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NETWORK SYSTEMS ANALYSIS IN CASE OF CRITICAL SITUATIONS

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The paper describes the analysis and discussion of the network systems in case of the critical situation that happens during ordinary work. The formal model is proposed – based on the two types of real sophisticated network systems – with the approach to its modelling based on the system behaviour observation. The definition of the critical situation sets are created by reliability, functional and human reasons. No restriction on the system structure and on a kind of distribution describing the system functional and reliability parameters is the main advantage of the approach. The proposed solution seems to be essential for the owner and administrator of the transportation systems.

Keywords: network systems, critical sets, reliability, dependability modelling

1. Introduction

Contemporary network systems are very often considered as a set of services realised in well-defined environment created by the necessary hardware and software utensils. The system's dependability can be described by such attributes as *availability* (readiness for correct service), *reliability* (continuity of correct service), *safety* (absence of catastrophic consequences on the users and the environment), *security* (availability of the system only for authorized users), *confidentiality* (absence of unauthorized disclosure of information), *integrity* (absence of improper system's state alterations) and *maintainability* (ability to undergo repairs and modifications) [1, 3, 8, 13].

The system realises some tasks and it is assumed that the main system goal, taken into consideration during design and operation, is to fulfil the user requirements. The system's functionalities (services) and the technical resources are engaged for task realisation. Each task needs a fixed list of services which are processed based on the system's technological infrastructure. The different services may be realised using the same technical resources and the same services may be realised involving different sets of the technical resources. It is easy to understand that the different values of performance and reliability parameters should be taken into account. The last statement is essential when tasks are realised in the real system surrounded by unfriendly environment that may be a source of threads and even intentional attacks.

Moreover, the real systems are built on the base of unreliable technical infrastructures and components. The modern systems are equipped with suitable measures and probes, which minimise the negative effects of these inefficiencies (a check-diagnostic complex, fault recovery, information renewal, time and hardware redundancy, reconfiguration or graceful degradation, restart etc). The contemporary network systems are created as very sophisticated products of human idea characterized by the complex structure. This way the critical situations observable during its exploitation are not always predictable for system's owners and managers, but could be very costly for a company and sometimes even damaging.

The aim of this paper is to point the problems of the critical situations in unified network system – product of essential elements and features taken from two kind of real systems: ***Discrete Transport System (DTS)*** and ***Computer Information System (CIS)***. Each part of the system is characterised by unique set of features and can caused the critical situation of whole system if it starts to work in unusual way or the fault or error of it is noticed. It is hard for an administrator, manager or an owner to understand the system's behaviour and to combine the large scale of variant states of it in single – easily observable and controlled global metric as a pointer to make the proper decision in short time period. To overcome this problem we propose a functional approach. The system is analysed from the functional point of view, focusing on business service realized by a system [14]. The analysis is following a classical [15]:

modelling and simulation approach. It allows calculating different system's measures, which could be a base for decisions related to administration of the transportation systems.

The results of the system observation – understand as the set of data collected during the simulation process are the basis to define the critical situations and they allow providing proper solution to lift-up the systems in effective way if the critical situation occurs. This is the only sensible way, because the critical situations are the real and not removable part of the system life. The organization of this paper is as follow. We start with description of the abstract service network model (Section 2). Base in it we define the normal conditions of the system's work (Section 3). In Section 4 we provide the most adequate – in case of the level of detail – the well-established description of the critical situation.

2. Service Network Model - Idea

The paper describes approach based on functional-dependability models understood as a concept of specifying dependability aspect for two perspectives: secure and dependable system as much as service-related operational system. In our research, we focus on two types of service models, that where close to our interest area: ***Discrete Transport System*** (***DTS***) [13, 14, 15, 16, 17] and ***Computer Information System*** (***CIS***) [8, 10, 11, 12]. Both systems can be analysed separately, but because of their specific goal, some common mechanisms can be seen. Taking into consideration more generic perspective, we decided to focus on a common view on the system model we call - ***Abstract Service Network Model***.

As mentioned, both systems have the same aim – to provide a service in a sense of user request accomplishment. For this reasons, the key point to analyse the systems is a *Task* (*T*) given to the systems. Task is defined by the user and parameters related with time (user patience time, delivery take, etc.) but also it is strongly and inextricably connected with some service scenario. In fact, when we analyse logically the way the service is provided, we can see that the scenario conditions define specific choreography (graph of various components) within a service.

The choreography must be defined and known. Since task is realized as an input to the *Business Service* (*BS*), therefore its choreography is based on predefined service components located in network nodes (reconfigurable components). Moreover, network nodes base on *Technical Infrastructure* (*TI*) – resources used as elements for providing dependable service seen as a hardware and software linked within a network. Various functional define each element of the Technical Infrastructure (routes and central points in *Discrete Transport System*, computers or network devices in *Complex Information Systems*) and dependability parameters, not to mention about some time functions. Time related with the technical resources is as much important as time on a service level, therefore we speak about – *Chronicle of the System* (*K*).

Taking into consideration these common features an abstract model can be proposed as follows:

$$ANS = < T, BS, TI, M, K >, \tag{1}$$

where

ANS – Abstract Network Services,
T – Task,
BS – Business Service,
TI – Technical Infrastructure,
M – User,
K – Chronicle of the System.

The unified description can guarantee the required level of abstraction for the analysis we are going to provide.

3. Network Service Description

3.1. Tasks Problem

The problems of the contemporary systems reliability certainly need to be extended to cover the envisaged fact that the main object (system) of its studies is a tightly connected complex of hardware resources, information resources (algorithms and procedures of operations and system management) and human-factor (managers, administrators and users).

The studied systems realize complex functions and are capable of substituting tasks on detecting faults (functional redundancy). The systems operate in a changing environment, often antagonistic to them. Users generate tasks which are being realised by the system. The task to be realised requires some services (functionalities) available in the system. A realisation of the service needs a defined set of technical resources. In a case when any resource component of this set is in a state "out of order" or "busy", the task may wait until a moment when the resource component returns to a state "available" or the service may try to create other configuration based on available technical infrastructure [2, 3, 4].

A technological infrastructure is considered as a set of hardware resources (devices and communication channels) which are described by sets of their technological, reliability and maintenance parameters. The information resources are understood in the same way. The human-factor's functions are defined little bit different: she or he can be defined as: a system operator, a service person, a system manager (administrator), etc. [21, 22]. The system management allocates the resources to the task realisation, checks the efficient states of the system, performs the suitable actions to locate faults, attacks or viruses and to minimise their negative effects. In many situations the system staff and the management system have to cooperate in looking for adequate decisions (for instance, to fight with a heavy attack or when a new virus is disclosed). The system events corresponds to: tasks realisation, occurrence of incidents (faults, viruses, attacks) and system's reactions to them (technological and information renewals). Task configurations change when the tasks are being processed. The software management, reacting with the system's users, determines the changes. Some changes may be the result of detecting system's faults and reacting to them. This is called system's reconfiguration [18, 20]. The subsets of resources used by the tasks do not need to be disjoint. A resource that can be allocated to more than one configuration at the same time is called sharable, whereas one that cannot is non-sharable. Some resources, for example the central processors in computer systems, are "time-sharable". This is a technique that allows sharing of resources that are essentially non-sharable, by very fast switching of the allocation in time [1, 10, 11].

3.2. Events

Different events of the service network are considered as:

- "normal" functional events described by such time parameters as the start or / and the end of the task, a moment of a system resources allocation, a time of occurrence of a new task, an (prognoses or real) task execution time, etc.,
- unfriendly incidents that are disturbed efficient system's execution; for example failures of transport structure, failures and errors, delay time of data packages, faults of network devices or dispatching system, etc.

It is easy to notice that the first class of system events is strictly connected with correct system's task realization and the second one groups all events disrupting the efficient operation of the system and which may start the system's defence reactions. In this way the first class of events will be called "efficient functional events" and the second one "dependable incidents" or "unfriendly events". A classification of dependable incidents and system's reactions is presented in the Figure 1.

A dependable incident is an event that might lead to some disruptions in the system's behaviour. The incident may cause some damage to the system's resources; transport structure, management actions and, in consequence, it may disrupt the executed transport processes [3, 4].

If a fault appears during the task execution then the system on the base of decision of its management system starts renewal processes. Time of technological renewal activities are added to the nominal time of the task so a real time of the task duration will be longer. The real duration time of the executed tasks depends on the nature of the system's faults. Failures of hardware may need both renewals of technological resources and information resources. Consequences of human errors or computer software faults are limited to renewals of information processes. Sometimes an incident, which has occurred in a short time interval, may have a more serious impact on the system's behaviour; it may escalate to a security incident, a crisis or a catastrophe. The failures of the network structure - physical failures of technical infrastructure need to use adequate service teams, spare elements or substituted routes. Very often "technical" system's renewal processes are considered with assuming of the limited resources, for example the number service team for the part of the network [5, 20].

Other sources of the network disruptions we can find in organization and management:

- overloading of the technical infrastructure,
- traffic problems or jams – caused by limited bandwidth or dispatching errors,

- dispatching faults – system is not able to keep up the dynamic changes of the situation in the working network.

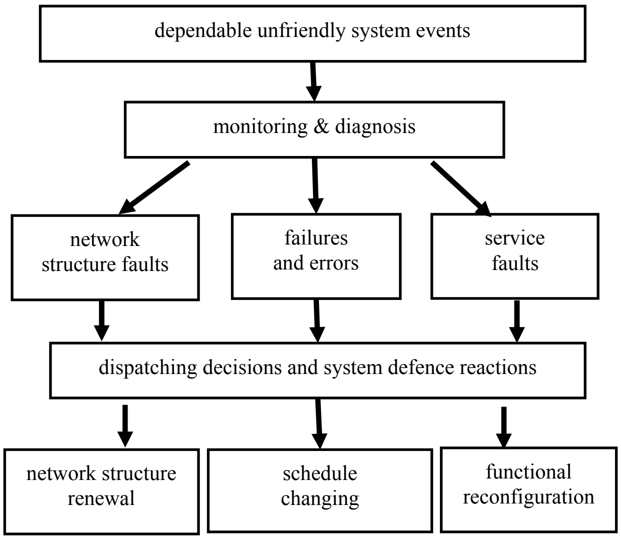

Figure 1. A classification of unfriendly events of a discrete transport system

In these cases exploitation system's renewal processes are initiated by the system's dispatcher. The processes very often consume more time and money than a renewal of a "simple (physical)" broken technical resource, e.g. a repair of a failed truck or a lift.

3.3. Maintenance

The modern systems are equipped with suitable measures, which minimise the negative effects of these inefficiencies (a check-diagnostic complex, fault recovery, information renewal, time and hardware redundancy, reconfiguration or graceful degradation, restart etc). The special services resources (service persons, different redundancy devices, etc.) supported by the so-called maintenance policies (procedures of the service resources using in purpose to minimise negative consequences of faults that are prepared before or created ad hoc by the system's manager) are build in every real system [3, 4, 17, 20]. The maintenance policy is based on two main concepts: detection of unfriendly events and system's responses to them. Detection mechanisms should ensure detection of incidents based on observation of a combination of seemingly unrelated events, or on an abnormal behaviour of the system. Response provides a framework for counter-measure initiatives to respond in a quick and appropriate way to detected incidents.

In general, the system's responses incorporate the following procedures:

- detection of incidents and identification of them,
- isolation of damaged resources in order to limit proliferation of incident consequences,
- renewal of damaged processes and resources.

Relations among the incidents and the reactions of the system are shown on Figure 2.

A services network is a system of functional services that are necessary for clients' tasks realisation process. The services networks are organized based on the technical infrastructure and technological services which are involved into a task realisation process according to decisions of the management system. The task realisation process may include many sequences of services, functions and operations which are using assignment network resources. Description of the allocation of network services and their implementation process will be hereinafter referred to as network choreography. We can build more general definition of the system introducing the idea of the net of services. It is described at the upper level of abstraction: a task or a job may use a single service or a few services – concurrent or sequenced – on the base of available network resources.

The management system – allocates services (functionalities) and network resources to realized tasks, checks states of the services network and controls suitable system's responses to detected and localized unfriendly events and minimizes their negative effects. The control of the defense reactions of the system is understood as the choice of an appropriate maintenance policy.

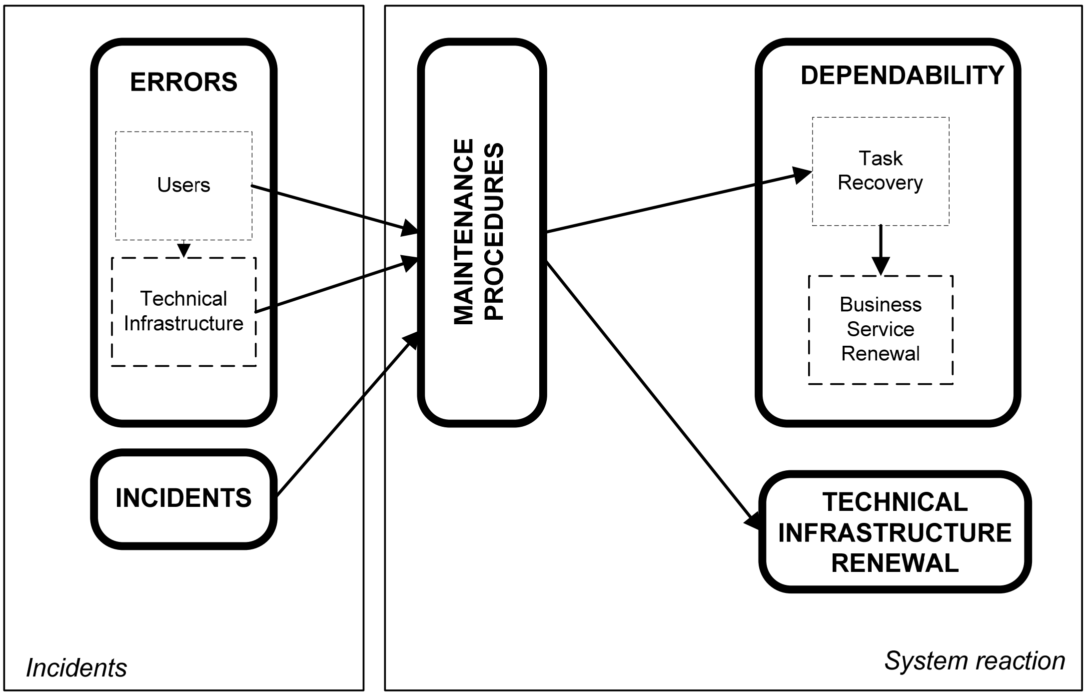

Figure 2. Incidents and reactions of the system

A service may be realised based on a few separated sets of functionalities with different costs which are the consequences of using different network resources. Because the services have to cooperate with other services than protocols and interfaces between services, and/or individual activities are crucial problems which have a big impact on the definitions of the services, and on processes of their execution.

Generally the management system has main functionalities:

- monitoring of network states and controlling of services and resources,
- creating and implementing maintenance policies which ought to be adequate network reactions on concrete events/accidents. In many critical situations a team of persons and the management system have to cooperate in looking for adequate counter-measures.

As a consequence, the services network is considered as a dynamical structure with many streams of events generated by realized tasks, used services and resources, applied maintenance policies, manager decisions, etc. Some network events may be independent but majority of events depends on a history of a network life. Generally, event streams created by a real network are a mix of deterministic and stochastic streams which are strongly tied together by network choreography. Modelling of this kind of systems is a hard problem for system's designers, constructors and maintenance organizers, and for mathematicians, too.

It is proposed to focus the dependability analysis of the networks on the fulfilment of requirements defined by user task [20]. Therefore, it should take into consideration following aspects:

- specification of the user requirements described by task demands, for example expected volume to transport, desired time parameters,
- functional and performance properties of the network system and theirs components,
- reliable properties of the technical infrastructure that means reliable properties of the network structure and its components considered as a source of unfriendly events which influence the task processing,
- threads in the network environment,
- measures and methods which are planned or build-in the network system for elimination or limitation of unfriendly incident consequences; reconfiguration of the transport system is a good example of such methods,
- the system of maintenance policies applied in the considered network.

The task realisation process is supported by two-level decision procedures connected with selection and allocation of the network services (functionalities) and infrastructure resources. The first level of decision procedure is focused on suitable services selection and a task configuration. The functional and the performance task demands are based on suitable services choosing from all possible network services. The goal of the second level of the decision process is to find needed components of the network infrastructure for each service execution and the next to allocate them based on their availability to the service configuration. If any component of technical infrastructure is not ready to support the service configuration then the allocation process of network infrastructure is repeated. If the management system could not create the service configuration then the service management process is started again and other task configuration may be appointed. These two decision processes are working in a loop, which is started up as a reaction on network events and incidents [3, 4, 5, 20].

3.4. Dependability Problems

The term dependability is well known in the literature and commonly used by fault tolerant and dependable computing community, but has been assigned many different meanings. For example, there is more than one definition of dependability [3, 4, 6, 7, 9].

The dependability of the system can be defined as the ability to execute the functions (tasks, jobs) correctly, in the anticipated time, in the assumed work conditions, and in the presence of threats, technological resources failures, information resources and human faults (mainly malfunctions) [5]. Dependability is the most comprehensive concept for modelling complex systems taking a top-down approach [1].

It is evolving into a distinct discipline attempting to subsume the preceding concepts of reliability, and fault-tolerance. There is no universally accepted definition of dependability; the term has been accepted for use in a generic sense as an umbrella concept [2, 3].

Users of the system realise some tasks using it – for example: send a parcel in the transport system or buy a ticket in the internet ticket office. It is assumed that the main goal, taken into consideration during design and operation, is to fulfil the user's requirements. We can easy find some quantitative and qualitative parameters of user's tasks [2, 20].

