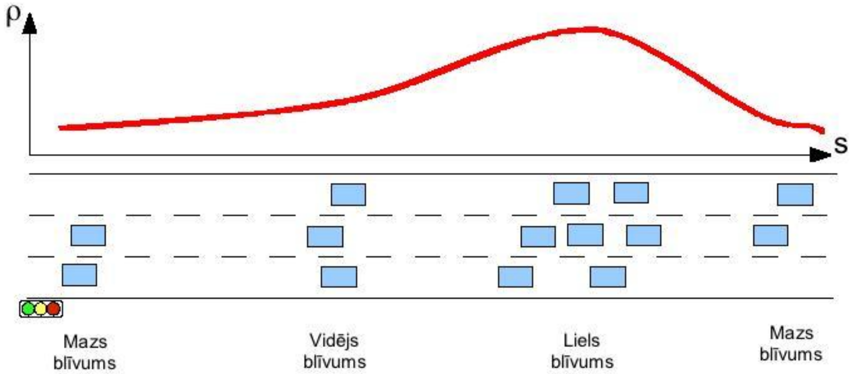


Fig. 2. Distribution of vehicles on the lane regarding Gaussian definition

Complexity of a model is defined by fact, that one case can be described by various sets of variables, that are incompatible between them. This fact can be by-passed if all variables and their values are proclaimed as independent. While traffic situations are continuous and similar, model is based on self-learning procedure, but this lead to over-complexity. Advantage of methods is in fact, that all variables are linear and proportional to count of spots observed. Negative aspect is that model ignore all interactions caused by neighbor segments, and this is very important in real situation.

Vehicle distribution models are describing time intervals between sequential vehicles within a segment of a road. This permit to adjust prediction model rapidly and detect probable interactions. Distribution model also reflect actual flow changes in the observed spot.

Time intervals between sequential vehicles is important parameter to create a prediction of situation evolution. In common, this characterize the dynamics and interaction in the flow. Analysis of time interval changes permit to predict a location after period of time. While time intervals between vehicles are not equal, then from systems point of view it is interesting to have a distribution density function. It is to acknowledge, that numeric values of distribution functions are demonstrating important safety rule, how drivers keep distance.

Interpretation for time intervals is separated for four cases (fig. 3) – free flow, when distance between vehicles is long; partially linked – when speed changes of one leading vehicle only after a while reflect on tailing; locked, when all vehicles are following each other by minimum safe distance, and bypass maneuver.

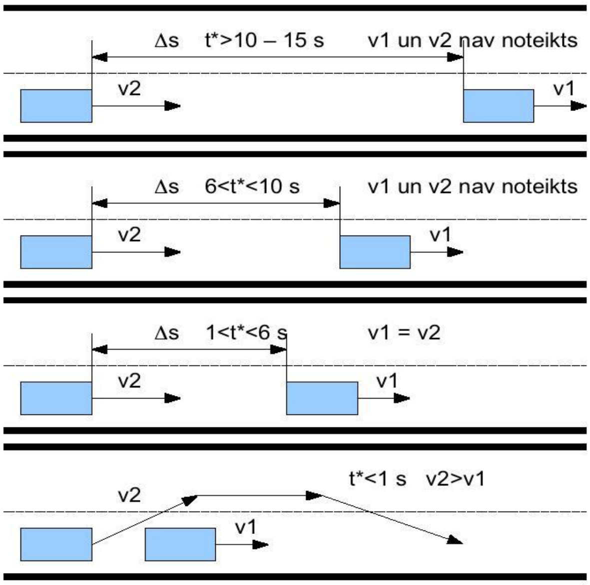


Fig. 3. Visual representation of various cases and bypass maneuver

While all prediction algorithms are discrete and their results are limited in time, then description of distribution must contain correction value with random-like characteristics. This affect prediction algorithms so they correctly interpret locked flow, but fail on free or partially linked flow. This can be observed at real measurement and theoretical data comparison.

By observation, when changes in count of vehicles forming a flow, distribution function changes minimally, is clear that common probability models does not provide accurate result. Experimentally is proven, that time interval distribution depend not only from flow, but also from meteorological conditions and vehicle format. That mean – presence of a truck or bus time interval increases for the same speed.

From time interval distribution functions a model can be derived, that is describing conditions for two flow cross or fold. Time interval distribution functions do not permit to define quality of maneuver, but can deliver information – is the time interval between two vehicles sufficient to safely insert another vehicle in the middle.

Folding or crossing two partially linked flows, two conditions can be defined. Another partially linked flow with minimal time intervals or a locked flow, that is interesting from ITS point of view, while resulting parameters can demand an intervention. For example, time intervals become too short and speed must be adjusted due to safety considerations.

Correction must take in account speed of a flow and time intervals, that are requirements for successful maneuver. So time intervals before maneuver must be so large, that after maneuver they remain in minimum permitted intervals for locked flow – 1 to 1,5 sec. It is possible to define a regularity between speed, length and required time interval.

If considering about time intervals regarding the safe distance, only for short vehicles they match to a locked flow. For high speed these time intervals are shorter than shortest form locked flow. In the same time for long vehicles time intervals are irrational while braking distance for various vehicles is approximately same.

Actually there can be a situation, when two locked flows with short time intervals must be folded. Then it will be reasonable to express probability that two flows with close to similar interval distribution, but different entropy, have such shift in interval, that allow to form a new flow with another distribution density function.

For multi lane (3 or more) roads, for interaction observation, it is mandatory to take in account a distribution function for lane that is behind a next. This is so while lane change ca happen from both sides for the middle lane. Bypass model does not fit in direct form while often drivers driving on one lane, make a maneuver to take a side lane but return to previous does not follow. As a result, statistical measurements display different distribution density in neighbor spots. From here it is to conclude that for multi lane ways distribution density functions are to evaluate common tendency and does not apply to real-time systems.

Mathematical models observed before apply to road sections without crossings or foldings. Time interval distribution density function for the lane changes when observed spot is near crossing. Parameter readings show distribution packing at short time intervals. This can be observed as lowering of speed. Actually, observations show, that packing is characteristic for equal direction crossings. If one direction has priority, then there packing is unsaid. Analysis of time intervals show moments, when vehicles driving on various directions can pass crossing without speed changes.

Regarding configuration, in the crossing of two streets, up to 12 various flows may persist. Count of possible flow directions C_{Φ} is expressed as

$$C_{\Phi}=i^2-i \quad , \qquad (1)$$

where **i** is total amount of road directions.

As a result, if taking out of interval distribution density functions, model becomes too complex while lot of flow interference must be evaluated and accuracy is not sufficient. Additionally, all measurements are made in a spot, and vehicle belongings to a flow can not be detected. Regarding collected statistics, it is possible to guess, which crossing outgoing flow vehicle will take, but this approach is not valid for ITS. So in fact, time interval distribution method for crossings is not useable. Not in a direct form.

From overview of mathematical models in 2nd chapter several **conclusions,** to follow while developing real-time ITS, can be expressed.

- There are known mathematical expressions for traffic evaluation, that try to describe dynamic process of a traffic with static measurements in a fixed spots. This approach permit to express a character of a flow in common, but lose individual data of a vehicle. Mathematical description is complex and can be realized with huge amount of computing cycles, besides, model contain uncertainties – noises.
- Improved quality models are based on time interval approach, while registers parameters of each vehicle. Time interval description is the way to create an optimization task – how to pack vehicles on the road, that during peak times, all vehicles are moving with minimal time intervals.
- It is important to understand connection between time intervals, driving speed and safe distance. Reaction time of a driver average from 1,1 to 1,3 seconds and this must be taken in account while evaluating safe distance at current speed and it's changes when speed changes. Time of distance exhausting can not be shorten than reaction time of a driver.
- Time interval method contain entropy so all predictions are just somehow accurate. Sensors used in system are spot-like, and deliver data only for current location, so situation in

remaining area is still unknown. From traffic management point of view, it is important to know about conditions on every place. Problem of time interval model is also a fact, that this is not a continuous model, but a pack of several separate with common parameters.

- While organizing traffic in crossings, signals for pedestrians must be separated form vehicle signals, while in peak moments switching must follow balance rule, where it is not permitted to enter a crossing if there is no space for vehicle on following road section. Usage of balance rule permit to design a system, that inform a driver about activity at the next crossing.

Chapter 3

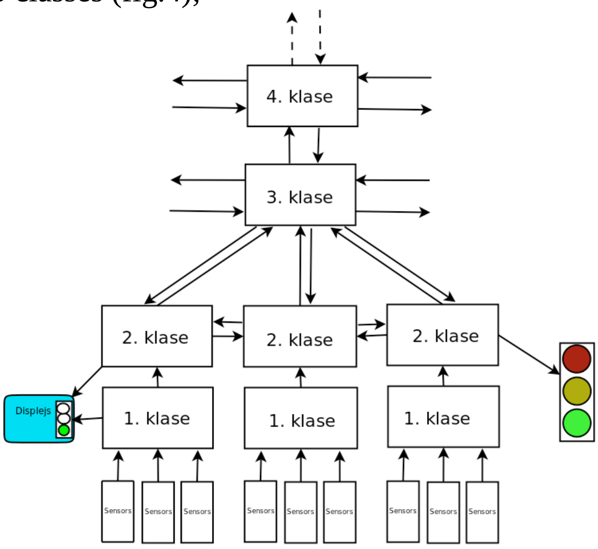
High integration level intelligent transportation system and required elements

In this dissertation another approach to design is proposed: Principle of ITS realization is to interpret a flow on the road with tiny cyclic processes, where any is described with simple algorithms, that do required calculations about:

- correct location coordinate;
- direction, speed, acceleration;
- location schedule and possible interaction with other traffic participants;
- parameters of traffic participants at junctions and road sections.

All calculated and measured parameters are accumulated in their databases where filter process separate operational data from statistical. Statistical data must be submitted for further use in calculations. All elements inside a system are connected with redundant data delivery channels and use majority principle to avoid faults or data tampering.

For large scale ITS to be easy manageable, a logic structure is mandatory. In fact, every piece of global ITS can act as stand alone system with reduced functionality. Structure of a system to be clear is separated into classes (fig.4);



4. att. Diversification of ITS by classes

- Lowest (first) class ITS is a group, that gather data from sensors, contain simple knowledge base, and functional result is exact description of a vehicle. First class ITS is not predicting, just consolidating the data.
- Second class ITS is at base of a network, here prediction of base parameters is performed. This class is first where majority principle is in use. Second class system use three independent sources of information – supervised first class system, another second class system, third class supervisor.
- Third class system is consolidation and supervision structure over second class systems. Third class system does not perform prediction, but operate with predictions made by second class system. Systems of third class are performing traffic management while only at this level, all required information is available.
- Forth class system is a supervisor over 3rd class and perform prediction of situation evolution in two directions – a long term prediction and control of 3rd class system integrity. At forth class level a connection to individual routing systems must be created, so a desired route and time can be uploaded to 3rd class and 2nd class systems with exact time-activity schedule.

To interpret a vehicle in the traffic flow, a mathematical description is required. While motion is continuous process (if we believe, that teleportation is not possible), then I describe it with a vector, where length is speed and angle connect it to coordinate grid (fig.5)

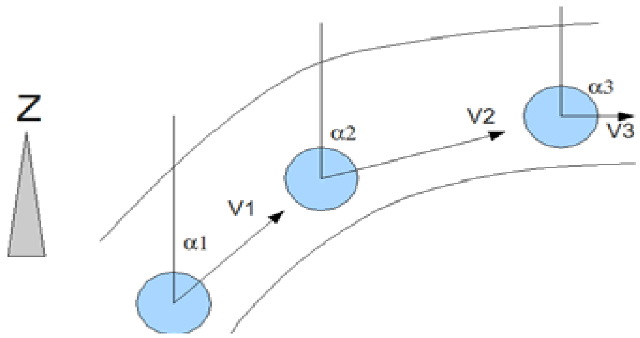


Fig. 5. Interpretation of a vehicle with direction vector version1 including safety radius

While all vehicles have certain size, it is possible to draw around an safety area, that can be used for collision prediction. In direction vector model version 1 it is considered, that within operation cycle (0,1 sec) vehicle move straight forward. Even if operation cycle is short, at high speed and twisty road a increasing difference between calculated and actual coordinate appear. This tendency called coordinate drift, has a one direction (calculated coordinate is all time ahead or behind real but not fluctuating around), except cases when in short distances vehicle rapidly accelerate and the brake.

Like a vehicle, road is also described with direction vector. In difference to vehicle, road direction vector is static and do not change, but by concept, it is similar. Vector contain direction where length is distance to next, radius (-1 for straight sections) and rotation direction (right is labeled as 0, left as 1). ITS believe that road must be divided in to sections that can be described as straight or curve with parameters.

In the simplest form coordinate calculations are expressed with approach that vehicle moves straight forward within a calculation cycle. Next coordinate is expressed as system:

$$\begin{cases} C_{NS+1} = C_{NS} + v\sin\alpha * dt \\ C_{EW+1} = C_{EW} + v\cos\alpha * dt \end{cases}. \qquad (2)$$

While direction vector contain two components, speed and angle, and coordinate system is orthogonal, then

$$\begin{cases} \vec{V}_{NS} = \vec{V}\cos\alpha \\ \vec{V}_{EW} = \vec{V}\sin\alpha \end{cases}, \qquad (3)$$

where NS and EW are geographical directions North-South / East-West respectively.