The system's functionalities (services) and the technical resources are engaged for task realisation. Each task needs a fixed list of services, which are processed based on the system's technological infrastructure or the part of it. The different services may be realised using the same technical resources and the same services may be realised involving different sets of the technical resources. It is easy to understand that the different values of performance and reliability parameters are taking into account.

The last statement is essential when tasks are realised in the real system surrounded by unfriendly environment that may be a source of threads and even intentional attacks. Moreover, the real systems are built of unreliable software and hardware components as well.

Therefore, it should take into consideration following aspects:

- specification of the user requirements described by task demands,
- functional and performance properties of the system and theirs components,
- reliable properties of the system's technological infrastructure that means reliable properties of the system's structure and its components considered as a source of failures and faults which influence the task processing,
- process of faults management,
- threads in the system's environment,
- measures and methods which are planned or build-in to eliminate or reduce the faults, failures and attacks consequences,
- applied maintenance policies (together with their costs) in the considered system.

It is hard to predict all incidents in the system; especially, it is not possible to envision all possible attacks, so system's reactions are very often "improvised" by the system, by the administrator staff or even by expert panels specially created to find a solution for the existing situation. The time, needed for the renewal, depends on the incident that has occurred, the system's resources that are available and the renewal policy that is applied. The renewal policy should be formulated on the basis of the required levels of system's dependability (and safety) and on the economic conditions (first of all, the cost of downtime and lost processing/computations) [2].

As a consequence, a system is considered as a dynamic structure with many streams of events generated by realised tasks, used services and resources, applied maintenance policies, manager decisions, etc. Some network events are independent but other can be found as direct consequences of previously history of the network life. Generally, event streams created by a real network are a mix of deterministic and stochastic streams, which are strongly tied together by network choreography. Modelling of this kind of systems is a hard problem for system's designers, constructors and maintenance organisers, as well as for mathematicians. It is worth to point out some achievements in the computer science area such as Service Oriented Architecture [3, 4, 19] or Business Oriented Architecture [19, 22], and a lot of languages for network description on a system's choreography level, for example *WS-CDL* [11], or a technical infrastructure level, for example *SDL* [11, 20]. The approach seems to be useful for analysis of a network from the designer point of view. The description languages are supported by the simulation tools, for example modified *SSF Net* simulator [14, 15]. Still it is difficult to find the computer tools which are combination of model languages and Monte Carlo simulators [12, 16, 17].

4. Critical Situations

The working point of a unified network system is defined by specific values of functional parameters (resulting from the existing infrastructure – load capacity of commodity carriers and the available number of carriers, passing transfer limits, connection quality, availability and quality of handling equipment, route selection, etc.) and reliability (mean time to elements failures, the number of repair crews, the frequency and duration of traffic jams and other problems, machine renewal time, etc.). In practice, only some elements of the system's model may be treated as decision variables. For example, a system's designer may adjust carrier capacities to the actual needs of the task but very often, he or she has no possibility to choose the elements base on their reliability features. For example, it is possible to choose a better throughput of the connection, but it is no chance to change the parameters of this part of the network. The appropriate operating point of the network system may be achieved thankfully to the dispatching mechanisms and the actions of organizational nature as: choosing the number of carriers and/or the number of repair crews, bypassing a blocked (overload) by traffic connections, rescheduling, etc. Dispatching decisions concerning allocation of services (functionalities) and resources can define the system's reconfiguration necessary to accomplish the planned tasks.

The dependability analysis of network systems is carried out to assess the degree of risk associated with the implementation of task agreements. Note that in this case, the risk is defined and assessed as likely to ensure the system's performance under certain conditions. Another important issue is the evaluation of the impact of various system parameters on defined measures of performance (performability, dependability). Dependability synthesis of network systems is based primarily on proper selection of services and resources to fulfil the functional requirements defined by users' tasks (the so-called. input tasks) – see functional – reliable models [14, 15, 20].

Optimisation of system's synthesis is carried out based on the minimization of potential losses resulting from breach of contract. Since the parameters and decision variables of the process of network system's synthesis are determined by nominal values contained in the intervals of tolerance, though unlikely, is a scenario corresponding an operation point defined by the worst of circumstances (for example, the simultaneous maximum demand of tasks, the maximum number of long-term traffic jams, outbreaks caused by different matters, etc.). The decision variables and the parameters are very often treated as random variables within appropriate tolerance ranges. The operation point of the system may be defined together with a multidimensional solid of tolerance that is created at the appropriate confidence level.

The tolerance solid of the network system may be used as a basis for estimating the risk of system's faults. It is worth noting the difference between the intended ("built-in") redundancy (functional, reliable) and pseudo-redundancies as a result of random variables distributions, and therefore both the system's constructor and the dispatching mechanisms should exercise adequate caution in these situations. The set of system operation points forms a system's efficient operation area defined in n-dimensional hyperspace of system parameters and decision variables. The task of synthesis of the network system can be formulated as to ensure the global task performance for a specified number of carriers, choosing the appropriate delivery route and the costs do not exceed a fixed value. Figure 3 illustrates the problem of selecting the operation point of the network system taking into account the number of carriers and repair utensils. The actual system's quality is measured by the availability parameter.

The boundaries of the efficient operation area shall be determined on the basis of the acceptable costs of tasks, the maximum allowable repair time, and cost of used infrastructure. The boundaries can be set for the expected values – the hyper-planes of maximum costs of working system and the hyper-plane of the minimum, but still acceptable, system's availability. It is easy to notice that the efficient operation area may consist of many operating points, which are associated with different operating costs or risk of incorrect operation of the system. It is introduced a concept of a critical operation point of the system, i.e., such an operation point within the efficient operation area that the occurrence of a single hostile incident (e.g. damage of single system's element) causes a transient exit (e.g. for renewal time) beyond the area of efficiency and an additional hostile event that appears during the renewal time (e.g. a traffic jam on one of the used routes) leads to system's crush (e.g., interruption of the supply chain in a just at time operating system).

A subset of the critical operation points constitutes the so-called critical efficient operation area of the system (Figure 3) corresponds to critical system operation states. The critical system's state can be a simple consequence of change of "process parameters", such as raising the intensity of damage of the system's elements as a result of their use or the result of unfavourable combination of circumstances (adverse realization of random variables). For example, without necessarily changing the intensity parameter, too many carriers would be damaged at the same time, and repair crews would be overwhelmed. In extreme cases, it may lead to an avalanche of hostile events, or even to crash the system.

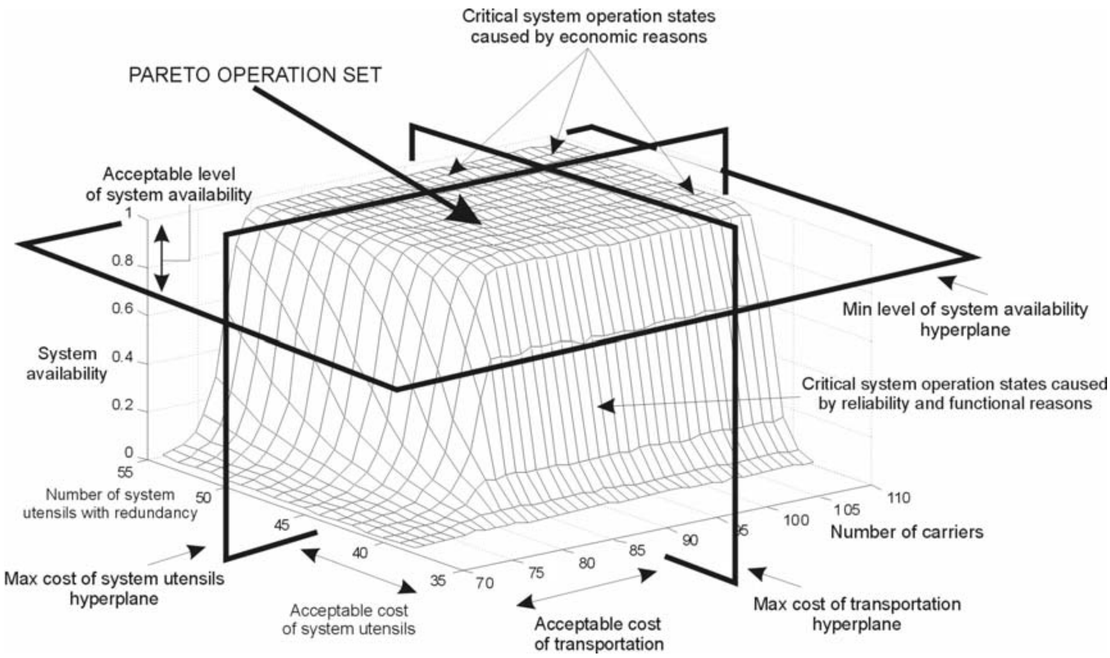

Figure 3. General idea of critical sets for network system

5. Conclusions

We have presented a formal model of sophisticated network system including reliability, functional parameters as well as the human factor component at the necessary level of detail. The model is based on the essential elements and features extracted from the ***Discrete Transport System (DTS)*** and the ***Computer Information System (CIS)***. We pointed the crucial conditions of the normal work of the system. The critical situation is described and discussed to create the Pareto set – guarantying the possible safety operating points for actual network system.

The proposed approach allows performing reliability and functional analysis of the different types of network systems, for example:

- determine what will cause a ”local” change in the system,
- make experiments in case of increasing volume of the commodity incoming to system,
- identify weak point of the system by comparing few its configuration,
- better understand how the system behaves.

Based on the results of simulation it is possible to create different metrics to analyse the system in case of reliability, functional and economic case. The metric could be analysed as a function of different essential functional and reliability parameters of network services system. Also the system could be analysed in case of some critical situation (like, for example, a few day tie-up [17]).

The presented approach – based on two streams of data: dependability factors and the features defined by the type of business service realized – makes a starting point for practical tool for defining an organization of network systems maintenance. It is possible to operate with large and complex networks described by various – not only classic – distributions and set of parameters. The model can be used as a source to create different measures – also for the economic quality of the network systems. The presented problem is practically essential for defining and organization of network services exploitation.

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DISCRETE TRANSPORTATION SYSTEM'S AVAILABILITY PROBLEM IN CASE OF CRITICAL SITUATION SETS

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The paper discusses the discrete transportation system's (DTS) availability problem in case of the critical situation, which happens during its ordinary work. The formal model of the transportation system suitable for modelling based on the system behaviour observation is proposed. Monte Carlo approach is in use for a simulation. The system's availability is calculated as global metric to find if the system is able to realise the loaded set of tasks. The critical situation discussed there is caused by reliability, as well as by functional and human reasons. No restriction on the system's topology and on a kind of distribution describing the system's functional and reliability parameters is the main advantage of the approach. The proposed solution seems to be essential for the owner and administrator of the transportation systems.

Keywords: reliability, discrete transportation system, Monte-Carlo simulation, critical situation sets

1. Introduction

At the beginning of the discussion about the critical situations – observable during exploitation processes of the discrete transport system – we have to say that they are not always predictable for system's owners and managers, but can turn to be very costly for a company and sometimes even damaging. The aim of this paper is to show a method of analyzing the critical situations of a discrete transportation system (*DTS*), i.e., a transportation system in which goods are transported by a fleet of vehicles of limited capacity. The vehicles operate according to schedules, carrying goods between destinations. The goods are fixed in size (the volume of goods is always a discrete number).

The performance of discrete transportation system depends on different factors [9]. Some of them are deterministic ones, like: distances between destinations, number of drivers and number of trucks. Others have random features, like: amount of goods to be transported, the reliability characteristics of trucks, transportation time (due to traffic jams) and the absence of drivers' sickness. Each part of the system is characterised by absolutely unique set of features and can cause the critical situation of the whole system if it starts to work in unusual way or the fault or error of it has been noticed. It is hard for an administrator, manager or an owner to understand the system behaviour and to combine the large scale of variant states of it in single – easily observable and controlled global metric as a pointer to make the proper decision in short time period. To overcome this problem we propose a functional approach. The transportation system is analysed from the functional point of view, focusing on business service realized by a system [16]. The analysis is following a classical [4]: modelling and simulation approach. It allows calculating different system measures which could be a base for decisions related to administration of the transportation systems. The metric are calculated using Monte Carlo techniques [7]. No restriction on the system structure and on a kind of distribution is the main advantage of the method. Such approach allows forgetting about the classical reliability analysis based on Markov or Semi-Markov processes [2] – idealised and hard for reconciliation with practice. The results of the system observation – understand as the set of data collected during the simulation process are the basis to define the critical situations and they allow providing the probably proper solution to lift-up the systems in effective way if the critical situation occurs. This is the only sensible way, because the critical situations are the real and not removable part of the system life.

The organization of this chapter is as follows. We start with the description of the Polish Post regional centre of mail distribution (Section 2), which is a base for a developed by authors the discrete transportation system model (Section 3). In our opinion, it seems to be the most adequate to the level of detail to provide the well-established description of the critical situation (Section 4). The quality of the analysed system is measured by the availability defined as an ability to realize the transportation task at a required time (described in Section 5). Next (Section 6), we give an example of using presented model for the analysis of the Dolny Slask Polish Post regional transportation system in case of critical situation.

2. Real Sophisticated Transportation System – an Idea

The analysed transportation system is a simplified case of the Polish Post. The business service provided by the Polish Post is the delivery of mails. The system consists of a set of nodes placed in different geographical locations. Two kinds of nodes could be distinguished: central nodes (*CN*) and ordinary nodes (*ON*). There are bidirectional routes between nodes. Mails are distributed among ordinary nodes by trucks, whereas between central nodes by trucks, railway or by plain. The mail distribution could be understood by tracing the delivery of some mail from point *A* to point *B*. At first mail is transported to the nearest ordinary node *A*. Different mails are collected in ordinary nodes, packed in larger units called containers and then transported by trucks scheduled according to some time-table to the nearest central node. In central node containers are repacked and delivered to appropriate (according to delivery address of each mail) central node. In the Polish Post there are 14 central nodes and more than 300 ordinary nodes. There are more than one million postal items going through one central node within 24 hours. It gives a very large system to be modelled and simulated. Therefore, we have decided to model only a part of the Polish Post transportation system – one central node with a set of ordinary nodes.

Essential in any system's modelling and simulation is to define the level of details of the modelled system. It could be done if a kind of measures calculated by the simulator is known. Since the business service given by the post system the postal delivery is on time. Therefore, we propose to calculate the time of transporting mails by the system. Since the number of mails presented in the modelled system is very large and all mails are transported in larger amounts – containers, we have decided to use containers as the smallest observable element of the system. Therefore, the main observable value calculated by the simulator will be the transportation time of a container from the source to the destination node. The income of mails to the system, or rather containers of mails as it was discussed above, is modelled by a stochastic process. Each container has a source and destination address. The central node is the destination address for all containers generated in the ordinary nodes. Where containers addressed to any ordinary node are generated in the central node.

The generation of containers is described by some random process. In case of a central node, there are separate processes for each ordinary node. Whereas, for ordinary nodes there is one process, since commodities are transported from ordinary nodes to the central node or in the opposite direction. The containers are transported by vehicles, which require a driver to control it. Each vehicle has a given capacity – maximum number of containers it can haul. Central node is a base place for all vehicles. They start from the central node and the central node is the destination of their travel. The vehicle hauling a commodity is always fully loaded or taking the last part of the commodity if it is less than its capacity. Vehicles operate according to the time-table. The time-table consists of a set of routes (sequence of nodes starting and ending in the central node, times of leaving each node in the route and the recommended size of a vehicle). The number of used vehicles, number of drivers and the capacity of vehicles do not depend on temporary situation described by number of transportation tasks or by the task amount, for example.

It means that it is possible to realize the route by completely empty vehicle or the vehicle cannot load the available amount of commodity (the vehicle is too small). Time-table is a fixed element of the system in observable time horizon, but it is possible to use different time-tables for different seasons or months of the year. Summarizing, the movement of the containers in the system, a container is generated with destination address in some of node (source) at some random time. Next, the container waits in the node for a vehicle to be transported to the destination node. Each day a given time-table is realised, it means that at a time given by the time table a vehicle, selected from vehicles available in the central node, and driver selected form available drivers starts from the central node.

A vehicle is loaded with containers addressed to each ordinary node added to a given route. This is done in a proportional way. When a vehicle approaches the ordinary node it is waiting in an input queue if there is any other vehicle being loaded/unload at the same time. There is only one handling point in each ordinary node. The time of loading/unloading vehicle is described by a random distribution. The containers addressed to given node are unloaded and empty space in the vehicle is filled by containers addressed to a central node. Next, the vehicle waits till the time of leaving the node (set in the time-table) is left and starts its journey to the next node. The operation is repeated in each node on the route and, finally, the vehicle is approaching the central node when it is fully unloaded and after it is available for the next route.

The process of vehicle operation could be stopped at any moment due to a failure (described by a random process). After the failure, the vehicle waits for a maintenance crew (if there are no available due to repairing other vehicles), is being repaired (random time) and after it continues its journey. The vehicle hauling a commodity is always fully loaded or taking the last part of the commodity if it is less than its capacity.

3. System Model

We decided to formally model a part of the Polish Post transportation system, one regional section, which consists of one central node and a set of ordinary nodes.

A realization of the system service needs a defined set of technical resources. Moreover, the operating of vehicles transporting mails between system nodes is done according to some rules – some management system. Therefore, we can model discrete transportation system as a 4-tuple:

$$DTS = \langle Client, Driver, TI, MS \rangle, \tag{1}$$

where

Client – client model, *Driver* – driver model, *TI* – technical infrastructure, *MS* – management system.