Accuracy of coordinate prediction C^P_{i+j} is determined by cyclic calculation for various time periods and expressed from actual (measured) coordinate C^f. In the expression dt is operation cycle time and j is count of operation cycles:

$$C^P_{i+j} = \begin{cases} C^F_{NS_i} + j\vec{V}_{NS}dt \\ C^F_{EW_i} + j\vec{V}_{EW}dt \end{cases}, \qquad (4)$$

comparison with actual values a Δ_C matrix is acquired

$$\Delta_C = \begin{vmatrix} C^F_{NS} - C^P_{NS} \\ C^F_{EW} - C^P_{EW} \end{vmatrix}. \qquad (5)$$

While vehicle location forms a coordinate matrix

$$\begin{vmatrix} C^{F\_TL1}_{NS} & C^{F\_TL2}_{NS} & C^{F\_TL3}_{NS} & \ldots & C^{F\_TLn}_{NS} \\ C^{F\_TL1}_{EW} & C^{F\_TL2}_{EW} & C^{F\_TL3}_{EW} & \ldots & C^{F\_TLn}_{EW} \end{vmatrix}, \qquad (6)$$

then position difference Δ_P^F matrix will be created, that by idea is identical to position prediction matrix Δ_P^P:

$$\Delta^F_P = \begin{vmatrix} C^{F\_TL1}_{NS} - C^{F\_TL2}_{NS} & C^{F\_TL2}_{NS} - C^{F\_TL3}_{NS} & \ldots & C^{F\_TL(n-1)}_{NS} - C^{F\_TLn}_{NS} \\ C^{F\_TL1}_{EW} - C^{F\_TL2}_{EW} & C^{F\_TL2}_{EW} - C^{F\_TL3}_{EW} & \ldots & C^{F\_TL(n-1)}_{EW} - C^{F\_TLn}_{EW} \end{vmatrix}, \qquad (7)$$

from where are selected cases when for each column rule 8 appear to be true

$$\begin{matrix} \Delta^{NS}_P - \Delta^{EW}_P \to R \\ \Delta^{NS}_P - \Delta^{EW}_P \to 0 \end{matrix}, \qquad (8)$$

where R is radius of a safety area and such conditions display dangerous approach. If column calculation tends to zero, this mean a risk of a collision.

Simplest forms of calculation are sufficiently accurate and is correct for straight sections of a road when speed of vehicle is automatically held constant (cruise control).If calculations are made by adjustable direction vector, then it is possible to calculate coordinate matrix for twisty road. This mean consideration, that vehicle will follow road direction vector and speed will be kept constant or safe.

Each coordinate prediction table is labeled with a time stamp (fig. 6) and it is possible to express a statistic, when and where vehicle was. From statistical data a probability chain can be created, that answer the question: “Where vehicle will be, if it follow most probable trajectory?”

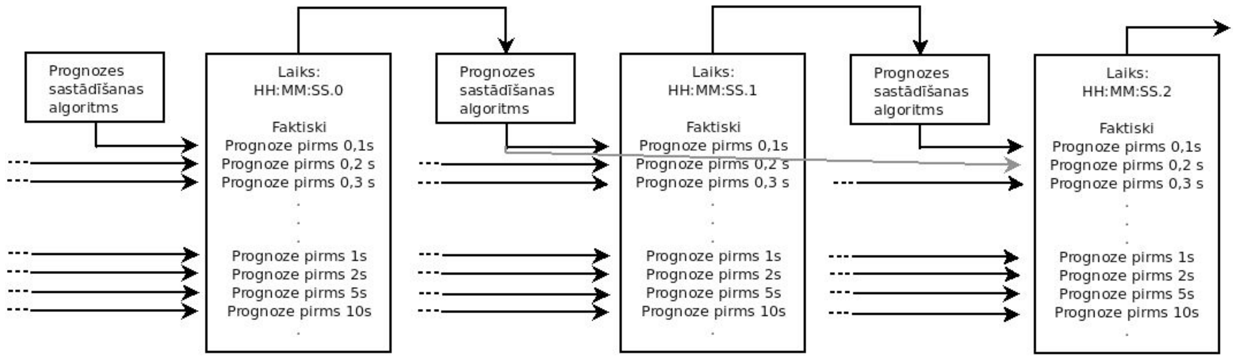


Fig. 6 Prediction tables for sequential time moments

Practical check, demonstrate, that real motion is very close to ideal, but fluctuate near it. This prediction method demonstrate sufficient accuracy to determine, will the vehicle for predicted moment before or behind a street crossing. In fact several prediction and reaction algorithms may co-exist.

Version zero (initial version), consider that speed vector V does not change and no dynamic adjustments are performed. It is considered, that any accumulated inexactness is annihilated in next synchronization point.

1st version calculation mechanism must be applied in cases, when vehicle accelerate or brake rapidly. Actually version one can be used instead of version zero but consume larger amount of computing operations. Usage of 1st version algorithm is triggered by two sensors. Significant changes of accelerator pedal or touch to a brake pedal. Next algorithm versions are derived from described.

2nd version means extension by addition of data from pedal state sensors and brake efficiency sensor. This mean, on-board system of a vehicle is equipped with certain knowledge base, how pedal positions and changes, temperature and humidity sensor data reflect to speed. Information from this database is entered into calculated prediction and adjusts the direction vector achieving greater accuracy. 3rd version algorithm is similar to 2nd but sensor from gearbox inform about actual gear.

4th version compared to 2nd and 3rd versions contain additional knowledge base, where typical speed for current coordinate for interested time moment is stored. This knowledge base also contain data about speed variations due to meteorological conditions and time interval between vehicles.

5th version model prediction perform regarding additional data from vehicle in front. There is a subversion for this algorithm, where coordinate matrix with up to ten vehicles can be taken in account, including evaluation of prediction accuracy of other vehicle.

6th version algorithm contain injected data from higher class ITS about conditions on the desired lane and signal light-time pattern. Regarding this information calculation for requested space is performed and if this plan is not acceptable, a reverse planning activity is performed, where available coordinate matrix is acquired and motion changes defined.

7th version algorithm for proper operation demand data from individual route planner while this permit to select larger coordinate blocks (route description) that covers area supervised by more than one section controller and in a result calculate exact and optimal route schedule.

Actually it is possible to set a schedule accurate to 0,1 s. with respective coordinate sequence that can be verified ad adjusted by accuracy measurements from previous prediction verifications. So an extreme (collision risk) moments can be calculated and if detected by 4^{th} class ITS and prediction verification accept chance of predicted risk, there is sufficient time to inform drivers about condition and suggest to change speed. In cases, when drive-by-wire technology permit and there is no time for interaction with driver, ITS can automatically adjust speed of a vehicle

To avoid appearance and accumulation of difference between fact and measurement in driven distance, a continuous correction method must be applied. If vehicle does straight section of a road, measured distance differ from geometrical. Difference often is very small and fluctuate around 0,1 – 0,2% to 1km. By sensitivity of a sensor of 0,5m, it give 1-2m difference for straight sections or more to twisty. While road sections are measured and labeled with greatest possible geometrical accuracy, then at 1^{st} class level it is to determine a count of sensor pulses per 1 km and when this number change, an updated value will be used for next cycle of calculations.

Motion of a vehicle in a traffic is somehow chaotic, so managing it is a difficult task. To make this task easier a function called flow normalization must be performed. Normalization mean activity, when vehicles with similar parameters are separated and grouped with locked flow time intervals. Normalization of a flow create two cases:

- vehicle grouping causes high flow values during time period;
- flow of grouped vehicles contains large “no vehicle” time intervals that are suitable for organization of cross-flow.

Another task for ITS is chaining of vehicles, and this is also a normalization task. Drivers have various comfort speed levels and this causes bypass maneuvers. Basically, if all traffic participants inform supervising ITS about desired speed level, this is a common value of vehicles for grouping. On multi lane road ITS select near located vehicles with similar desired speed. A route of these vehicles must be determined to select a common part. Regarding route and speed vehicles are packed on a lane. So a chain of vehicles with common destination and equal desired speed is created. In traffic light management such chain is serviced as one extremely large vehicle so achieving high lane throughput ratio, that is desirable result of an ITS. While destination for each vehicle in the chain vary, only part of a route is common, vehicle order must be selected so, that last vehicle has closest destination. This approach minimize need to adjust speed of a chain in case if a common route for someone is ended.

Flow normalization change time interval distribution when intervals from common 3 to 4 sec. shrink close to 1 second. On the street such condition can be observed like intense flow within safe distance.

Due to normalization all traffic participants bypass observation spot in shorter time period so flow expression

$$F=\int_{t_0}^{t_1} N dt \qquad (9)$$

for count of participants N_{norm} acquire form

$$F=\int_{t_0}^{t_1} N_{norm} dt=\int_{t_0}^{t_2} N dt; t_2>t_1. \qquad (10)$$

From rules defined by flow normalization a street crossing prototype with balance rule has been proposed (fig. 7). Vehicles are permitted to enter a crossing if they can leave it. ($Q_1=\Phi_1 dt_1$, $Q_2=\Phi_2 dt_2$, $Q_3=\Phi_3 dt_2$). A draining flow Φ_O in time period dt is producing space for vehicles Q_Φ and section capacity is Q_0. In this case vehicle count Q_1 are those, who are driving straight, and Q_2,Q_3 are turning out from side-street:

$Q_1+Q_2+Q_3=Q_\Phi+Q_0$ (11)

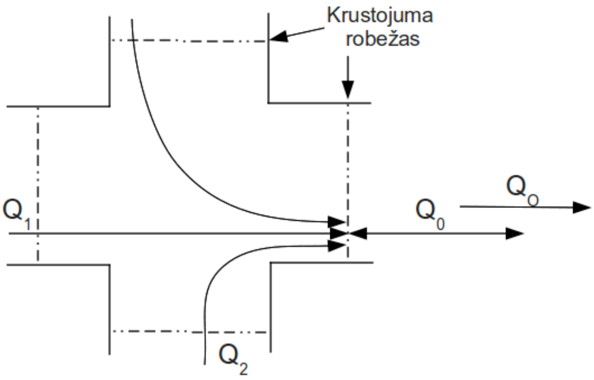


Fig. 7. Crossing schematics

Vehicle count N, that are driving through crossing in time period T_{sig} at various speeds can be expresses as

$$N=\frac{T_{sig}}{\frac{L_{TL}}{v}+t_i} \quad . \qquad (12)$$

For data exchange between systems it is necessary to use dedicated protocols, that in predefined form contain coordinate and prediction tables. Such protocols are V2V and VCP that in OSI level are above TCP/IP. This mean, that TCP/IP is used as routing and channel control protocol while V2V and VCP encode the payload.

In the same time, while ITS generate tremendous amount of data, a validity period is crucial at lower classes. This mean, that in system only operational data exist and information for post-processing and statistics must be separated and submitted to 4. class system before it is deleted from the system. If system hold fully interpretable data (log-file) for last 5 minutes, it occupy 720,98 MB of storage. Operating with these amounts of data define specific requirements to storage – how many input-output operations per second this system is capable to perform. If requirements of a vehicle on-board system are covered by any modern storage device, then central supervising node can expect million or more IO operations per second and this require specific hardware.

For proper operation ITS demand synchronized time with deviation less than 0,1 sec (desired level - 0,1sec divided bu pi). While synchronization data can not be received at each transmission, all autonomous and semi-autonomous modules must contain accurate clock. ITS centralized time is updated in cyclic manner and is backed with high accuracy global time sources. Centralized time update is performed via NTP protocol where upper class system is time source for lower.

All modern and reliable ITS must contain permanent reference and stability points with initial data. Use of direction vector define a need to label a road, and this is achieved using RFID (Radio Frequency Identifier) technology. Preprogrammed tags, that carry sufficient amount of data about coordinate and direction of the lane. While road network is linked to coordinate grid, position of tags in key points form a reference grid.

ITS can be connected to five fixed sensors, and it is sufficient:

- inductive loop installed in road surface can read data about proximity fact, speed of a vehicle and weight. Inductive loop does not identify vehicle by its individual parameters.
- Radar sensor placed near a lane with minimum spread of a beam can give data about proximity fact and speed. This sensor does not identify vehicle.
- RFID tag reader can inform about proximity fact, can identify certain individual parameters (if entered in tag). Does not detect speed.

- Optical sensor can confirm proximity, specific methods permit to calculate speed, image recognition permit to detect several individual parameters of a vehicle.
- Communication beacon can determine proximity in area but can not read coordinates of a vehicle in unaided mode.

Vehicle for proper operation as structure of ITS must contain several elements. Each vehicle must be equipped with sensors:

- Steering position sensor;
- Accelerator pedal position sensor;
- Brake pedal position sensor;
- Brake system actual pressure sensor;
- Wheel angular speed sensor;
- Common speed sensor inside of gearbox;
- GPS signal receiver;
- Front and rear distance sensor;
- Tire pressure sensors;
- Level (slope) sensor;
- Actual selected gear sensor;
- RFID transponder reader device;
- Revolution counter;
- Compass;
- Vehicle weight and weight distribution sensors;
- Brake temperature sensors;
- Accelerometers;
- Fuel consumption sensor.

Each sensor is connected to controller that is inserted into controller area network Master device in CAN is data acquisition module – a microcomputer that beside CAN interface has connection with data analysis and communication module. Depending on performance, microcomputer can perform data acquisition and analysis.

Data acquisition module is preparing sensor signals for processing.

Data analysis module is a processing device that depending on received data and comparison results select predefined conclusions and do resolutions. Data analysis module receive data only from data acquisition module.

Communication module (fig. 8) connect various ITS so, that data exchange between systems are minimal but sufficient. Communication module contains at least two Ethernet ports connected to data acquisition and analysis modules. It also contains at least two CDMA/CD type wireless connection interfaces – one for communications between vehicles using V2V, other for communication with fixed systems. If more ports are available, they can be used for extended features or redundancy.