3.1. Technical Infrastructure

The technical infrastructure of a discrete transport system is understood as a system of resources - vehicles, reloading machines, service men – and transport network utensils – roads with their traffic characteristics, terminal stations. The transport infrastructure of the discrete transport system can be presented as a directed graph. The terminal station is a node of the transport network system where the vehicles are uploading or unloading with goods caused by consumers' tasks. The station may be equipped with a storehouse - with limited capacity for example - and supported by reloading machine, cranes, fork-lift tracks etc. Roads can be modelled as directed arcs connected to nodes. Engineering parameters of the road are integrated and reflected into one representative measure of transport resource available at road segment. Of course such parameter – the average speed for instance – depends on cargo, transport means type, direction of traffic, day time or month time, etc.

The technical infrastructure is allocated by the management system *MS* for transportation tasks realization on the base of available road nets and functional services. Transport resources are described by their functional (e.g., load capacity of a truck), technical (e.g., fuels expendable per kilometer) and reliability parameters (e.g., mean time between failures or mean time renewal), which may have deterministic or probabilistic nature. Employees (e.g., drivers, workers, machine operators) create a specific class of the system resources.

The transportation task is understood as a pickup of a fixed cargo from the start node and a delivery of it to final node according to assumed time-table. Of course, the transportation task may be defined in more complicated way, e.g., a cargo may be collected in a few nodes and reloaded in several ones. Transport schedule can be defined in different ways, for example a cargo ought to be delivered to the node before the end of fixed time-period, because a train cannot wait for a truck with the cargo.

A transportation task is defined as a sequence of actions and jobs performed by a transportation system in a purpose to obtain desirable results in accordance with initially predefined time schedule.

The transport services are used for execution of user's (client's) tasks. The services are built based on the technical infrastructure and the technological services which are involved into transportation task realization process according to decisions of a management system. The task realization process may include many sequences of services, functions and operations which are using assignment network (system) resources. In the computer science this process of assignments and realization steps is called choreography and this term will be modified into transport choreography.

The management system *MS* organizes a work of the *DTS* system that means available system resources are assigned to executed tasks and maintenance policies are used to minimize system loses caused by some disturbances in the system operation. Dispatcher decisions are taken based on needs of assumed transportation tasks and according (if it is possible) to assumed proper time-tables. When some disruptions (failures, faults) occur the dispatcher chooses adequate system reactions.

The dispatcher is helped by computer tools that improve an allocation process of system resources to tasks of transport, creation time-tables of system traffic (planned and reserved for emergency conditions), and a design of maintenance policies prepared to use both for in normal and extraordinary situations of the transportation system work. The system dispatcher is supported by special computer tools and decisions of the dispatcher are made on the base of computer hints, dispatcher experiences and his management intelligence. It is possible to define many classes of dispatchers of the discrete transport system. A passive dispatcher realizes transportation tasks agree to previously defined conditions and schedules. The passive dispatcher uses earlier prepared lists of assumed *DTS* disruptions and lists of planned adequate system reactions in case of disruptions. A task oriented dispatcher is focused on execution of a selected task or a defined set of tasks and such strategies as *FIFO*, *LIFO*, *FILO,* etc., are applied. A dynamic dispatcher is monitoring on-line a system and takes decisions adequate to system situation; of course, the dynamic dispatcher cannot work as a fantastic virtuoso manager. If more detailed supporting data (collected from different components of the system) have been prepared a priori, then evaluated dependability properties (performance and reliability parameters) of the considered *DTS* system will be closer to reality.

3.2. Client's Model

The service realised by the clients of the transportation system are sending mails from some source node to some destination one. Client's model consists of a set of clients; each client is allocated in one of nodes of the transportation system. A client allocated in an ordinary node generates containers (since, we have decided to monitor containers not separate mails during simulation) according to the Poisson process with destination address set to ordinary nodes. In the central node, there is a set of clients, one for each ordinary node. Each client generates containers by a separate Poisson process and is described by intensity of container generation.

3.3. Driver's Model

The human infrastructure is composed by the set of drivers. So the description of this part of system infrastructure requires the analysis of the drivers' state and the algorithms, which model the rules of their work. Each driver could be in one of following states (s_d): rest (not at work), unavailable (illness, vacation, etc.), available (at work – ready to start driving), break (during driving), driving.

The number of driver working hours is limited by the labour law. For analysed Post Transportation System the daily limit for each driver equals to 8 hours and a single driver operates with one truck. It gives a simple algorithm:

if $w_h > limit$, then $state$ = "rest" & $w_h = 0$,

where
w_h – working hours, $limit$ = 8 hours.

Drivers in Polish Post work in two shifts, morning or afternoon one. So twice a day a driver's state and shift type is analysed:

- at 6am for each driver:
  - if $shift$ == morning & s_d == rest then s_d = available,
- at 1pm for each driver:
  - if $shift$ == afternoon & s_d == rest then s_d = available.

The next problem ought to be modelled is the driver's illness state. We propose the following approach:

- for every driver at 4 am:
  - if s_d == rest and $rand() < d_i$ then during x days (according to a given distribution) the driver is in s_d = unavailable,

where:
d_i – driver's illness parameter.

Moreover we propose to categorise the driver's illnesses as follows: short sick: 1 to 3 days, typical illness: 7 to 10 days, long-term illness: 10 to 300 days [21]. We prepare the daily record of the driver. The algorithm to fix the driver to the vehicle is the last part of the driver's model:

- if no driver – the vehicle does not start,
- driver can be chosen if: s_d = available
  and w_h + *estimated time of journey* < *limit* * 1.1,
- the driver is chosen randomly or by least value approach:
  abs(limit – w_h – *estimated time of journey*).

3.4. Management System

The decisions (send a truck to a given destination node) are taken in moments when a container arrives to the central node. The truck is sent to a trip if:

- the number of containers waiting in for delivery in the central node of the same destination address as that just arrived is larger than a given number,
- there is at least one available vehicle,
- the simulated time is between 6 am and 22 pm minus the average time of going to and returning from the destination node.

The truck is sent to a node defined by destination address of just arrived container. If there is more than one vehicle available in the central node, the vehicle with size that fits the best to the number of available containers is selected, i.e., the largest vehicle that could be fully loaded. If there are several trucks with the same capacity available the selection is done randomly. The restriction for the time of truck scheduling (the last point in the above algorithm) are set to model the fact that drivers are working on two 8 hours shifts.

4. Critical Situation Discussion

The dependability of the system can be defined as the ability to execute the functions (tasks, jobs) correctly, in the anticipated time, in the assumed work conditions, and in the presence of threats, technological resources failures, information resources and human faults (mainly malfunctions). Contemporary systems, such as transportation systems, are very often considered as networks of services. The system's dependability can be described by such attributes as availability (readiness for correct service), reliability (continuity of correct service), safety (absence of catastrophic consequences on the users and the environment), security (availability of the system only for authorized users), confidentiality (absence of unauthorized disclosure of information), integrity (absence of improper system state alterations) and maintainability (ability to undergo repairs and modifications). The system realises some tasks and it is assumed that the main system goal, taken into consideration during design and operation, is to fulfil the user's requirements. The system's functionalities (services) and the technical resources are engaged for task realisation. Each task needs a fixed list of services, which are processed based on the system's technological infrastructure. The different services may be realised using the same technical resources and the same services may be realised involving different sets of the technical resources. It is easy to understand that the different values of performance and reliability parameters should be taken into account. The final statement is essential when tasks are realised in the real system surrounded by unfriendly environment that may be a source of threats and even intentional attacks. Moreover, the real systems are built on the base of unreliable technical infrastructures and components. The modern systems are equipped with suitable measures and probes, which minimise the negative effects of these inefficiencies (a check-diagnostic complex, fault recovery, information renewal, time and hardware redundancy, reconfiguration or graceful degradation, restart, etc).

The special service resources (service persons, different redundancy devices, etc.) supported by maintenance policies (procedures of the service resources using in purpose to minimise negative consequences of faults that are prepared before or created ad hoc by the system manager) are build in every real system [3, 12, 13, 16]. The maintenance policy is based on two main concepts: detection of unfriendly events and system responses (system reactions) to them.

In general, the system responses incorporate the following procedures:

- detection and identification of incidents,
- isolation of damaged resources in order to limit proliferation of incident consequences,
- renewal of damaged processes and resources.

Different events of discrete transportation system operations are considered:

- "normal" functional events described by such time parameters as the start or / and the end of the task, a moment of a system resources allocation, a time of occurrence of a new task, an (prognoses or real) task execution time, etc.,
- unfriendly incidents that are disturbed efficient system execution; for example failures of transport means, accidents on roads, delay time of reloading cars, faults of workers or the system dispatcher, etc.

It is easy to notice that the first class of system events is strictly connected with correct system task realization and the second one groups all events disrupting the efficient operation of the system and which may start the system defense reactions. In this way the first class of events will be called "efficient functional events" and the second one "dependable incidents" or "unfriendly events". The dependable incident is an event that might lead to some disruptions in the system behavior. The incident may cause some damage to the system resources; transport means (hardware), management actions, employees or information and, in consequence, it may disrupt the executed transportation processes. If a fault appears during the task execution then the system on the base of decision of its management system (its dispatcher) starts renewal processes. Time of technological renewal activities are added to the nominal time of the task so a real time of the task duration will be longer. The real duration time of the executed tasks depends on the nature of the system faults. Failures of hardware may need both renewals of technological resources and information resources. Consequences of human errors or computer software faults are limited to renewals of information processes. Sometimes an incident – road accident or a series of truck failures which are occurred in a short time interval – may have a more serious impact on the system behavior; it may escalate to a security incident, a crisis or a catastrophe. The failures of the transport resources – physical failures of vehicles or roads or reloading devices need to use adequate such the DTS means as service teams, garages, spare elements or substituted routes. Very often "technical" system renewal processes are considered with assuming of the limited resources, for example, one service team for five vehicles.

Other sources of the DTS disruptions we can find in organization and management:

- overloading of the technical infrastructure: roads, reloading machines, etc.,
- traffic accidents or jams - considered as human errors,
- dispatcher faults – he or she is not able to keep up the dynamic changes of the situation in the working DTS system.

In these cases exploitation system renewal processes are initiated by the system dispatcher. The processes very often consume more time and money than a renewal of a "simple (physical)" broken technical resource, e.g., a repair of a failed truck or a lift. Of course, the correctly tuned system ought to be characterised by the set of fault tolerant features. It means – the system is able to realise the loaded tasks even if the different faults occur because of reliability or functional insufficiencies. The problem pointed above needs a multi-criteria solution. In other words, it is possible to find a kind of Pareto set (Fig. 1) to guarantee the system as functional ready for the defined tasks. The critical situation occurs if actual operating point of the system is located outside of the Pareto set. The main goal if the critical situation is noticed is to drive the system to the Pareto set as soon as possible. The proper management reaction is the first option to rescue the system's situation.

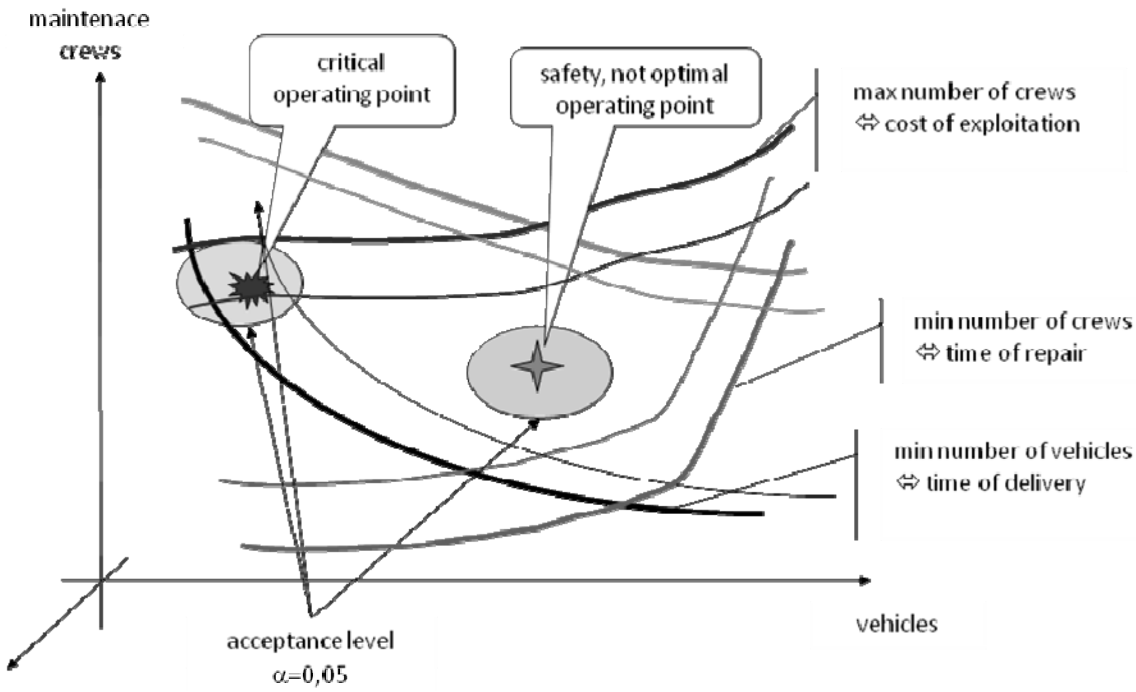

Figure 1. General idea of the Pareto set

5. Availability Measure

One can define the system's availability in different ways, but always the value of availability can be easily transformed into economic or functional parameters perfectly understood by owner of the system. The availability is mostly understood as a probability that a system is up and is defined as a ratio of the expected value of the uptime of a system to the observation time. It is a simple definition still it requires defining what does it mean that transportation system is working.

In paper [20] we have proposed the definition of up time as a time when the number of delayed containers does not exceed a given threshold. Let introduce the following notation:

- T – a time measured from the moment when the container was introduced to the system to the moment when the container was transferred to the destination (random value).
- T_g – a guaranteed time of delivery, if exceeded the container is delayed.
- $N_{delayed}$ (t) – a stochastic process describing the number of delayed containers at time t, i.e., the number of containers for which $T > T_g$.

Therefore, the functional availability $A_k(t)$ can be defined as a probability that the number of delayed containers at time t does not exceed k, the value k is the level of acceptable delay:

$$FA_k(t) = \Pr\{N_{deleyed}(t) \leq k\}. \tag{2}$$

Next, we want to analyse the system's performance against the risk of periodic shortage of drivers and/or trucks or enlarge in number of containers to be transported. The system is forced to a state of reduced operability for a fixed period of time.

For the purpose of such analysis we have to redefine system's availability defined by (2). Let's consider a 24 hour time period for determining the availability. Then, the sequence of time instances (τ_0, τ_1, … , τ_n) will fix the boundaries of the consecutive days, for which the metric is assessed. $N_d(\tau_i, \tau_{i+1})$ denotes the number of containers delivered in the period (τ_i, τ_{i+1}). $N_{pd}(\tau_i, \tau_{i+1})$ denotes the number of delivered containers on time. Therefore, the system's availability could be measured by an average ratio of on-time deliveries, defined as:

$$A_r(\tau_i) = E\left(\frac{N_{pd}(\tau_{i-1}, \tau_i)}{N_d(\tau_{i-1}, \tau_i) + 1}\right), \tag{3}$$

where E denotes the average value (and is determined from the simulator results by evaluating the mean value of multiple runs).

The denominator includes +1 modification to prevent the ratio to go to infinity in case of a full stoppage of the system (i.e., no containers delivered in the analysed period).

6. Critical Situation Analysis

6.1. Exemplar System

We propose for the case study analysis an exemplar *DTS* based on Polish Post regional centre in Wroclaw. We have modelled a system consisting of one central node (Wroclaw regional centre) and twenty two other nodes – cities where there are local post distribution points in Dolny Slask Province. The length of roads was set according to real road distances between cities used in the analyzed case study. The intensity of generation of containers for all destinations was set to 4.16 per hour in each direction giving in average 4400 containers to be transported each day. The vehicles speed was modelled by Gaussian distribution with 50 km/h of mean value and 5 km/h of standard deviation. The average loading time was equal to 5 minutes. There were two types of vehicles: with capacity of 10 and 15 containers. The MTF of each vehicle was set to 20000. The average repair time was set to 5h (Gaussian distribution). We also have tried to model the driver's availability parameters. We have fulfilled this challenge by using the following probability of a given type of sickness – short sick: 0.003, typical illness: 0.001, long-term illness: 0.00025.

6.2. Critical Situation Feedback

As it has been mentioned in the Chapter 4 the system is designed to work at a given level of availability by including some redundancy to system resources (mainly trucks and drivers). It results in situation that at night (when the system is non-operational due to the free time for drivers) there are almost no delayed containers. However in case of unpredictable and rare situations like shortage of drivers (for example, due to some contagious diseases or a strike) or short enlarge in a number of containers to be transported, number of delayed containers starts to cumulate in the system. In other words, the system is not able to transport all containers.

The only solution to such critical situation is to enlarge system resources, i.e., hire more drivers and trucks for a short time. The question is how many additional resources should be added to the system to eliminate the critical situation and for how long time. The consequences of the critical situation are said to be eliminated when the daily ratio of on-time deliveries reaches a predefined level α (say 0.995).

The designed by authors simulator of DTS [17, 20] allows us to help in taking some management decisions.

The Figure 2 presents the system's availability (average ratio of on-time deliveries) after three days of operation for various numbers of vehicles and drivers and containers delayed in the system.