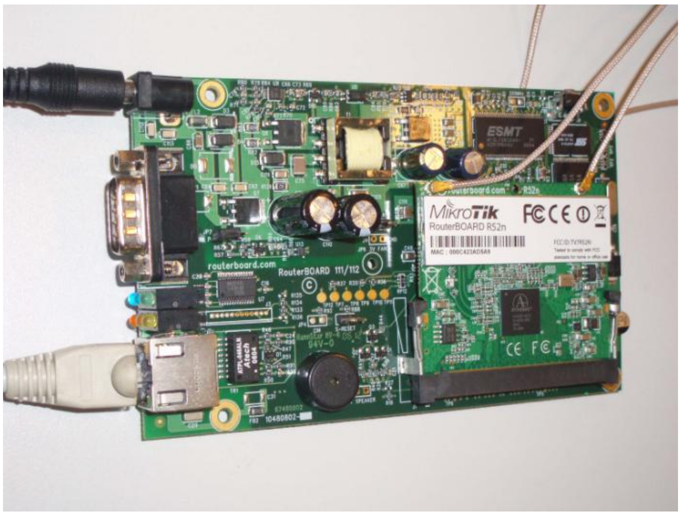


Fig. 8. Prototype of communication module

If connection between data acquisition and analysis modules is simple and does not require extra comments, then connection between systems is complicated. Task of a communication module is to prepare data in encrypted form including exact addressing and decrypt and filter received packets.

Integration between Drive-by-Wire technology and ITS is mandatory by one reason. Reaction time of a modern ITS is thee times shorter than trained human demonstrate. If inside of a vehicle are no mechanical connection between control and executive parts, depending on data from analysis speed or trajectory of a vehicle can be adjusted. In fact, if all traffic members are connected to common network, then implementation of Drive-by-wire can provide fully functional auto-pilot solution. Due to individual characteristics of a driver, ITS can be used only for crash avoidance and traffic management.

Every fixed location module receive data from three channels. They are sensors of a element. Data received from vehicles, and data received from supervising system. Task of a fixed location module is to detect a proximity of a vehicle. Functionally receiver's controller associate received data for further processing.

From elements described before, a lightweight and easy implementable modules are built – controllers for street light, unmanaged crossing, road supervision etc. From ITS point of view – street light section is not just a confined and regulated area. Street light section include part of a road before and behind a crossing. This is because street light is a key element in traffic management and proper light diagram is crucial.

ITS elements – direction vector and prediction allow to calculate – who and when will pass a crossing. Technologically every vehicle receive information about next street light. While ITS has fixed coordinate grid in background, each vehicle can "inform" next streetlight, when it will bypass, if nothing changes. Depending on prediction about speed change, ITS calculate a schedule, when vehicle must bypass a crossing. Regarding to requests from vehicles, ITS perform adjustment of green light permitting direction with greater count until balance rule is not violated.

Data acquired from sensors give an option to calculate actual braking distance. This calculation feed on-board system about safe distance that is calculated from reaction time, safety gap and braking distance of other observed vehicle.

ITS synchronization is crucial and is achieved by several parallel flows of operational data. Information sources and transmission directions are various for required level of integrity and redundancy. Synchronization channels are made by:

- RFID sensor coordinate grid that is fixed and independent source of data. Data form RFID tag is unequivocal and in indisputable manner define location coordinate of a vehicle.

- Global positioning system – in case of ITS is any of available GPS (USA), GALILEO (EU) or GLONASS (Russia), that is sufficiently accurate for location, speed and direction detection. Global positioning system is independent source of data.
- Position prediction comparator. During motion each vehicle calculate its coordinate depending on speed and direction. Initially position is synchronized from RFID tag and is a reference for next section. Calculated and measured coordinates are compared to changes reflected in GPS and accuracy is confirmed by similarity of values. In opposite case system is labeled as unsynchronized until next synchronization through RFID.
- Time synchronization must utilize single and common source of time. If connection to coordinate grid is realized with three independent data sources, then time synchronization is performed with push (and in some cases pull) technique.
- Time stamps for data packets are for evaluation of network integrity. As mentioned before, prediction mechanism rely on coordinate calculations for a time moment in a future. For supervising elements to "know" when prediction was performed and what is due time, stamps must be used. Time stamp is synchronizing element for data structures while only tables with identical time stamp can be compared.
- Proximity sensors are independent structures, that through wireless network detect location of a vehicle inside of supervised area.

Amount of data processed inside of ITS is proportional to vehicles in the traffic. So due to limited performance of computers, whole transportation infrastructure must be split in to cell-like areas. Cell controller (supervisor) is a computing complex with one or many processors, that contain one or many cores. Traffic coordination cell can contain any combination of road sections (elements) while they are in one elevation level. This is mandatory to avoid conflicts in logics when two vehicles have the same coordinate (bridge over a street) but are located on different roads. If elevation levels are not separated, then announce of coordinate can frustrate the system and generate false "dangerous situation" alert. Traffic management cell is a 3rd class ITS with 2nd class ITS for street light management and 1st class for road sensor control.

Information exchange is performed through independent channels and comparison at destination point allow to verify integrity and detect faulty element. During run time of ITS accurate data is crucial and approach: "Check, and re-check in case of error" does not suit. So environment must be capable to provide data from alternate source – parallel data exchange channel, and perform continuous self test also to detect malfunctioning element.

Normally operating ITS must comply to concurring regulations. It must be capable to operate automatically in case of faults and loss of connection to supervisor and in the same time remain manageable by human. Supervision is depending on class of a system. One or more 1st class systems are supervised by 2nd class system, several 2nd class systems (fig.4.) are supervised by 3rd class ITS, 3rd class systems are supervised by 4th class. Location of 4th class systems define topology of a coordination.

4. chapter

Experimental results

Experimental equipment is a computing complex with high precision distance sensor, wheel angular speed sensor, GPS signal receiver Magellan Explorist XL, modified driven distance, average speed and other parameter control device Terratrip 202. For parallel data output and control dedicated software is installed on a notebook computer.

Device complex follow the structure described before:

1st class – vehicle sensor control, data acquisition processing and transmission;
2nd class – on-board computing complex that perform prediction and data exchange;
3rd class – section supervision and communication node;

4th class – centralized traffic management server.
Centralized traffic management server perform data consolidation and prediction, is located in fixed place. It is connected to section supervision and communication node that function as proxy between fixed infrastructure and vehicle.

Experimental check of prediction accuracy and deviation

Time period for prediction is variable an can be set quite free. During experiment prediction values were observed for time periods from 0,1s to 1s with step 0,1s, 3s, 5s, 10s, 15s, 30s.
While calculations are performed for time period of 0,1s, the it is considered that vector V is constant. For calculations actually first seven from eight available algorithm versions can be used but in the research first six, from ver. 0 till 5 has been used.

Fig. 9. contain graph that represent deviation between predicted coordinate and fact for various time periods if algorithm ver.1 is in use. For each prediction time period 50 worst moments were selected. A worst case mean that vehicle move with rapidly changing speed – accelerate , brake, accelerate, brake and so on.

For algorithm verification two sequentially moving vehicles are in use. Leading vehicle operate 3rd version algorithm and tailing vehicle use 5th version. Both vehicles can not be operated with 5th version while this require incoming information from leading vehicle, that is missing in this case. This is also just normal, while it is considered, that leading vehicle does not meet any disturbing aspects, that affect speed or any other parameters.

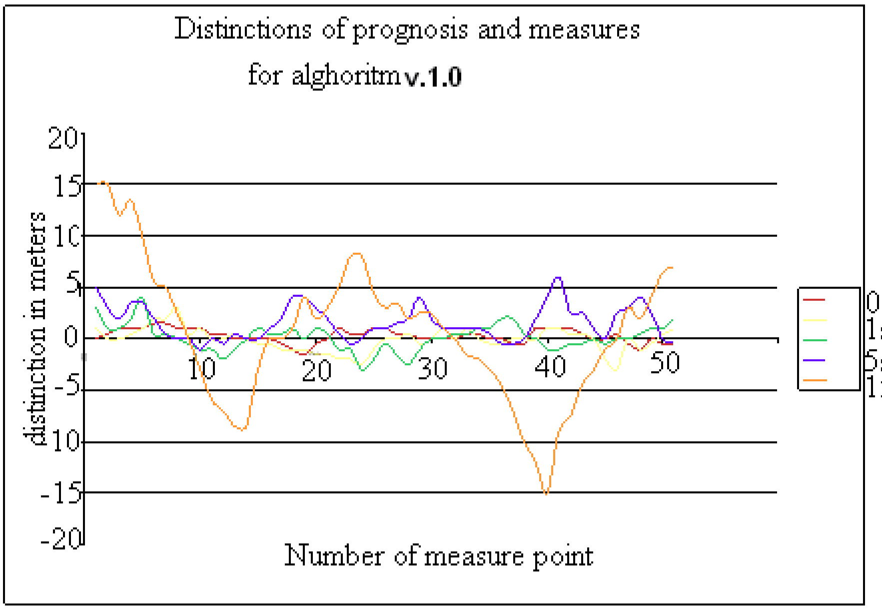


Fig.9 . Deviation between actual and predicted coordinate if algorithm ver. 1 is in use.

From graphs in fig.9 it is to conclude, that algorithm lose its accuracy for extended time periods. This mean that rapid changes of speed are reflected in results after certain delay. So prediction for 10s ahead may give 15m shift. Such graphs can be acquired for other algorithm versions also, and then significantly smaller shifts (grater accuracy) is observed even for worst cases. Uncommon activities on the road does not frustrate the algorithm but reduce accuracy.

Until vehicles announce their locations, inside of a system a prediction tables (fig.10) are rotating. Prediction table is generated from current coordinate and content may vary depending on algorithm used. In fig. 10 predicted coordinates for 30 time moments ahead are presented. Prediction use combined speed value that is synthesized from actual speed and average speed proportional change during motion. Prediction use angle ALPHA linked to coordinate and is downloaded from section supervising system. This replace non existent RFID tags. Correction for both coordinates is expressed from accumulated shift calculated by comparison of predicted and measured coordinates. Correction actually is somehow dual. One is appearing in case, when vehicle does not move with predicted or other – when a collision risk is detected. Second case trigger "target" algorithm that calculate safe position and desired speed.

Important aspect is integrity of a system in case when between equipped vehicles appear unequipped or "faulty" vehicle. So exist set of requirements, how system is locating such ambiguous (alien) vehicle. Experiment is performed on maximum four vehicles where two – Subaru Legacy and Mitsubishi Pajero are equipped with on-board ITS prototype and other two - Volkswagen Golf MkIII and Mercedes Actros 2541LL, has default equipment provided by manufacturer.

Prognozes Periods	Z koordināte	A koordināte	Ātrums	ALPHA	Solis Sek.	Korekcija Z (m)	Korekcija A (m)
TS = 16:00:04.0	350294,15	414002,86	90,1	339,79			
+0.1	350296,50	414002,00	90,2	339,79	0,1	0	0
+0.2	350298,85	414001,13	90,2	339,79	0,1	0	0
+0.3	350301,21	414000,27	90,3	339,79	0,1	0	0
+0.4	350303,56	413999,40	90,4	339,79	0,1	0	0
+0.5	350306,02	413998,53	90,5	339,79	0,1	0,1	0
+0,6	350308,38	413997,66	90,6	339,78	0,1	0	0
+0.7	350310,75	413996,79	90,7	339,77	0,1	0	0
+0.8	350313,11	413995,80	90,8	339,75	0,1	0	-0,12
+0.9	350315,48	413994,92	90,9	339,75	0,1	0	0
+1.0	350317,85	413994,05	91	339,73	0,1	0	0
+1.5	350330,23	413989,66	91	339,7	0,5	0,52	0
+2.0	350342,08	413985,28	91	339,7	0,5	0	0
+2.5	350353,93	413980,89	91	339,7	0,5	0	0
+3.0	350365,79	413976,50	91	339,67	0,5	0	0
+3.5	350377,64	413971,83	91	339,65	0,5	0	-0,28
+4.0	350389,48	413967,43	91	339,62	0,5	0	0
+4.5	350401,33	413963,02	91	339,6	0,5	0	0
+5.0	350413,41	413958,50	91	339,6	0,5	0,23	-0,11
+6.0	350437,09	413949,67	91	339,55	1	0	0
+7.0	350460,77	413940,82	91	339,5	1	0	0
+8.0	350484,76	413931,95	91	339,45	1	0,32	0
+9.0	350508,41	413922,82	91	339,35	1	0	-0,21
+10.0	350532,17	413913,87	91	339,25	1	0,12	0
+12	350579,04	413895,93	90,5	339,1	2	-0,1	0
+14	350625,53	413877,99	90	338,85	2	-0,14	0,1
+16	350671,87	413859,95	89,5	338,73	2	0	0
+18	350717,81	413841,98	89	338,68	2	-0,12	0
+20	350764,50	413823,83	90	338,6	2	0,14	0,1
+25	350877,49	413766,75	91	333,2	5	0,18	-0,1
+30	350986,43	413702,08	91	329,3	5	0,26	-0,14

Fig. 10. Prediction data table

Experimentally is verified a case, when alien vehicle is moving before, or behind of a equipped vehicle, is between two equipped vehicles. During experiments, there were verified several combinations of equipped and unequipped vehicle location. Depending on combination system was able to detect and recognize alien vehicle an define a data set for it.

Structure with task to provide network services only to authorized elements and deter unauthorized activities with goal to crush the system, was functionally verified. Structure include authentication mechanism and verification of received information. In this case it is considered to be safe by error to reject valid data than accept fake.

Proximity logic present how communication module of an ITS can perform as sensor. In this experiment two equipped vehicles – Subaru and Mitsubishi was used. Experiment was performed on the road section without supervising structure. Experiment demonstrate how two systems of the same class create a communication channel automatically and perform data exchange. Proximity of a vehicle is determined by appearance and level of wireless network signal.

Fig. 11 present graph of signal strength when two equipped vehicles are approaching, bypass and move away. Signal level is observed on device mounted in vehicle Subaru.

Fig. 11. Signal strength graph when two vehicles approach and move away

During motion depending on signal strength systems create communication channel and when succeeded, start actual coordinate and prediction table exchange. From coordinate information vehicles “know”, when they are approaching and when moving away. Task for an ITS in this case is to provide road section supervision functionality without central module.