The system manager knowing the number of delayed containers presented in the system selects one of presented figures from Figure 2, next he selects the number of vehicles and drivers that allow eliminating the critical situation after three days (by selecting points for which the availability is larger than the predefined level).

Knowing the actual number of drivers and trucks she/he could estimate the number of resources to be additionally hired. If longer time for eliminating the critical situations is allowed – 7 days, for example, – the manager could use simulation results presented on Figure 3.

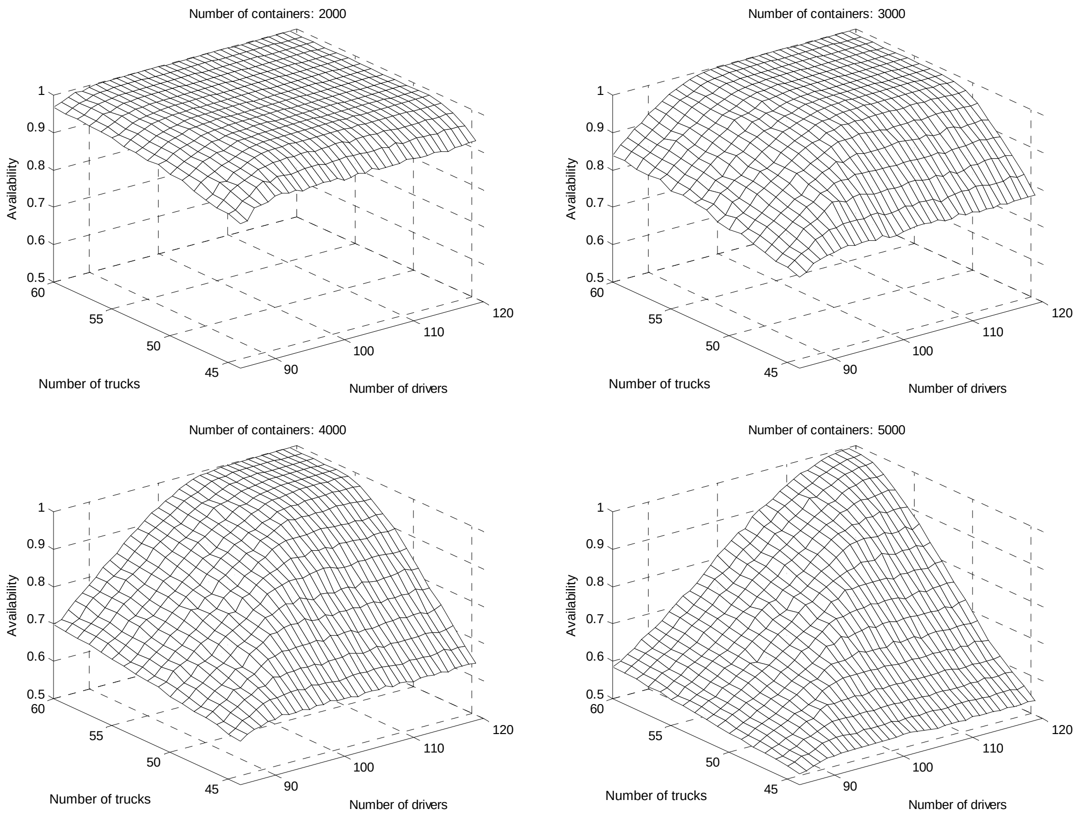

Figure 2. The system's availability (average ratio of on-time deliveries) for various numbers of vehicles and drivers and containers after three days of operation

7. Conclusions

We have presented a formal model of discrete transportation system (*DTS*) including reliability, functional parameters as well as the human factor component. The *DTS* model is based on Polish Post regional transportation system and reflects all key elements of it with the set of the most important functional and reliability features of them. The critical situation is pointed out and described at the necessary level of details for the further analysis. The proposed availability metric is the source to create the Pareto set – guarantying the possible safety operating points for actual *DTS*.

The realised analysis based on the real data – taken from the Polish Post transportation system at Wroclaw area – allowed testing the effectiveness of the system management when the critical situation occurs. We introduced the exemplar *DTS* into critical situation to discuss how deep breakdown it has caused and to test, which management approach can drive the system operating point into Pareto set as soon as possible. The proposed approach allows performing deeper reliability and functional analysis of the *DTS*, for example:

- to determine what will cause a ”local” change in the system,
- to make experiments in case of increasing number of containers per day incoming to system,
- to identify weak point of the system by comparing few its configuration,
- to better understand how the system behaves in ordinary and critical situations.

The solution presented can be used as practical tool for defining an organization of vehicle maintenance and transportation system’s logistics.

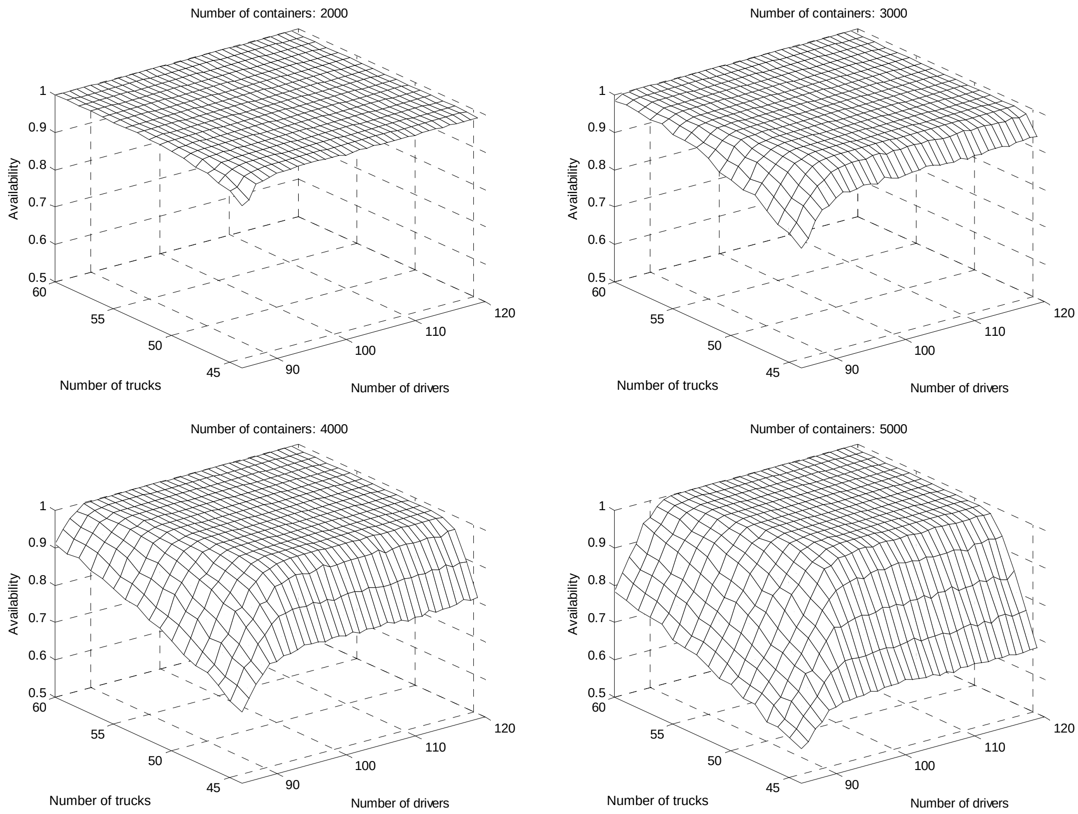

Figure 3. The system’s availability (average ratio of on-time deliveries) for various numbers of vehicles and drivers and containers after seven days of operation

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RELOCATION OF RESOURCES IN A HIERARCHICALLY MANAGED TRANSPORTATION SYSTEM UNDER CRITICAL CONDITIONS

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Critical state of operation is reached by a system when it is exposed to an unexpected coincidence of faults (such as periodic rapid increase of the service demand, unavailability of a significant proportion of vehicle operators, simultaneous breakdown of all or a large part of the vehicle fleet). This leads to complete disruption of the transportation system, which persists even after the faults are removed. The duration of critical state of operation is defined as the time needed to resume normal operation after such an incident. It is shown that this time can be predicted using the simulation tools. Furthermore, a contingency plan is proposed, based on relocation of some resources between independent parts of a hierarchically organized transportation system. This contingency plan is analysed to determine the optimal percentage of resources to be relocated and the duration of this relocation.

Keywords: discrete transportation, reliability analysis, simulation tools, risk management

1. Introduction

When designing a discrete transport system, it is essential to take into account the possible faults that may occur during its operation. The dependability (reliability) analysis of such systems lets us determine the level of redundancy that ensures continuity of service at an economically justified level of assurance. There are a lot of techniques that support this type of analysis [1, 3, 9, 10].

Dependability analysis ensures that all the faults are considered proportionately to the probability of their occurrence. Thus, the analysis tends to underemphasize the events that are very improbable, such as the simultaneous breakdowns of all or almost all system components. Such situations are addressed by the techniques of risk analysis, which consider the probability of risk occurrence and their effects [2, 4, 5, 6, 8]. The paper analyses these situations, specifically as applied to the discrete transportation.

It should be noted that it is rarely justifiable to try to prevent these improbable faults by increasing redundancy of the transport resources – it would be a gross waste of those resources. Instead, an important aspect of the risk management is to propose contingency plans in case such an unlikely event occurs. The effects of the event may persist for a long time after its passing, if the system is left without an intervention. The system is said to operate under critical conditions when it is exposed to such an event and while its effect still persists.

It is proposed to demote this problem, by temporarily relocating some of the transport resources from an unaffected part of the system. Thus, the time of critical operation is reduced at the cost of increasing its extent. It is clearly an important aspect of contingency planning to predict the consequences of the critical state of operation in case of the alternate management plans. This is addressed by using the simulation tools developed for the dependability analysis, slightly modified to deal with the critical conditions.

2. Model of the Transport System

We consider a class of discrete transport systems (DTS) organized hierarchically, i.e. having a number of independently run regional distribution centres (RDC) and a central system interconnecting them. The model is inspired by the organization of the Polish Postal Service, though it is in no way limited to it [3, 9]. The basic assumptions are as follows:

- the distribution of cargo is realized in discrete quantities (containers carried by vehicles),
- each regional centre is completely independent of the others, having its own fleet of vehicles, its own human resources (vehicle drivers) and organization,
- the flow of cargo, to be distributed, cannot be regulated: the distribution centre has to accept all the incoming volume of cargo, regardless its current capabilities to handle it.

In the presented model we concentrate on the operation of a single RDC, a limited segment of the system typically used to distribute goods locally. The system consists of nodes (locations from which goods are collected and to which they are carried) and vehicles travelling between the nodes. The vehicles are manned by the human drivers, who may be allocated to different vehicles. The RDC is modelled as a collection of:

- the set of nodes X, in which a central node $x_0 \in X$ is distinguished (the local distribution centre),
- the set of routes between the nodes R,
- the set of vehicles V,
- the set of assignments Z, which determines the volume of cargo to be transported,
- the set of travel timetables C,
- the set of vehicle operators (drivers) K, assigned to vehicles when they transport goods between the nodes,
- the set of maintenance teams (mechanics) M that are required to service the vehicles after a break down.

2.1. Transportation assignments

The assignments are connected with specific needs for cargo transportation. The amount of goods in an assignment is expressed as a discrete number of standard containers. The assignments specify the source node from which the cargo is collected and the destination node it is carried to. The assignments are always either from the central node or to the central node. Assignments between other nodes are not allowed.

There is a fixed time in which each assignment must be completed. Depending on the nature of the DTS system, this time is fixed by local regulations or is part of the service agreement between the assignees and the transport service provider.

2.2. Nodes

There is a single central node and a number of local ones. The central node generates cargo destined to all the local nodes. It represents the connecting gateway to the other regional distribution centres. The assignments are generated independently in each node, using random distributions. Each local node has an attribute which determines its characteristic rate of assignments generation. The central node is described by an array of rates, one for assignments to each local node.

2.3. Vehicles

It is assumed that the vehicles are described with similar functional and reliability related parameters: capacity (expressed as the number of cargo containers it can carry), average cruising speed (determining the route latency), failure rate, renewal time. All the vehicles are based in the central node and travel from it to realize the assignments.

At any moment in time, each vehicle may be in one of the following states: it might be en route between nodes (a specific distance from the starting node, carrying specified amount of goods), it might be out of gear due to a failure, it might be waiting for cargo to be loaded, it might be stopped due to unavailability of a driver or due to regulatory rest period of its driver.

A vehicle may be realizing multiple assignments at the same time. It will be fully loaded if the pending assignments allow it. If there are insufficient assignments for nodes towards which the vehicle is destined, then it may be partially loaded or even travelling empty. It will collect goods en route if there are pending assignments in the visited nodes.

The vehicles are assumed to break down occasionally, in accordance to their reliability parameters (failure rates). They stop operation and wait for a maintenance team. On being repaired (after a random repair time), the vehicles continue the task they were realizing before breakdown. No transloading of the cargo is considered.

2.4. Vehicle operators

The number of operators is limited. Whenever a vehicle is assigned to a task (due to a timetable) an operator must also be associated with it. Any unallocated driver can be associated with any vehicle. Only one driver at a time is associated with a vehicle (since we do not consider long distance routes with standby drivers).

The work of vehicle operators is regulated by local and EU legislature. The daily working hours are limited (to 8 hours); there are also compulsory rest breaks while driving. Thus, at any time the driver can be in one of the following states:

- resting (not at work),
- unavailable (due to illness, vacation, etc.),
- available (at work – ready to start driving),
- pausing (having a break while driving),
- driving.

It is assumed that the vehicle operators work in 8 hour shifts. Thus, the state of each one changes to "resting" whenever his daily working time limit is exceeded and he arrives in the central node. He stays in this state until the beginning of his shift next day. Then, his state changes to available. If there is a pending driving schedule (timetable) and an available vehicle, then his state changes to "driving".

While driving, the driver has to heed the limits on the maximum length of time that he can work without a break. Normally, the timetables assure that the required breaks are fulfilled while the vehicle is loaded in the visited nodes. If a route is unnaturally long or there are travel delays on the way, then the driver is required to take a break en route. The parameters determining the daily working hours limit, maximum uninterrupted driving period, minimum break duration are associated with the vehicle operators' model.

Drivers are liable to sickness and other events that can make them temporarily unavailable. After a prescribed leave of absence they again become available at work. Driver illness is modelled as a stochastic process. The process is fairly complicated to reflect the typical periods of illness. Details of such a model are discussed in [8].

The allocation of drivers to the jobs (described by the timetables in the model) is governed by some simple rules:

- vehicles cannot carry goods between nodes if there is no operator available,
- the driver is chosen from among those, whose daily working time limit allows them to complete the job with at most 10% overtime (i.e. estimated journey time is less than 110% of the left work time limit).

2.5. Routes

Routes represent the direct connections between nodes of the system. They are characterized by the distance that the vehicles must travel. Taking into account the average travelling speed of vehicles, this determines the latency connected with moving from one node to another. This latency is further distorted by the travel delays, which represent the natural variation of latency, e.g. caused by the traffic congestion. These delays are modelled using a random distribution.

2.6. Timetables

Vehicles are travelling in accordance to fixed timetables (travel schedules). Each timetable determines the time to leave the central node and a sequence of nodes that must be visited by the vehicle as well as the times of these visits. It describes the daily work of the vehicle associated with the timetable, independent of the actual needs as determined by the assignments.

The set of timetables does not change in the analysed time horizon. It can be changed (reconfigured) at predetermined times such as different seasons of the year, holiday times, weekends. The schedule starts at the central node, on reaching each consecutive node in the timetable, the goods destined to it are unloaded and the goods waiting there are loaded in their place. The time used for unloading and loading is randomly chosen. If there are other vehicles in the node, then they are queued and the period of loading/unloading is extended commensurately. The timetable does not specify the time to leave a node (except the timetable start time).

When the vehicle returns to the central node (at the end of a schedule) it is completely unloaded. It can then be associated with another timetable or it may be placed in the pool of available vehicles, waiting to be associated with a job.

The timetables are not directly associated with vehicles or drivers. Instead, any available vehicle and operator is allocated to each schedule. If there are no vehicles or drivers available, then the timetable cannot be realized. The system model does not openly include an intelligent (human) decision centre or dispatcher. This is hidden in the implementation of the travel timetables.

2.7. Maintenance teams

The model does not distinguish any specific parameters of the maintenance teams, just their number. If a vehicle breaks down, it will be repaired by one of the maintenance teams. The distribution of the repair time is associated with the vehicle, not with the team. Each maintenance team repairs only one vehicle at a time. If all the maintenance teams are currently occupied, then the vehicle repair is delayed until one of the teams becomes available.

3. Critical State of Operation

The transport system is designed to cope with the normal load of work, under usual conditions of operation. In fact, it incorporates an economically justifiable level of redundancy that ensures uninterrupted operation in case of the expected incidents (driver absentees, vehicle break-downs, traffic delays) or normal fluctuations in the workload. The proposed model can be used to determine this level of redundancy, as discussed in [8, 9].

Critical state of operation occurs when the system is faced with an unpredictable coincidence of incidents that it is not designed to cope with. As such, critical state of operation is very unlikely and it is not economically viable to safeguard against it by having redundant resources. To investigate this state in more detail, it is necessary to introduce some measure of the "normality" of system operation. It is proposed to use for this purpose the ratio of on-time deliveries.