Experimental verification of normalization thesis demonstrate that for congestion reduction it is reasonable to extend permitting light signal if balance rule permit. This increase average speed of a flow and larger amount of vehicles are driving through the crossing in the period of time.

Vehicle count **N**, that bypass a crossing within time period $\mathbf{T_{sig}}$ at various speeds **v** is presented by graph in the fig. 12.

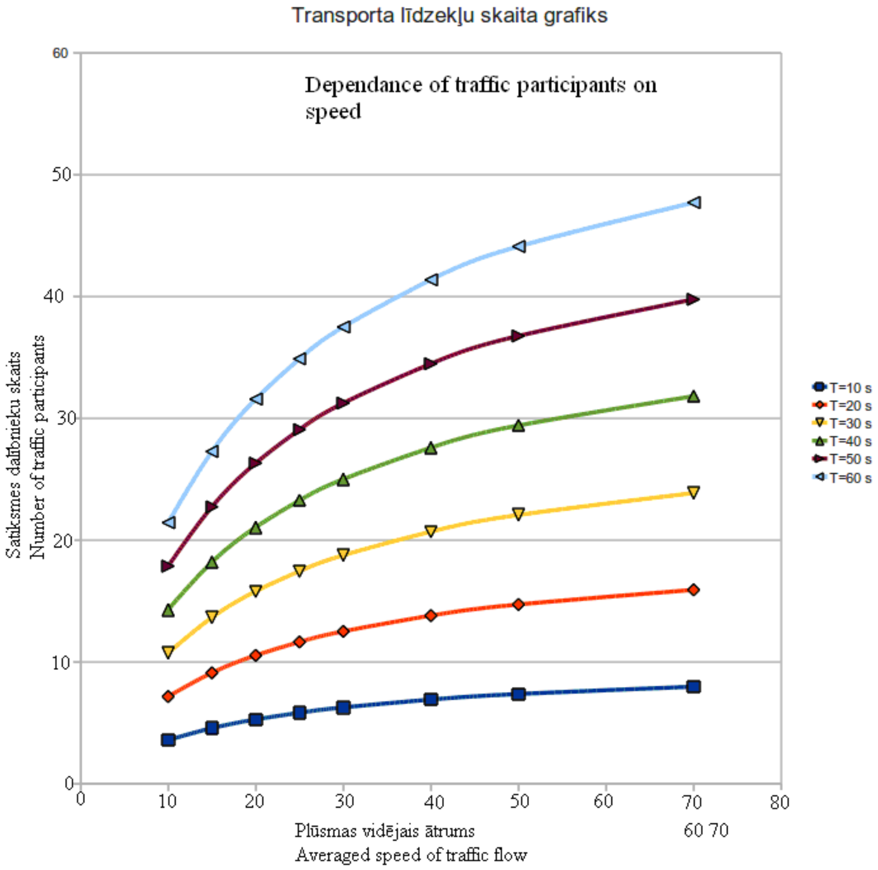


Fig. 12. Count of vehicles bypassing a crossing depending on speed

In the same time it is observed, that time intervals between vehicles are longer for accelerating flow caused by appearance of green light, than for flow moving with stable speed. This statement is true until speed of a flow reach administrative limits. Time intervals between vehicles that move faster than allowed, demonstrate larger time intervals. Average values of the observation is presented graphically in the fig. 13.

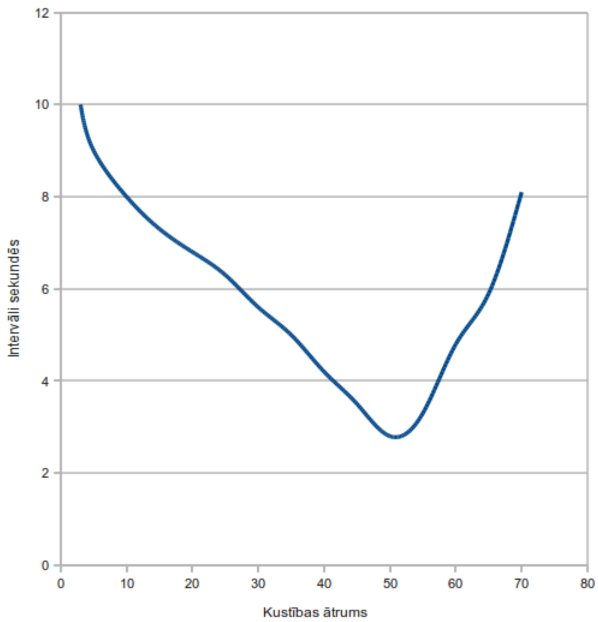


Fig.13. Lane productivity depending on speed.

Fig. 14 present synthetic process, that is approximated to be close to real conditions when count of vehicles Q_0 is observed behind a street light managed by ITS (fig. 7). Observed fluctuations demonstrate regulation of the traffic with prolonged green light until section is filled regarding balance rule (observations from 1. till 126.). In that moment delay is triggered so limiting incoming amount of vehicles and permitting to empty the section at constant time of a signal that form Q_O (from 131. till 156.). While observations are made with variable time interval, graph is demonstrating a tendency. From observation 156. till 241. flow normalization algorithm is in use and by constant green signal time no accumulation of vehicles is observed while time schedule avoid that and all vehicles can pass the crossing.

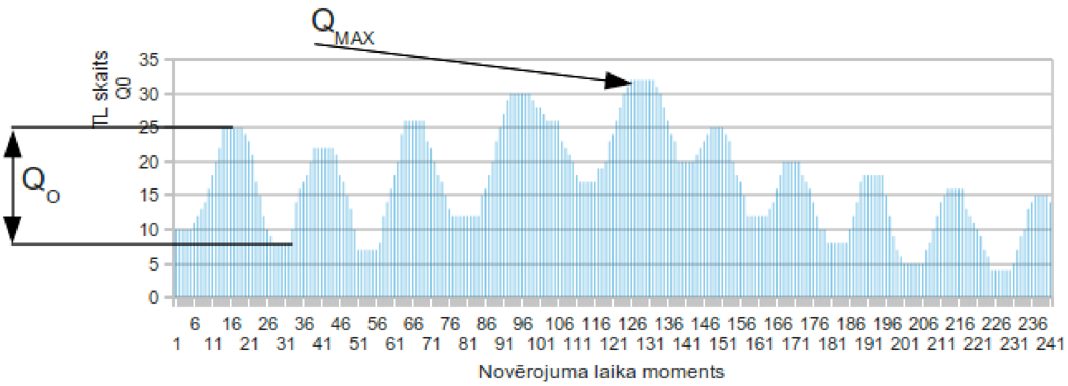


Fig 14. Count of vehicles depending on flow regulation.

Fig. 15 represent two street light management interpretations when flow increase is managed by longer green light until limitations by balance rule is reached. Difference between shortest and longest time is called as regulation range. Regulation range depends on actual flow and is equal with time when vehicles Q_I fill dedicated space. Such regulation approach is valid for if one direction is dominating in the crossing, but this cause a tendency to accumulate vehicles for transverse direction and this must be avoided. This task technically can be solved by increment of a transverse flow speed using sluicing method. This mean that vehicles are accumulated before street light and when certain level regarding balance rule or time-out is reached, then **all accumulated** vehicles are permitted to bypass crossing. A sample of this approach can be observed in Riga near shopping mall Alfa for direction from Jugla, but in this case street light does not permit all accumulated vehicles to pass, as it is needed.