3.1. Ratio of on-time deliveries

The quality of service realized by the transport system is characterized by its ability to deliver all the cargo assignments on time. Each assignment has a guaranteed time of delivery T_g. The real time of delivery T is a random variable, which depends on the current volume of cargo, travel latency, faults of the vehicles, driver's sickness, etc. There are two possible relations between the delivery deadline T_g and the actual assignment realization T:

- If the assignment is completed before the deadline, i.e. $T \le T_g$, there is no penalized delay. There is no reward for the early delivery, though.
- If the assignment is completed after its deadline, $T > T_g$, then there is a late delivery penalty incurred.

The short term measure of the quality of service is obtained by counting the assignments that are delivered on time (before the deadline). If the system is operational, it should realize all the assignments on time. On the other hand, a completely failed system does not realize assignments at all, causing them all to be delivered late. Thus, in a traditional system with up/down states only, the average ratio of on-time deliveries is equivalent to the system availability. In the considered analysis, the measure is not so easy to interpret, since the system hardly ever fails completely. Instead, if an incident occurs, some of the assignments are realized late.

The ratio of on-time deliveries A_r is defined as the proportion of assignments that are delivered on time to the total number of assignments in the system during a fixed time period. Of course, this measure is a random variable that reflects the nondeterministic properties of the whole system. We consider a 24 hour time period for determining the average ratio of on-time deliveries.

The sequence of time instances (t_0, t_1, … , t_n) fixes the boundaries of the consecutive days, for which the ratio is considered. $N_d(t_i, t_{i+1})$ denotes the number of assignments completed in (t_i, t_{i+1}). $N_{pd}(t_i, t_{i+1})$ denotes the number of those assignments, which are completed on time. There are also assignments, which enter the system in one period and are completed in the next. $N_{in}(t_i)$ denotes all assignments en route at time t_i. Correspondingly, $N_{pin}(t_i)$ denotes a part of these assignments, which are not yet late in delivery at time t_i (though they may become late during the next period). Average ratio of on-time deliveries is defined as:

$$A_r(t_i) = E\left(\frac{N_{pd}(t_{i-1}, t_i) + N_{pin}(t_i)}{N_d(t_{i-1}, t_i) + N_{in}(t_i)} \right), \tag{1}$$

where E denotes the mean value of the measure.

The ratio is used to characterize the reliability of the regional distribution centres (RDC). One has to set an acceptable level of the coefficient (e.g. 80%, 90% or 99%). By providing a sufficient level of redundancy (in the number of vehicles and drivers), the system can be designed to fulfil the requirements (ensure fault tolerance) in normal circumstances.

It is assumed that each RDC is characterised by its specific ratio of late deliveries. There is no global measure applied to the system as a whole. Each regional centre is independently assessed. The quality of system performance is a vector of the coefficients of late deliveries of the various centres.

Global measure can be defined on this vector, but this is not desirable as the penalties are local.

3.2. Condition for critical state of operation

The system is considered to operate in the critical state if the ratio of on time deliveries is significantly below an acceptable level for a number of consecutive days k_{crit}. This corresponds to the condition that the ratio is smaller than a set level A_{crit} in this period, i.e.

$$A_r(t_i) < A_{crit} \text{ for } \quad j = i, i+1, \ldots, i+k_{crit} . \tag{2}$$

A very important criterion of the system operation in critical state is its ability to regain normal operation. This is measured by the duration of the critical state of operation T_{crit}.

3.3. Operational risks leading to the critical state

The critical state of operation should never be attained in normal circumstances. Its probability is negligibly small in a properly designed system. This does not mean that it is impossible. There are a number of situations that may lead to this state of operation, all unrelated to the presented model. While they are improbable, there has to be a contingency planning to deal with them (in case they do occur). Some of these circumstances are discussed hereafter to support the need of such planning.

Periodic rapid increase of the service demand

This situation occurs naturally due to the seasonal changes in service demand. It manifests itself by much higher rates of assignments arriving in all the nodes. This is handled by the routine design of the transport system (periodic changes in the amount of available resources). More to the point, this risk may be connected with failures of other, competitive transport systems operating in the same region. In effect there is a sudden influx in service demand, swamping the system with assignments that it cannot handle. In consequence, the RDC cannot handle all the cargo and there is an accumulated backlog of assignments keeping the system in critical state.

Unforeseeable unavailability of a significant proportion of drivers

This can be caused by a strike of a part of the drivers. Else, it can be a consequence of an epidemic illness, such as flu or other virus infection. As a result, a significant proportion of the drivers may be simultaneously absent from work. Some of the travel schedules cannot be realized, building a backlog of unsettled or late assignments.

Unforeseeable reduction in the number of available vehicles

This is usually connected with disrupted supply chains, resulting in shortage of fuel or vehicle replacement parts. As a result, a significant part of the vehicles cannot be kept operational (as if they all failed simultaneously). The risk analysis is very similar to the previous situation.

4. Prediction of the System State Using Simulation

The normal state of operation of a regional distribution centre (RDC) is described by the model discussed in Section 2. The model can be analysed by a number of approaches, such as state-transition or fault tree analysis. Due to its complexity and large number of non-homogenous components, the most practical approach is based on Monte Carlo simulation [3]. In this approach, it is not necessary to enumerate all the system states (functional and reliability related), which significantly simplifies computations.

The analysis is performed using a simulator, custom designed for this purpose at Wroclaw University of Technology. It is based on the publicly available SSF simulation engine that provides all the required simulation primitives and frameworks, as well as a convenient modelling language DML [7] for inputting all the system model parameters. DML is a dedicated language used by the SSF simulation framework that supports a hierarchically structured representation of simulation model parameters. It is simple to use and more convenient than the GUI based interfaces of commercial simulators.

By repeating the simulator runs multiple times using the same model parameters, we obtain several independent realizations of the same process (the results differ, since the model is not deterministic). These are used to build the probabilistic distribution of the results, especially the average measures. For the purpose of the presented considerations, the simulator can be used to predict the ratio of on time deliveries.

This approach is obviously insufficient to analyse the critical states of operation. The simulator cannot reach such a state during normal simulation runs (due to its very low probability of occurrence). Thus, the simulator was modified to enable this analysis. The occurrence of risks mentioned in Section 3.3 can be predetermined manually in the simulator. Then, the simulator can be used to predict their effects on the rate of on-time deliveries. The system is analysed against its ability to resume normal operation after a disruption of service. This is measured by the period of time that the system remains in the critical state of operation. The time can be significantly longer than the actual duration of disruption. Moreover, the duration of the critical operation can be limited by some management decisions, as discussed in Section 5. The effect of these decisions can also be predicted by the modified simulator analysis.

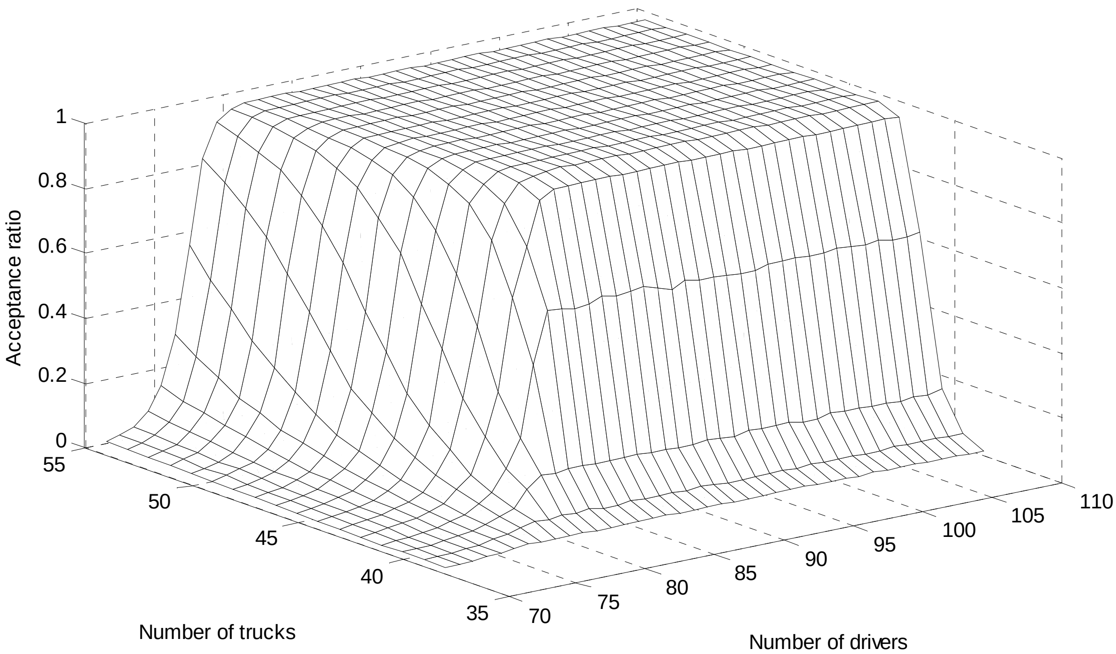

Figure 1. The average ratio of on-time deliveries for various numbers of vehicles and drivers

4.1. Case study

All the simulation results are based on the observation of the organization of the Polish postal service, specifically its Lower Silesian regional mail distribution centre. It consists of the central node located in Wroclaw and 22 local nodes located in main towns of the region. The distances between nodes, used in the simulation runs, were determined from a road map of Poland. The stream of assignments (generation of cargo) is assumed the same for all the destinations. It is modelled as a Poisson stream with the rate set to 4.16 per hour in each direction. On average this corresponds to 4400 containers to be transported every day.

The system is serviced by a number of vehicles, designed to fulfil the transportation demand with some redundancy. All the vehicles can each carry 10 containers at a time. The velocity of vehicles is modelled by the Gaussian distribution with the mean value of 50 km/h and standard deviation of 5 km/h. The average loading time is equal to 5 minutes. The mean time to failure of each vehicle is assumed as 20,000 hours. The average repair time is 5 hours (Gaussian distribution).

The vehicles are operated by drivers working in 2 shifts (morning: 6 a.m. till 2 p.m., afternoon: from 1 p.m. until 9 p.m.). The number of drivers is designed to fulfil the transportation requirements. The rates of drivers' disabilities are observed to be as follows:

- short sickness: 0.003,
- typical illness: 0.001,
- longer disability: 0.00025.

The system works with fixed timetables. These are organized so that the vehicles and drivers have a grace time of 20 minutes after completing one journey, before starting on the next one.

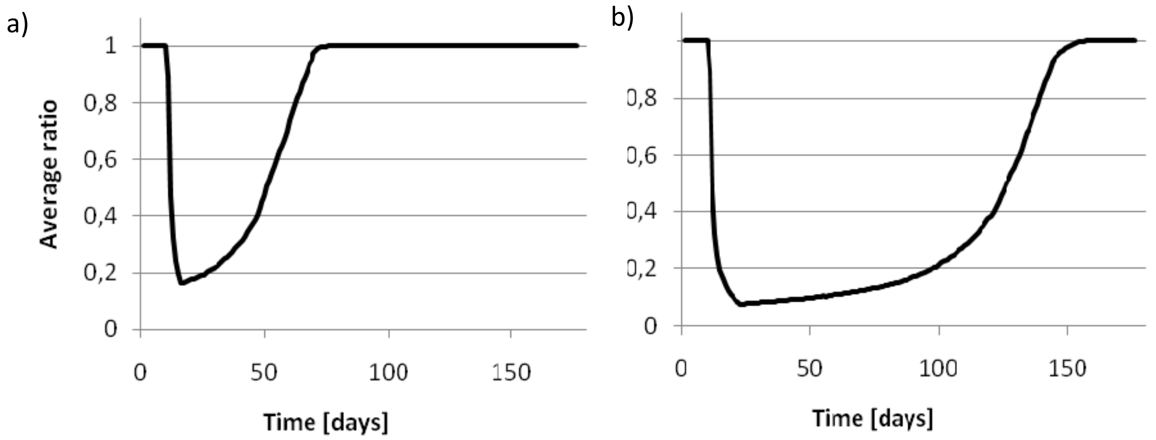

Figure 2. Daily average ratio of on-time deliveries: (a) with stoppage from day 10 until 15; (b) with stoppage from day 10 until 22

The numbers of vehicles and drivers are established on the basis of simulation in the normal state of operation. Figure 1 presents the results of this analysis – how the ratio of on-time deliveries varies depending on the number of vehicles and drivers provided in the system. The steep drop in the ratio corresponds to situations when the resources are too scarce to provide the required service. In this case, these numbers were fixed as 45 vehicles and 90 drivers. This assures that the total volume of cargo, that can be transported daily, exceeds the average demand by 15% (overall). This is accepted as a reasonable level of redundancy in the discussed system.

4.2. System analysis in critical state of operation

The system is analysed against the risks of periodic stoppage of service and of unforeseeable unavailability of a significant proportion of drivers. In each case the system is forced to a state of inoperability or reduced operability for a fixed period of time. This is illustrated on Figure 2, which presents the changes of the daily average ratio of on-time deliveries during the disruption and after resuming operation. On Figure 2a the system is being stopped for 5 days (on the 10th day). It should be noted that the measure does not drop to 0, even though the system is completely stopped. This is a consequence of counting undelivered goods that are not yet outdated at the end of each day as being on time (see Equation 1).

The critical state of operation is eliminated when the daily ratio of on-time deliveries reaches the predefined level A_{crit}. If this level is set at 0.99, then the duration of critical operation is assessed as 70

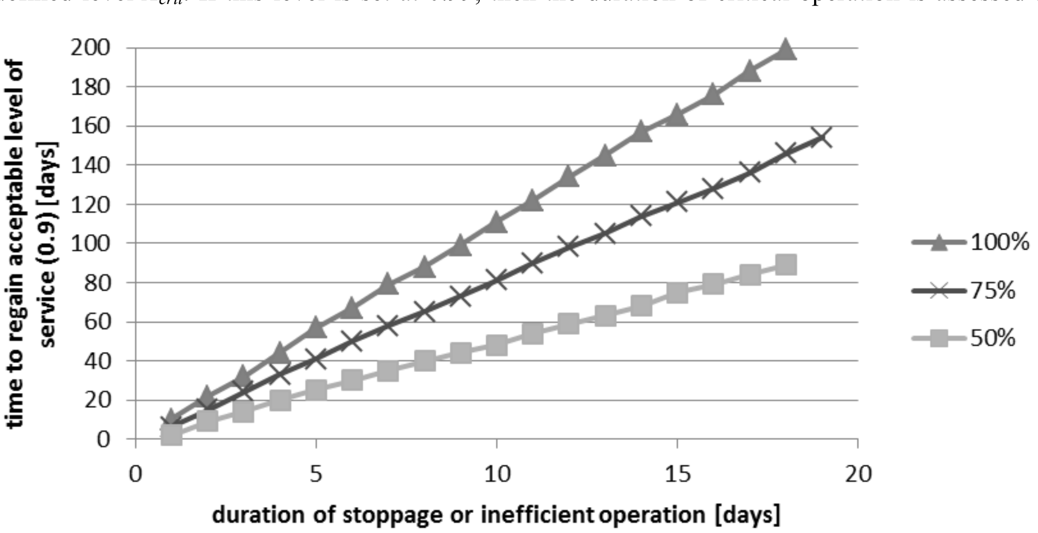

Figure 3. The duration of critical state of operation after a disruption caused by system stoppage (100% inoperability) or reduced efficiency (of 75% and 50%)

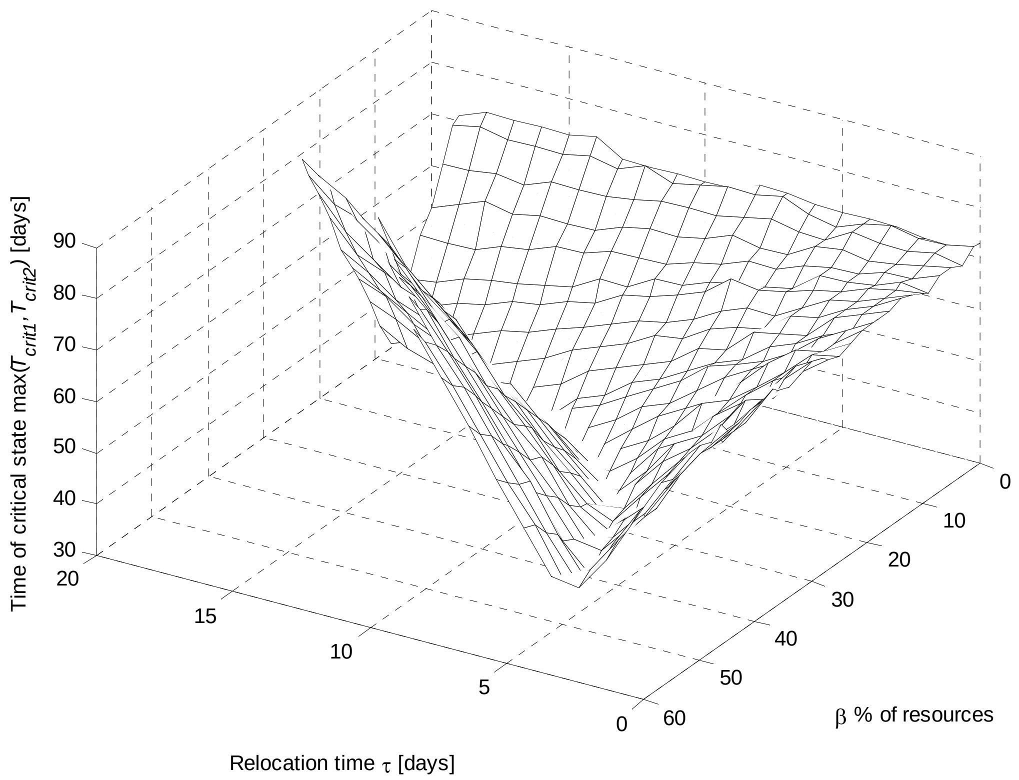

Figure 4. Time of critical state of operation max(T_{crit1}, T_{crit2}) of the two RDC's after temporary relocation of β % of resources between them (following 5 days of stoppage in one RDC)

days. Figure 2b presents a very similar analysis, but the period of system stoppage is 12 days. Then, the time required to regain normal operation is over 150 days.

Figure 3 presents the summarized results of multiple simulation runs, determining the duration of critical state of operation, assuming varied times of system disruption and the proportion of crew that is affected (100% corresponds to system stoppage). It should be noted that in the considered (reasonable) range of values the relation is almost linear, which can facilitate simplified analysis.

5. Assessment of Management Decisions

The situations identified in Section 4 require contingency planning, i.e. the system management should have some procedures for dealing with them if they occur. It is unacceptable to wait for the system to resume normal operation on its own – it simply takes too long! There has to be a procedure to acquire temporarily additional resources (drivers and vehicles) to speed up system recovery. In case of the considered hierarchically organized system, this can be achieved by displacement of some resources from one regional distribution centre to another. This is the type of management decisions that are being assessed in the paper. All the presented considerations assume that there are only two subsystems, i.e. the resource relocation affects only one subsystem that was exposed to the critical conditions and another, from which some resources may be relocated. This is done only for the sake of simplicity. The results can easily be generalized to include a number of sound subsystems that can donate resources to the affected one.

5.1. Management decisions and their consequences

The management decision, when reducing the consequences of critical operation, concerns the choice of:

- the time when the additional resources should be relocated from one regional centre to another; it is assumed that this intervention start immediately after normal operation is resumed after a stoppage or unavailability of the drivers; and it continues for τ days;

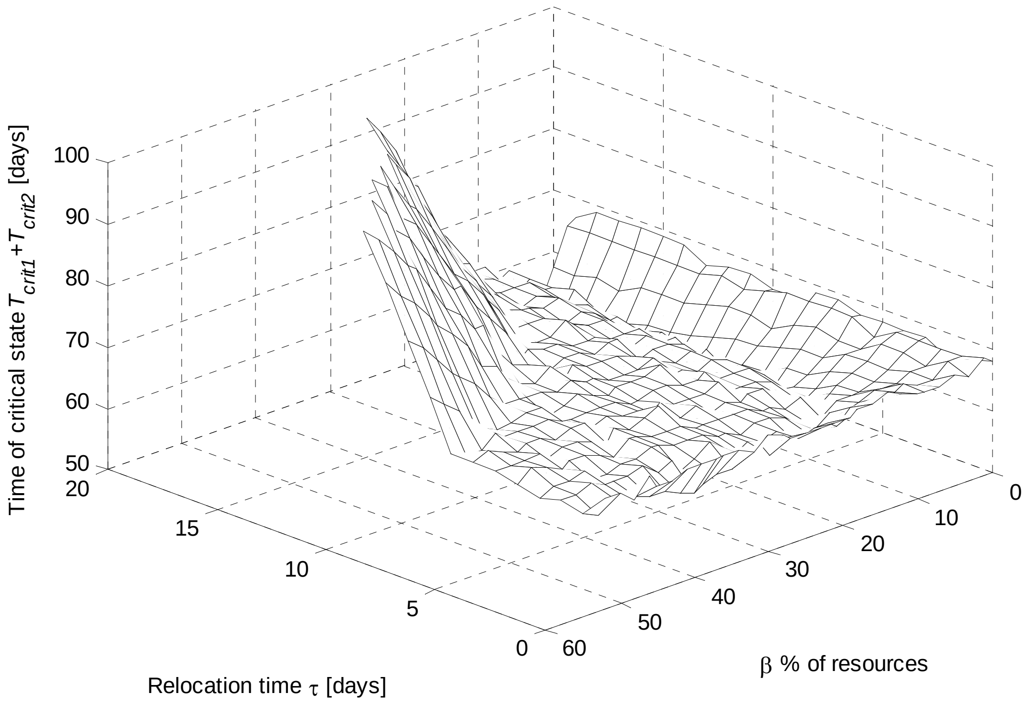

Figure 5. Time of critical state of operation T_{crit1} + T_{crit2} of the two RDC's after temporary relocation of β % of resources between them (following 5 days of stoppage in one RDC)

- the number of drivers and vehicles that are relocated; this is expressed as a percentage β of the total number of drivers and vehicles allocated to a regional distribution centre.

Clearly, the greater and longer the intervention, the shorter is the critical state of operation. But, just as obviously the disruption in the other centres, from which the resources were relocated, is greater.

5.2. Assessment results

The various management strategies are characterized by the values of (β, τ). The system is analysed, by the proposed simulation technique, to obtain the corresponding duration times of the critical state of operation in the affected RDC's. As already mentioned, for the case study analysis, we have assumed that the resources are moved just between two similar regional centres, i.e. that only two centres are affected by the strategy and that the two centres are identical in terms of their models and initially allocated resources. The two affected RDCs both operate in the critical state for some times, denoted as T_{crit1} and T_{crit2}. In this case, instead of analysing independently these times, it is more meaningful to consider their sum $T_{crit1} + T_{crit2}$ and maximum value max(T_{crit1}, T_{crit2}).

Figure 4 presents the simulation results for the various strategies (β, τ) after a 5 day stoppage of the system. It should be noted that the fastest resumption of normal operation is achieved for the shortest maximum times. The ridge of local minima represents the alternate optimal management contingency plans for dealing with this stoppage, if one neglects the expenses of the relocation of resources.

The analysis performed for $T_{crit1} + T_{crit2}$ shows (Fig. 5) that near these values the sum of critical operation times is practically not affected by the choice of the management strategy.

6. Conclusions

The proposed method of analysing critical situations fills the gap that is not addressed by the traditional reliability approach. Normally, the transportation systems are designed with some redundancy to ensure continuity of service when foreseeable incidents occur, the key being their probability of occurrence. In the proposed method we deal with very improbable situations that are neglected in the reliability analysis due to their very low probability of occurrence. It is never economically justifiable to design the system to prevent them. Yet, low probability does not mean that these critical situations cannot occur. We propose a viable method of dealing with these situations and of assessing the various contingency plans.

It should be noted that the contingency plans' analysis is performed using a simulation tool that has been validated in normal operation conditions. This ensures the best chance of obtaining accurate predictions, since it is hardly possible to validate the tools against practical data collected from the critical state of operation (such data simply does not exist).

The analysis can easily be extended by taking into account the economic aspects of relocating resources between the RDCs. These relocation costs can significantly influence the choice of contingency plans. The impact of the choice of the cost factors can outweigh the analysed operational aspects.

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MANAGEMENT OF GREEN CORRIDOR PERFORMANCE

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In the context of a harmonized transnational transport system the green corridor concept represents a cornerstone in the development and implementation of integrated and sustainable transport solutions. Important properties of green corridors are their transnational character and their high involvement of public and private stakeholders, including political level, requiring new governance models for the management of green corridors.

Stakeholder governance models and instruments for green corridor governance are going to be developed and tested in different regional development projects in order to safeguard a better alignment of transport policies at various administrative levels and a strengthening of the business perspective. A crucial role in this context belongs to involvement of public and private stakeholders in order to safeguard efficient corridor performance.

The paper presents recent research results about green supply chain management in the frame of network and stakeholder model theory and its application to the stakeholders of green transport corridors.

Keywords: green supply chain management, green transport corridors, stakeholder governance

1. Introduction

Due to globalisation today's industry is not dependent solely on location of resources and raw materials but is present all around the globe and decision makers having chosen their locations more in consideration of cost factors like labour costs, real estate prices and tax regulations but not on geographically close location to the markets and low transportation costs. Therefore, one of the main challenges connected to energy provision and use in a green logistics perspective is the energy consumption during transportation of goods. In a supply chain, CO_2 emissions related transportation accounts for 14% of the total emissions according to [1].

When it comes to growth on the one hand and sustainable development on the other hand, the responsibility lies mainly on the companies' shoulders as the supply chains can be seen as the key factors in creating a sustainable supply to the customers [2]. The growth rate of trade volumes is expected to continue in the future increasing the demands in the performance of logistics networks. The current estimations for Europe are predicting a 50% increase in passenger and freight transport within the next 20 years [3]. The emphasis of the European Union is laid on green transport corridors, i.e., European trans-shipment routes with concentration of freight traffic between major hubs and by relatively long distances of transport marked by reduced environmental and climate impact while increasing safety and efficiency with application of sustainable logistics solutions, inter-modality, ICT infrastructure, common and open legal regulations and strategically placed trans-shipment nodes [4].

2. Theoretical Background

A. Supply Chain Management

Green supply chain management is based on the principle of supply chain management with an extra add-on on green impacts, meaning environmental friendly and efficient aspects. Supply chain management aims at providing the logistic aspects of the production process in the company in the most efficient way. That means that also suppliers, manufactures, customers and disposal companies are involved in the supply chain activities. In the context of green supply chain management, there exists interdependency between conventional supply chain management and eco-programs [5]. This includes the approach on how ecological aspects can be considered in the whole business processes in the most effectively way. The work [6] proposed that green supply chain management practices, which include green purchasing, green manufacturing, materials management, green distribution/marketing and reverse logistics, refer to the involvement of environmental thinking into the supply chain management from the extraction of raw materials to product design, manufacturing processes, delivery of the final products to the consumers and end-of-life management [7]. Therefore, it can be assumed that the involvement of green aspects in the supply chain of a company also involves changes in the supply chain itself. Of course, this will then also have an impact on the cooperative alliances with suppliers, manufactures and the customer at the end of the logistics chain.

However, there have been few studies exploring the issue of green supply chain management in the network approach. The performance evaluation of the supply chain management is one aspect of managing the transport corridor performance as an alliance and interdependence of stakeholders in the transport corridor. Hence, applying green supply chain concepts is essential in order to reduce environmental impacts, enhance market competition, and ensure regulation compliance.

The challenge within each supply chain is to choose the right mode of transportation, to use the right equipment, and to use the right fuel [8]. Among the modes of transportation we find plane, ship, truck, rail, barge and pipelines, all with different attributes when considering costs, lead time, environmental performance and availability. However, the reality is that it rarely happens that all modes of transportation are realistic options when shipping goods. The reason is that the goods might set limitations on which modes that can be used. The customers will also be very influential when choosing mode of transportation as they might be demanding a very high service level with quick delivery. When shipping goods over long distances, the alternatives are normally transport by air or ship. However, when distances are short, truck, airplane, train, or short sea ships are used [8].

Another important factor that has great impact on the environmental performance is the type of fuel that is used. Today the main categories of fuel are gasoline, biofuels, and electricity. Modern gasoline is much cleaner than it used to be. Biofuel can be mixed with regular gasoline, but if biofuel is used extensively, then the engine will have to go through some costly adoptions. Biofuel is fuel based on organic waste, and in that sense it is environmental friendly, but the problem is that it takes a lot of gasoline to make biofuel, which makes the total environmental performance of biofuel quite pure. However, if the technology and methods that are used for making biofuel are improved in the future, the environmental performance might raise significantly. Electric vehicles are clearly environmental friendly as they have very low levels of emissions, and the production of electricity can be controlled in order to calculate the emissions. The most important restriction for electrical vehicles is their range, which is too limited in order to be fully competitive with the combustion engine. This limitation might be eliminated in the future if the technology on battery capacity moves forward [8].

Finally, there is also a possibility for a development and use of other types of equipment. This might for instance be to use Giga-liners (long trucks), to use extra-long trains, and larger vessels at sea. These are all improvements that could decrease the emissions per kilo transported. However, if then the load factor drops, then the environmental performance might get lower than it originally was. Another method that already is used extensively is to lower the speed; this is for instance used in the shipping industry when the rates are low. A bi-effect is that the environmental performance rises.

Additionally, [8] proposed that Operations Research (OR) leads to a more efficient use of resources, which is not only cost attractive, but also tends to create less emissions of greenhouse gases. Therefore, with new methodologies in OR these savings and reduction of emissions can be considered as one solution to the challenge of high energy consumption in the transport and logistics sector. Furthermore, OR helps to identify transport solutions, especially with multi-criteria decision analysis, when it comes to multi-modal choice and alternative route optimisations. One key aspect of new solutions is the exploration of new and innovative transport connections by using multi-modal transport chains. The method of multimodal transports allows cargo to be transported faster with lower environmental impact. One attempt, mainly in the European aspect, is to consider transport chains as transport clusters along certain routes, the so-called transport corridors.

B. Network approach

In order to understand what a transport corridor means by theoretical backgrounds it can be helpful to see the corridor as a conglomeration of different stakeholders which act along a defined geographical area in order to achieve different goals but with the same objective not only to minimize the environmental impact but also to reduce costs, increase efficiency, and create sustainable logistics solutions. Realization of the increasing complexity of the interactions among actors along their supply chains suggests that a network perspective may better explain the emergence of collaborative practices and integrative behaviours in logistics in general and supply chain management from organization's point of view [9]. Researchers have begun to suggest the need for a network-based view of supply chains, recognizing that the interactions between organizations in a supply chain are rarely as sequential as a chain structure would suggest [10]. As a whole, studies acknowledge the importance of a network structure for the effective diffusion of supply chain-related practices [11], as well as for efficiency and flexibility of the responses of the supply chain to customer expectations [12].

As the stakeholders act in a coherent sense and are located in a certain geographical area such a transport corridor can be described as a tubular cluster performance. Due to natural reasons transport and logistics activities have often close relations to strategic alliances, cooperation and collaboration agreements which can result in cluster activities. Arising from the social network theory a transport corridor can be seen as a scale free network. It started from dyadic relationships between two stakeholders and grew to a broader network. Specific characteristics of scale-free networks vary with the theories and analytical tools used to create them, however, in general, scale-free networks have some common characteristics. One notable characteristic is the relative high number of nodes with relations to other nodes which greatly exceeds the average. The nodes with most of the relations are often called "hubs", and may serve specific purposes in their networks. It turns out that the major hubs are closely followed by smaller ones. These ones, in turn, are followed by other nodes with an even smaller number of degrees and so on. This hierarchy allows for a fault tolerant behaviour. If failures occur at random, which, in the case of transport corridors, means the drop out of a stakeholder and the vast majority of nodes are those with small degree, the likelihood that a hub would be affected is almost negligible. Even if a hub-failure occurs, the network will generally not lose its connectedness, due to the remaining hubs. On the other hand, if a few major hubs are taken out of the network, the network is turned into a set of rather isolated graphs.

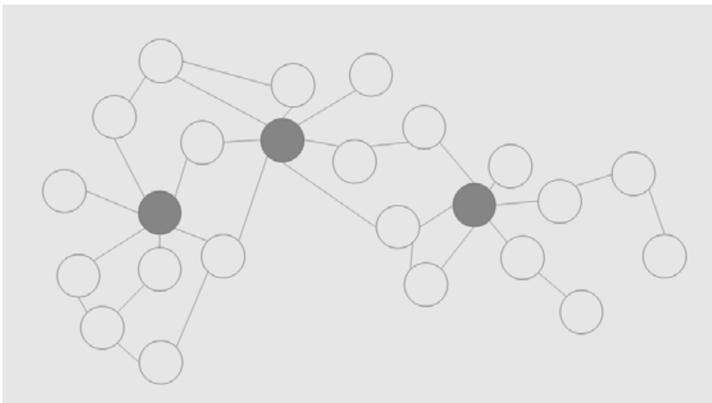

Figure 1. Transport corridor in social network theory

Thus, hubs are both strength and weakness of scale-free networks. These properties have been studied analytically using percolation theory by [13] and by [14].

In the work [15] such a social network perspective to the stakeholder theory of the firm has been applied. Accordingly, research has started to address systems of dyadic interactions and stakeholder multiplicity, which can be also of importance for the understanding of a transport corridor concept. Opportunities for organizational resistance or adaptations to stakeholder expectations [16], [17] and [18] can be investigated. In the work [19] the predictors for stakeholder networks for value chains have been investigated. The identified two structural features of such stakeholder networks: Firstly, network density, defined as the degree of completeness of the ties between the actors in a network, has been identified as a likely determinant of corporate responsiveness in that it affects the ease of communication and efficiency of information flow across actors in the network [20], [17], and [21]. The second predictor, the degree of centrality in the network, that is, the extent to which an organization occupies a central position in the network, has been suggested as a further influence on the attentiveness of companies to stakeholder concerns and their willingness to accommodate their requests [15]. How different stakeholders with different typologies can cooperate efficiently and how they might be managed can be described with the stakeholder model theory.

C. Stakeholder model theory

In contrary to the shareholder model theory which says that in an organization or a firm only the shareholders have an interest in creating value for themselves and serving the interest of the other direct shareholders, the stakeholder model theory assumes that the firm has to serve several stakeholders. These can be not only direct involved interest groups but also the society, employees or suppliers of third party organizations or public institutions or political stakeholders. The stakeholder approach was initiated by [22] but was constantly developed during the last decades (see [23], [24], [25] and [26]) as in capitalistic markets the importance of the decision-making by stakeholders is increasing. Decisions do not only have an impact on the organization itself but also to society and a wider group of stakeholders, mainly when it comes to environmental effects and public serving obligations like it can be assumed for the green transport corridors.