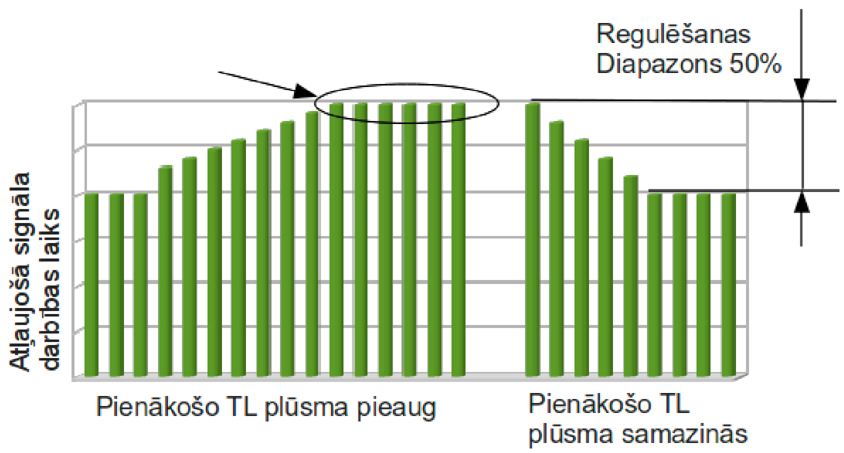


Fig. 15. Green light time diagram

So this direction has permitting light time diagram similar to version presented in fig. 16.

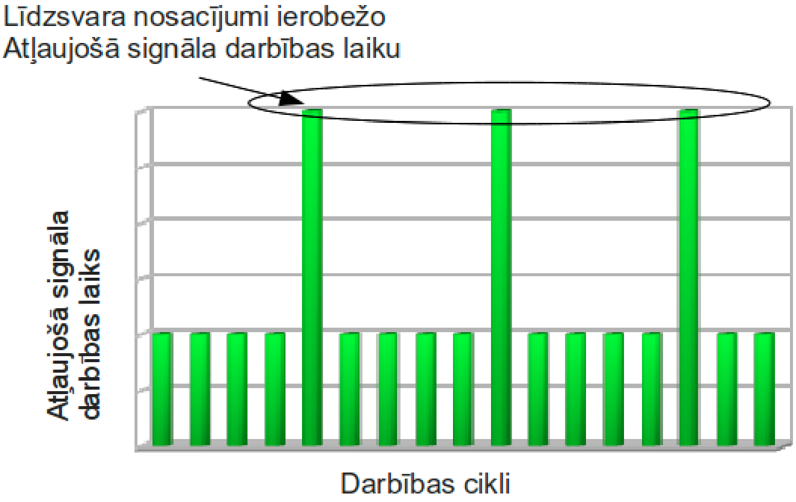


Fig. 16. Green light time diagram

In figure difference in green light time is presented demonstrating how it depend on available free space and upcoming flow. General difference is in fact, that regulation is calculated for every direction separately so avoiding appearance of conflicting flows. Street lights in this case must be full size (with both turn away sections) to minimize risk of misunderstanding. Actually sluicing is well suited for crossings with plenty of space before and after the crossing, for example, a Lielirbes street and Ulmana avenue junction forming Jurmala highway, so a lot of vehicles will pass according to normalization rules.

From conditions defined for stand alone crossing a prototype for chain of crossings is designed. In this prototype every crossing follow balance rule analyzing available space and correlation to flow parameters defined by count of service requests. This mean, that resolution of a congestion starts at crossing that has so much free space behind to keep balance rule at quite any upcoming count of vehicles.

Common conclusions

- Today transport management is built on many local autonomous systems:
  - without mandatory interoperation links;
  - standalone systems are working with mutually incompatible mathematical models, that solve only local problems;
  - standards and format and software used by vendors are closed making integration quite impossible.
- Task of a modern ITS is not to replace a driver, but minimize and avoid problems caused by lack of skills or superficial manner of driving.

- Motion description and prediction with discrete-arithmetical modeling methods are only that in conjunction with coordinate matrix and direction vector are suitable for real-time systems;

- System must be multi-level where each of them has specific task so avoiding ideological conflicts and balancing load in computing environment;

- All traffic participants and their positions must be registered in common system and described in common form;

- Time division of 0,1 second is sufficient:

    - to act on dangerous situations faster as skilled driver can in the same time keeping certain reserve if first cycle does not perform adequately;

    - all operations are so simple, that there is no problem to perform in dedicated time slot including multiple verifications.

- Definition of prediction algorithm classes depending on parameters permit to choose best fit and available processors cycles allocate for data sorting;

- A consequence is observed, that increase of parameters included in prediction increase accuracy for rapidly changing situations, that from traffic safety point of view must be exterminated;

- For full function system must take in account traffic participants that due various reasons can not inform supervising elements about presence, so other must be able to recognize such and it is technically possible;

- In road sections, that due to minimal flow are not covered by centralized supervision, is important to know about proximity of other traffic participants so avoiding collisions in dead turns or hit pedestrians.

- Traffic congestion can be reduced by improvements in flow management by avoiding unneeded stops and clogging a street crossing:

    - Vehicle packing and forced minimization of time intervals during green light increase throughput of a crossing;

    - It is permitted to enter crossing only when there is space behind;

    - Responsibility about congestion reduction lies on crossing that has most space behind;

    - If flow is created by large amounts of vehicles, regulation with street light is useless and two or more level crossing must be built.

- Task of a ITS is to care about traffic safety and it must be able to operate at any speeds observed on the road. This mean – speed limits are defined by actual situation, surface condition and geometry of the road but not administratively;

- Operative data must be protected against rogue activities like addition, replacement and injections so not only access control must be set, but also a continuous data validity verification is mandatory.

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3. Krūmiņš O., Raņķis I., Ribickis L. Transporta automātiskās kustības sistēmas – tramvaja modelis. Enerģētika un Elektrotehnika. 2005. g. Rīga. Sērija 4. Sējums 15. 57-64 lpp.

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10. Krumins O. Autoadaptive Intelligent Transport Management System. Proc. of the 5th Intern. Symp. Doct.school of energ. and geot., Kuressaare, Estonia, 2007. pp.170-173

11. Krūmiņš O., Raņķis I.Virziena vektora pielietojums kuģu kustības drošības novērtēšanai.- *Proceedings of 12th International Conference "Maritime Transport and Infrastructure – 2010"*, Rīga:LJA , 2010 – 88.-92. lpp.

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13. Krūmiņš O., Raņķis I. Discrete arithmetic models for traffic interpretation and prediction. Power and Electrical Engineering. The 51st International Scientific Conference. 2010. g. Riga. Electron. Proc. , pp. 245-248