When it comes to governance structure of an organization like a green transport corridor also the question of property rights arises. Property rights theory has mainly been developed by [27], [28] and [29]. The party that possesses the rights to an asset can decide the use of it and is entitled to receive the income from it. Unfortunately, this is not obvious to distinguish in the case of transport corridor as the rights of the available assets, i.e., roads, terminals, railways, land, infrastructure, etc. belongs to different stakeholders. Mainly these assets belong to public institutions which by their nature have no interest in earning income form their assets but serving the society and ensuring economic freedom. Next to the question of the property rights there are also other opinions when it comes to assets of the organization. [30], [31], [32] and [23] argue that the assets of the firm do not only consist of physical assets but also the skills of its employees, the expectations of customers and suppliers, and its reputation in the community. This is not only applicable to the transport corridor concept in general but to every participating company on lower level as well.

One crucial aspect of governance of a transport corridor is still how the decision making process can be solved with such a big group of different stakeholders. In the work [33] already have been stated that “the more groups of stakeholders there are, the more complicated it will be to reach a decision, especially as the stakeholders often have different goals”.

In order to analyse the possibilities of introducing the stakeholder model in governance of transport corridors it is important to have a clear idea of what is meant by stakeholders respectively owners. It can be assumed that stakeholders by nature are also owners of the corridor structure. Therefore we further define stakeholders as these parties which have a stake on the corridor and are part of the governance structure of the same, as [22] definition states that stakeholders are: ‘‘…any group or individual, who can affect or is affected by the achievement of organisation’s objectives’’. The work [34] defines stakeholders as ‘‘…persons or groups that have, or claim ownership, rights, or interests in a corporation and its activities, past, present, or future.’’ He further differentiates between primary and secondary stakeholders. The first group includes stakeholders, like shareholders, employees, customers, suppliers, government and communities, without their participation the organization cannot exist. The secondary stakeholders are ‘‘…those who influence or affect, or are influenced or affected by, the organisation, but they are not engaged in transactions and are not essential for its existence.’’ Examples of secondary stakeholders are the media and competing companies. Other researchers [25] differentiate between “social” and “non-social” stakeholders. Furthermore there are direct and indirect stakeholders. Examples of direct social stakeholders are customers, employees and investors and examples of indirect non-social stakeholders are the natural environment and future generations which applies very much to the concept of green transport corridors. As the concept for a transnational governance model, the management of a green transport corridor, is new and not completely investigated it might be useful to assume the group of stakeholders and try to define their expectations and intentions.

According to the network theory the stakeholders can be divided into smaller nodes and actors which function as hubs along the corridor. What makes a transport corridor also specific and more complex than a logistics network is the geographical and political scope? The transport corridor covers several countries, regions and terrestrial and maritime areas as well as national, regional and transnational political bodies. One could assume that the highest political institution is automatically considered as the institution with the highest degree respectively highest decision making power in the network. However, by looking deeper to the actual performance of a transport corridor and the role the individual stakeholders play it becomes obvious that the hubs are rather represented by other institutions.

1) Ports and logistic centres

Ports and also strategically planned logistic centres are considered as hubs due to their location. Because of the connection to many transport modes (sea, inland waterway, road and railway) the cargo is shifted or stored for a certain time period. When looking at the ideal transport chain along the corridor, every cargo has to pass the main hubs at least twice during their entry and exit points. This simple fact makes the ports or logistic centres to a very crucial part of the transport corridor. Owners of hubs and logistics centres can be private but also public bodies. But anyhow they aim to cover their running costs and earn additional income for their offered activities.

2) Logistic forwarders

Logistic forwarders, like rail companies, international courier services, and ferry lines, are not dependent on one geographical location. Upon the company size they are rather considered as a hub due to their close and manifold relations to other stakeholders in the corridor. They provide large portions of equipment (containers, trucks, ferries, rail wagons) and also professional knowledge and skills of their employees. Therefore they are a very crucial part of the performance of the corridor.

Logistic forwarders are almost 100% owned by private companies respectively represent a stakeholder group which is very much interested in generating value and income for their own shareholders. They will only act as stakeholders of a common transport corridor if the savings through cooperation are higher than the losses.

3) Political institutions on several levels

Political institutions of all levels in all countries represent the national or regional governments. Governments are not mainly interested in earning income for themselves from establishing a transport corridor. However, they are obliged to represent the local market economy and ensure the best framework condition so that private companies can perform well. This includes also equal access to all transport corridor activities. From that point of view they have more like a representing function. Additionally as the governments support the corridor activities with public funds the whole society is interested in the investments. Therefore the political institutions act also agents for the general society.

3. Monitoring of Green Transport Corridors

When it comes to the issue of monitoring and controlling green transport corridors there are many attempts from the individual companies and industry representatives but also from international government level. The EU forces in the recent years the development of guidelines on criteria how to monitor and assess the green logistics actions. The authors participated in the European funded project East-West-Transport-Corridor under the Baltic Sea Region Programme 2007-2013, where for the first time a “Green Corridor Manual” based on the green East-West-Transport-Corridor was developed trying to give a holistic and consistent monitoring concept for multi-modal sustainable transport [35]. The green corridor manual consists of a set of recommendations and guidelines on how to implement a green multi-modal transport chain according to the EU freight agenda and as promoted by the EU Baltic Sea Strategy. It also proposes a set of Key Performance Indicators (KPI) and incentives and regulations for more efficient, high quality, safe, secure and environmental friendly transport facilities and services. Such a manual can list indicators and measures with their potential impacts, together with a governance model for the development of a stepwise deployment of a green transport corridor. It is also possible to look into and elaborate on different options for the certification of green transports, which is of great economic interest for the whole transport market.

There are different aspects, which will influence the performance of transport chains. One approach is to separate them into enabling and operational criteria. Enabling criteria describe the settings of the transport chain in regard to the hard infrastructure, meaning roads, railways, terminals, ports, etc. The soft infrastructure includes the information and communication systems which supports the transport logistics services offered in the defined transport route or set of factors. Other aspects of enabling the performance of a transport chain are regional, national and international policies and regulations which apply to all stakeholders. Operational aspects describe the geographical settings as such, the transport and logistics solution by involving new and innovative business models. The implementation of transport techniques will have also a direct impact on the performance of a transport chain measured by given KPIs.

Table 1. Performance indicators

Performance areas	Operational indicators	Enabling indicators
Economic efficiency	Total cargo volumes On time delivery	Corridor capacity
Environmental efficiency	Total energy use Greenhouse gases, Co2e Engine standards ISO 9001 dangerous goods	Alternative fuels filling stations
Social efficiency	ISO 31 000 ISO 39 000	Safe truck parking Common safety rating Fenced terminals

Table 1 gives an overview about the KPIs, which were selected from the East-West-Transport-Corridor project and were also tested during the project duration. Additionally to the table of performance indicators often the enabling factors are described by a corridor dashboard aiming to connect the short-term KPIs and the enabling KPIs by visualizing capacity, accessibility and performance. So the dashboard stimulates improvements of the corridor infrastructure and facilitates the cooperation of all stakeholders along the corridor in order to improve total performance [35].

Economic efficiency and service quality performance of a transport corridor can be demonstrated by the total cargo volumes. Large cargo volumes increase the attractiveness of a transport corridor as it might influence decisions from potential stakeholders whether to accept the transport corridor or not. Furthermore, efficiency and service quality is reflected by the ability of the transport chain stakeholders to provide on time delivery. It is measured by the arrival time in relation to transport timetables. A key element with regard to on-time delivery is a uniform provider and shipper entity for measuring lead times and its arrival time with relevant precision. The enabling performance under this area is the transport chain capacity, which is set by the enabling criteria of hard and soft infrastructure and policies.

Total energy use aims at describing the general environmental efficiency. Indirectly it also describes, to which extend the traffic flow is efficient, when, e.g., idle times, empty returns and long-waiting times are reduced. In addition, operational performance in regard to the environmental efficiency can be measured on fuel consumption, as it enables the calculation (if needed) of SO_2, given the legal fuel conditions or the actual quality used. In case renewable energy resources are used, the emitted Greenhouse gases (carbon dioxide, methane and nitrous oxide) can describe the impact on climate affecting emissions of the transport corridor. As an enabling indicator the availability of the corresponding fuel stations must be measured by assessing the numbers of traditional fuel stations and alternative fuel stations. The more alternative fuel stations are available the more environmental efficiency can be assumed.

Engine standards (also includes after treatment devices), which are regulated for all stakeholders of a certain transport corridor, can also be used as a performance indicator as they indirectly describe the emissions related to impact on health and nature. Further indicators are related to dangerous goods, which are already regulated quite strictly by international standards (e.g., ISO 9001 dangerous goods) and are, therefore, quite known to measure the safety aspects of the transport corridor.

Social efficiency can be also measured by operational performance of the transport corridor. Indicators and common standards are already precisely stated in the ISO norms for risk management (ISO 31 000 and ISO 39 000). In these norms the cargo security aspects are regulated as well as the traffic safety aspects firstly meant for organizations but can be also transferred to the monitoring of a transport corridor (e.g., road traffic accidents). Another indicator for social performance can be measured with the sick leave rates of companies, fluctuation by employee turnover, the number of temporary employees and workers and the average salary level and salary differences between the stakeholders of the transport corridor. These indicators will give an indication on how the social performance is developed in the corridor today but they do not reflect in the indicator in regard to sustainability of the corridor. First test results from the East-West-Transport-Corridor project show that more detailed aspects must be considered. These could be age, gender, level of education, and experiences of the employees. Indicators, which enable social performance in regard to cargo security and safety, are the consistent usage of fenced terminal areas with access controls and safe truck parking systems along the transport corridor [35].

4. Conclusions

Sustainable logistics solutions are high ranked on the political agenda and first results in the implementation of green transport solutions have been generated paving the way to general sustainable logistics. The results from green corridor projects on European level like the East-West-Transport-

Corridor lead to holistic and consistent green monitoring concepts for multi-modal transport solutions, which can be expressed in KPIs, in its turn, which are applicable for green supply chain management.

The performance of transport chains is influenced by enabling and operational factors, trying to representing and connects the corridor's hard and soft infrastructure as well as operational aspects. But the first experiences of green corridors on European level are showing that beyond the development of appropriate KPIs the success and performance of corridors heavily depend on the commitment and cooperation of the involved stakeholders. So governance models and cultural aspects are representing important success factors of green corridors.

Even due to the fact that companies are aware of environmental issues they are still lacking behind the realization of the full potential of green supply chain management. Most businesses need additional incentives to realize environmental investments, either by law or by economic motivations. First test results of KPI application in the East-West-Transport-Corridor showed also that organizations and corridor stakeholders were not willing to publish their performance indicators by fearing to lose their competitive advantages despite the fact that green and sustainable supply chain management within organizations could result in cost reductions and better business performance. Further research work has to be realized in order to tackle these strategic bottlenecks of green corridors.

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SIMULATION BASED PERFORMANCE OF MUMBAI-PUNE EXPRESSWAY SCENARIO FOR VEHICLE-TO-VEHICLE COMMUNICATION USING IEEE 802.11P

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Traffic safety applications using vehicle-to-vehicle (V2V) communication is an emerging technology and promising area within the ITS environment. Many of these applications require real-time communication with high reliability; to meet a real-time deadline, timely and predictable access to the channel. The medium access method used in 802.11p, CSMA with collision avoidance, does not guarantee channel access before a finite deadline. The well-known property of CSMA is undesirable for critical communications scenarios. The simulation results reveal that a specific vehicle is forced to drop over 80% of its packets because no channel access was possible before the next message was generated. To overcome this problem, we propose to use STDMA for real-time data traffic between vehicles. The real-time properties of STDMA are investigated by means of the highway road simulation scenario, with promising results.

Keywords: CSMA, STDMA, V2V, VANET

1. Introduction

The new emerging applications for traffic safety found within the vehicular ad-hoc network environments which can be classified as real-time system. Existing vehicle-to-vehicle safety systems together with new cooperative systems using wireless data communication between vehicles which can potentially decrease the number of accidents on the highway road in India , i.e., transmit the messages within deadline time. In addition, requirements on high reliability and low delay are imposed on wireless communication system [1]. For example, Lane departure warning messages merge assistance and emergency vehicle routing are all examples of applications [2]. Information that is delivered correctly, but after the deadline in a real-time communication system, is not only useless, but can also have severe consequences for the traffic safety system. This problem is pointed out in [3-5]. In most cases, the extremely low delays required by traffic safety applications, the need for ad-hoc network architectures support direct vehicle-to-vehicle communication. The original IEEE 802.11, intended for WLAN, has two drawbacks within its MAC technique CSMA; it can cause unbounded delays before channel access as well as collisions on the channel. The MAC protocol decides who has right data/packet to transmit next on the shared communication channel. In CSMA, the node first listens to the channel an if the channel is free for certain amount of time period, then the node transmits data/packets directly with the implication that another node can have conducted the exact same procedure, resulting in a collision on the channel. CSMA is used by IEEE 802.11 family as well as its wired counterpart IEEE 802.3 Ethernet. One of the reasons for the success of both WLAN and Ethernet is the straightforward implementation of the standard resulting in reasonable priced equipment.

2. Medium Access Control

Vehicular ad-hoc network (VANETs) is a spontaneous, unstructured network based on direct vehicle-to-vehicle (V2V) communication and its topology is changing constantly due to high mobility of vehicle nodes on highway road. In VANET it is harder to deploy a MAC scheme that is relying on a centralized controller.

2.1 IEEE 802.11p/DSRC Protocol

The IEEE 802.11p standard (WAVE) emerges from the allocation of the Dedicated Short Range Communications (DSRC) spectrum band in the United States and the work done to define the technology to be used in this band. There are two types of channels in DSRC, all of them with a 10 MHz width: the control channel (CCH) and the service channel (SCH). The CCH is restricted to safety communications only and the SCHs are available both for safety and non-safety use. Applications for vehicular communications can be placed in three main categories - traffic safety, traffic efficiency and value-added services (e.g. infotainment/business) [7-11].

In Europe, the spectrum allocated by the ETSI for cooperative safety communications has a range 5,875 - 5,925 GHz. It is divided into traffic safety (30 MHz) and traffic efficiency (20 MHz). In the traffic safety spectrum, two SCHs and one CCH are allocated. In the traffic efficiency two SCHs are allocated [11]. WAVE is fully intended to serve as an international standard, which is meant to: describe the functions and services required by WAVE stations to operate in VANETs, and define the WAVE signalling technique and interface functions that are controlled by the IEEE 802.11 MAC. WAVE is an amendment to the Wireless Fidelity (Wi-Fi) standard IEEE 802.11 [18,12].

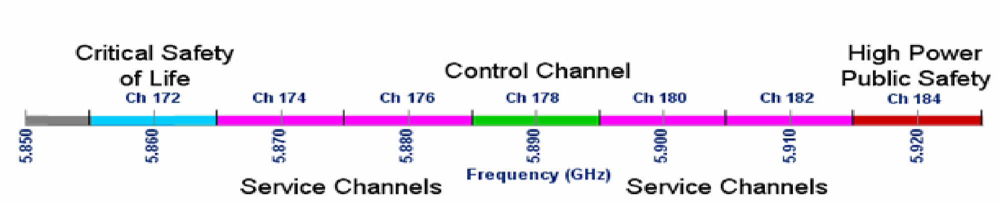


Figure 1. DSRC spectrum band and channels

2.2 MAC Layer

For the adaptation of IEEE 802.11a to IEEE 802.11p, no changes in the MAC layer have been done [20-22].

2.2.1 Overview of MAC services

2.2.1.1 Data service

This service provides peer entities in the LLC (Local Link Control) MAC sub-layer with the ability of exchanging MSDUs (MAC Service Data Units) using the underlying PHY-layer services. This delivery of MSDUs is performed in an asynchronous way, on a connectionless basis [15].

2.2.1.2 MSDU ordering

In nQSTAs, the ones simulated in this paper, there are two service classes within the data service. By selecting the desired service class, each LLC entity initiating the transfer of MSDUs is able to control whether MAC entities are or are not allowed to reorder those MSDUs at reception [25-27].

2.3 MAC sub-layer functional description

2.3.1 MAC architecture

The MAC architecture can be described as shown on Figure 3 as providing the Point Coordination Function (PCF) and Hybrid Coordination Function (HCF) through the services of the Distributed Coordination Function (DCF) [23, 24].

2.3.1.1 D C F

DCF is the fundamental MAC technique in the IEEE 802.11 standard. It employs an access function performed by the CSMA/CA algorithm and a collision management function carried out by the binary exponential back-off procedure.

2.3.1.2 P C F

The original IEEE 802.11 standard defines another coordination function in the MAC layer. It is only available in structure mode networks, where the nodes are interconnected through at least one AP in the network. In the scope of this paper, PCF is not used.

2.3.1.3 H C F

HCF is a coordination function that enables the QoS facility. It is only usable in networks that make use of QoS, so it is only implemented in the QSTAs. The HCF combines functions from the DCF and PCF with some enhanced, QoS-specific mechanisms and frame subtypes to allow a uniform set of frame exchange sequences to be used for QoS data transfers. The HCF uses both a controlled channel access mechanism, HCCA, for contention-free transfer and a contention-based channel access method mechanism, EDCA.

2.3.1.4 H C C A

HCCA works similarly to PCF. It uses a QoS-aware centralized coordinator, called a Hybrid Coordinator (HC), and operates under rules that are different from the PC of the PCF.

2.4 Self-Organizing Time Division Multiple Access (STDMA) MAC Layer Algorithm

The STDMA algorithm, invented in [16, 17], is already used in commercial applications for surveillance, i.e., the Automatic Identification System (AIS) used by ships and the VHF data link (VDL) mode 4 system used by the avionics industry. By adding data communication based on STDMA, more reliable information can be obtained about other ships and airplanes in the vicinity and thereby accidents can be avoided. STDMA is a decentralized MAC scheme where the network members themselves are responsible for sharing the communication channel. Nodes utilizing this algorithm, will broadcast periodic data messages containing information about their position. The algorithm relies on the nodes being equipped with GPS receivers. Time is divided into frames as in a TDMA system and all stations are striving for a common frame start. These frames are further divided into slots, which typically corresponds to one packet duration. The frame of AIS and VDL model 4 is one minute long and is divided into 2250 slots of approximately 26 ms each. All network members start by determining a report rate. Then follows four different phases; *initialisation, network entry, first frame,* and *continuous operation*. During the *initialisation,* a node will listen to the channel activity during one frame length to determine the slot assignments. In the *network entry* phase, the node determines its own transmission slots within each frame according to the following rules: (*i*) calculate a nominal increment (*NI*) by dividing the number of slots with the report rate, (*ii*) randomly select a nominal start slot (NSS) drawn from the current slot up to *NI*, (*iii*) determine a selection interval (SI) of slots as 20% of *NI* and put this around the NSS according to Figure. 4, *(iv)* now the first actual transmission slot is determined by picking a slot randomly within SI and this will be the nominal transmission slot (NTS). If the chosen NTS is occupied, then the closest free slot within SI is chosen. When the first NTS is reached in the super frame, the node will enter the third phase called the *first frame*.

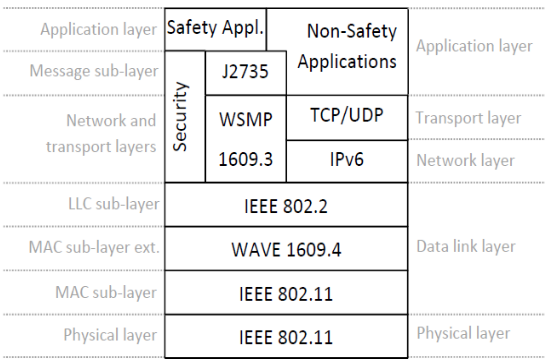


Figure 2. An overview of the WAVE protocol stack containing both a road traffic safety applications' part as well as a non-safety part

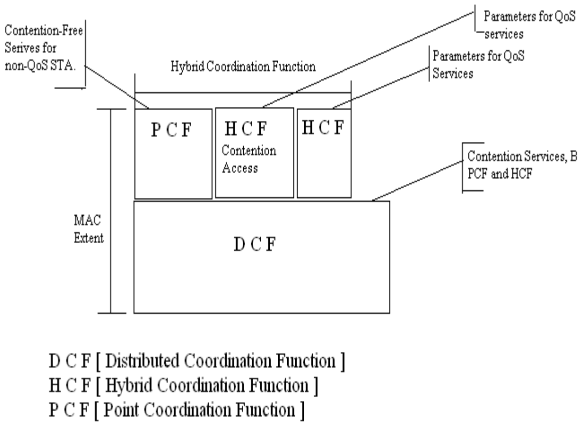


Figure 3. MAC architecture

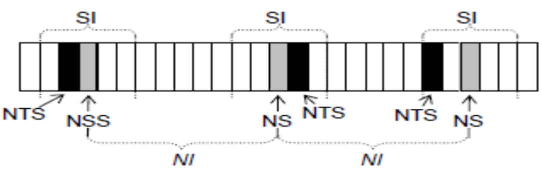


Figure 4. The STDMA algorithm in the first frame phase

Figure 5. Scenario of Mumbai-Pune Highway Road

After the first frame phase (which lasts for one frame) when all NTS were decided, the station will enter the *continuous operation* phase, using the NTSs decided during the *first frame* phase for transmission. During the *first frame* phase, the node draws a random integer $n \in \{3,...,8\}$ for each NTS. After the NTS has been used for *n* frames, a new NTS will be allocated in the same SI as the original NTS.

3. Simulations

The real-time properties of the system, the interesting issue here is how the two MAC protocols will influence the capability of each sending vehicle node to timely deliver data/messages packets. We are dealing with an uncontrolled network since the number of network vehicle nodes cannot be determined in advance as we are considering vehicles are controlled by humans. On the highway road, the highest relative speeds are found and this causes the network topology to change often and more rapidly. If a traffic accident occurs, many vehicles could be gathered in a small geographic area implying troubles with access to the shared wireless communication channel for individual vehicle nodes. The promising emerging application within VANET is a cooperative awareness system such as the automatic identification system for the ships, where the vehicles will exchange location messages with each other to build up a map of its surrounding and use this for different traffic safety efficiency application [27]. Consequently, we have also chosen to use broadcasted, time-driven location messages as the data traffic model in the simulator. Many traffic safety systems will rely on vehicles periodically broadcasting messages containing their current state. We have developed a simulator using Open Street Map, eWorld, SUMO version 0.12.3 (traffic simulator), NS-2 version 2.34 (Network Simulator) and TraNs version 1.2 (Intermediate simulator between SUMO and NS2) also we require Gnu plot to plot the graphics presentation (Figure 6 for Simulation Flow diagram) where each vehicle sends a location message according to a predetermined range of 5 or 10 Hz. The vehicle traffic scenario is a Mumbai-Pune Highway Road of 120 kilometres (km) , i.e., 12000 meter with 3 lanes in each direction (i.e., total 6 lanes including both the directions), see Figure 5.

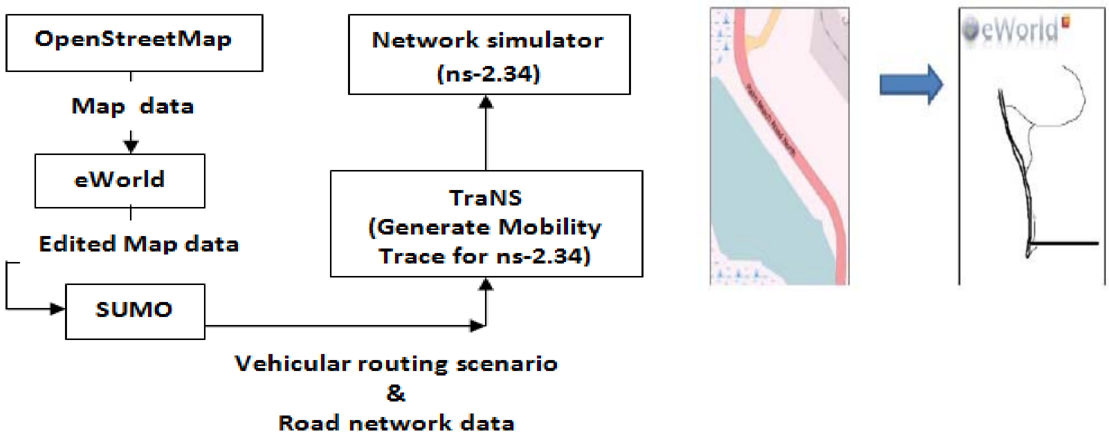


Figure 6. Simulation Flow Diagram

The Mumbai-Pune Highway Road scenario is chosen because here the highest relative speeds (i.e., min 80 km/h to max 120 or above km/h) in vehicular environments are found and hence it should constitute the biggest challenge for the MAC layer. The vehicles are entering each lane of the highway road according to a Poisson process with a mean inter-arrival time of 3 seconds. The channel model is a simple circular transmission model where all vehicles within a certain sensing range will sense and receive packets perfectly. The simulated sensing ranges are 500 m and 1000 m. We have tried to focus on how the two MAC methods perform in terms of time between channel access requests until actual channel access within each vehicle node [28]. The transfer rate is chosen to be the lowest rate supported by 802.11p, namely 3 Mbps as in Table 1.

Table 1. Simulation parameter setting for Mumbai-Pune Highway Road scenario simulation

Parameter	Value
Start-point of Highway Road	Panvel
End-Point of Highway Road	Pune
Simulation Time	1 hour 30 mins. (In-time 6.30 a.m. & Out-time 8.00 a.m.)
Length of Highway Road	120 Km or 12 000 m
Traffic direction	2 ways
Number of Lanes in each direction	6 lanes (3 in each direction)
Vehicle type	Cars, Private vehicles, Buses, Trucks, etc.
Number of Vehicle Nodes on Highway	2000
Speed of Vehicle nodes	80-120 km/h,
Communication Protocol	802.11p and STDMA
Traffic type	UDP
Packet sending frequency	5 Hz, 10 Hz
Packet length	300 bytes (Ratio 40% vehicles), 500 bytes (Ratio 30% vehicles) and 1000 bytes (Ratio 30% vehicles).
Transfer Rate	3 Mbps
Slot time, T_{slot}	9μs
SIFS, T_{SIFS}	16μs
CWmin	3
CWmax	Not used
Communication Range	500 meter, 1000 meter
Back-off Time, $T_{Backoff}$	0,9,18,27 μs
AIFS (listening time before sending) CSMA parameter	34 μs (the highest priority)
STDMA frame size	1 s
No of slots in the STDMA frame	1165 slots (300 byte packets), 718 slots (500 byte), 418 slots (1000 byte)

The channel model is a simple circular sensing range model, Figure 7, in which every vehicle node within the sensing area receives the message perfectly. Note the vehicle nodes could be exposed to two concurrent transmissions, where transmitters TX1 and TX2 are sending at the same time since the transmitters cannot hear each other: the receivers RX1, RX2, and RX3 on Figure 7 will then experience collisions of the two ongoing transmissions, unless some sort of power control or multi-user detection is used. The simulation has been carried out with three different packet lengths: N=300, 500 and 1000 bytes and two different sensing ranges 500 and 1000 meters. We used in our CSMA simulations, all vehicles use the MAC method of 802.11p, and hence each vehicle must listen before sending and back-off if the channel is busy or becomes busy during the automatic identification system. A broadcast packet will experience at most one back-off procedure due to the lack of ACKs in a broadcast system. Since all data traffic in our simulation scenario has the same priority, only the highest priority automatic identification system and CW_{min} have been used and therefore all transmitters will have the same T_{AIFS} value (34μs). The back-off time is the product of the slot time, T_{slot}, and a random integer uniformly distributed in the interval [0,3] implying four possible back-off times, $T_{backoff}$: 0,9,18 and 27 μs respectively. The STDMA algorithm found in automatic identification system cannot be used right away since the dynamics of a vehicular ad-hoc network and a shipping network are quite different. There is a natural inertia inherent in a shipping system that is not present in the vehicular environment.

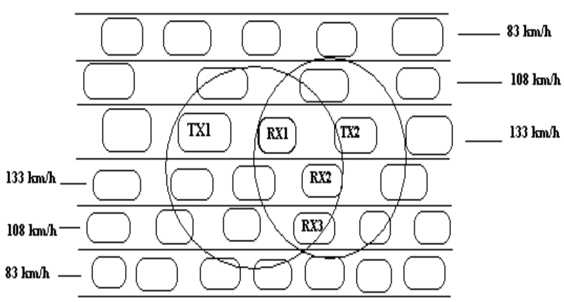


Figure 7. Simulation Set-up

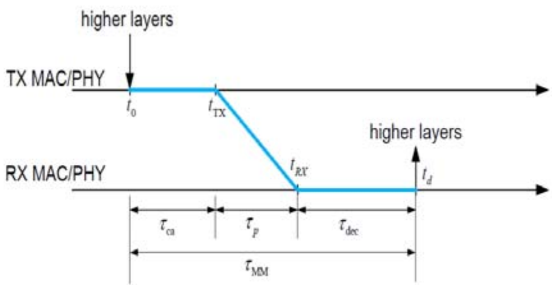


Figure 8. Mac-to-Mac (E2E) Delay

Both MAC protocols used in the simulation are assumed to use the same physical layer from 802.11p. The frame duration, T_{frame}, in our simulated STDMA scheme has been set to 1 second and the number of slots is changed inside the frame to cater for different packet lengths. A transfer rate, R of 3

Mbps has been used and this rate is available with the PHY layer of 802.11p, which has support for eight transfer rates in total where 3 Mbps is the lowest. In the STDMA simulations, the vehicles will go through three phases: initialisation, network entry and first frame, before it ends up in the continuous operations. The vehicle stays in the continuous phase after it has been through the other three. STDMA always guarantees channel access even when all slots are occupied within an SI, in which case a slot belonging to the vehicle node located furthest away will be selected. The time parameters involved in the simulation are selected from the PHY specification of 802.11p. The CSMA transmission time, T_{CSMA}, consists of an AIFS period T_{AIFS} in 34µs, a 20 µs preamble, $T_{preamble}$, and the actual data packet transmission, T_{packet}. The STDMA transmission time, T_{STDMA}, which is the same as the slot time, consists of two guard times, T_{GT}, of 3 µs each, $T_{preamble}$, T_{packet}, and two SIFS periods, T_{SIFS} of 16 µs each derived from the PHY layer in use. The total transmission time for CSMA is

$$T_{CSMA} = T_{AIFS} + T_{preamble} + T_{packet} \qquad \textbf{Eqn (1)}$$

and the total transmission time for STDMA is

$$T_{STDMA} = 2\,T_{GT} + 2\,T_{SIFS} + T_{preamble} + T_{packet} \qquad \textbf{Eqn (2)}$$

We have assumed that all the vehicle nodes in the system are perfectly synchronized with each other in both MAC protocol scenarios and that in the STDMA case they are also aware of when the frame starts and how many time slots it contains. The delay that takes to a packet sent from the transmitting vehicle until it is decoded by the receiving vehicle at the MAC layer level. This delay is expressed as:

$$T_{MM}=Tca + Tp +Tdec \qquad \textbf{Eqn (3)}$$

At the receiver side, to be a packet candidate to be decoded and sent to higher layers, it should have arrived within 100 ms, which is the maximum allowed delay at the receiver vehicle for CAM messages to be considered.

4. Performance Evaluations of CSMA and STDMA

Since CSMA will be the prevailing MAC method of emerging standards for VANET based road traffic safety applications. In addition, STDMA as described will also be evaluated, since this MAC method has the potential to fulfil the requirements imposed by VANET based road traffic safety applications. The channel access delay highlights the ability of the MAC method to provide a predictable delay which is a functional requirement. The packet reception probability is a non-functional requirement, i.e., a quality measure determining how well the MAC method schedules transmissions in time and space.

The performance of CSMA and STDMA has been evaluated by means of computer simulations in SUMO and NS2.34. The highway scenario was selected to model the vehicle traffic pattern since the highest relative speeds are found here and therefore it is likely the most stressing case for the MAC methods since stations can show up and quickly disappear again due to high velocities.

A 120 km highway scenario with 6 lanes, three in each direction, has been used for the simulations. The vehicles arrive at the highway entrance in each direction in each lane according to a Poisson distribution with mean inter-arrival time of three seconds. The vehicle speeds are drawn independently from a Gaussian distribution with a common standard deviation of 1 m/s, but with three different mean values (23 m/s, 30 m/s, and 37 m/s) depending on lane. The vehicles maintain the same speed as long as they are on the highway and overtaking is not considered (i.e., vehicles may pass in the same lane by driving over each other). The resulting vehicle density is then approximately 120 vehicles/km of highway (in total about 1200 to 2000 vehicles on the highway at the same time). All vehicles are moved every 100 ms. Simulation is carried out by parameters setting in Table 1. Data from the simulations have been collected only when the Mumbai-Pune Highway Road was filled with vehicles. The results from all 20 simulated scenarios using CSMA are shown in Table 2 where the numbers represent the data packet drops in percent. A data packet is dropped or discarded by the vehicle node when the next data packet is generated.

Table 2. Packet drops on average for different data traffic scenarios

CSMA		Sensing range			
		500 meter		1000 meter	
Data Packet Rate		5Hz	10 Hz	5Hz	10 Hz
Packet length	300 byte	0%	0%	0%	36%
	500 byte	0%	23%	34%	54%
	1000 byte	0%	30%	45%	60%

From Table 2 it can be seen that, if 1000 byte long data packets are sent every 100 ms and the sensing range is 1000 meters, only 45% of the channel access request will result in actual channel access for 802.11p. But, this value is averaged over all transmissions made by all vehicles in the system which means that certain nodes experience an even worse situation. On Figure 9, the best and worst performance experienced by a single user is depicted together with the average for all users in the system. In the worst case, a vehicle node achieves successful channel access only 14% of the time, i.e., 85% of all generated packets in this vehicle node are dropped. When the sensing range is 1000 meters, a vehicle node will complete for the channel with approximately 230 other vehicle nodes.

4.1 Channel access delay

On Figure 9, the CDF of the channel access delay for CSMA is depicted for all update rates when using the Nakagami channel model described above. On Figure 9 (a) update rates of 2-6 Hz is shown and as can be seen, no station experiences a channel access delay that is longer than 3 ms. On Figure 9(b), depicting update rates 8-20 Hz, a maximum channel access delay of 12 ms is encountered for the highest update rate, 20Hz. We can conclude that with an update rate of 2 Hz, 85% of all generated packets achieve channel access after the mandatory minimum waiting time of an AIFS of 71 μs, whereas with an update rate of 20 Hz, less than 10% of all generated packets experience the same minimum wait, implying that 90% of all initial transmission attempts result in a back-off procedure. In STDMA, the channel access delay is upper-bounded, i.e., a station always knows when it is allowed to transmit during its SI intervals. However, the size of the SI depends on the number of packets transmitted during one second. As the update rate increases, the SI will shrink and thereby the number of slots contained in the SI also reduces. On Figure 10, the channel access delay for STDMA is depicted with the same update rates and channel model as for CSMA on Figure 9. As can be deduced from Figure 10(a), the worst case channel access delay that STDMA can exhibit is 100 ms and this occurs when the update rate is set to 2 Hz (implying 500 ms between every generated packet). However, 50% of the generated packets have been transmitted after 50 ms even in this case. Conversely, the shortest channel access delay occurs for 20 Hz (i.e., 50 ms between every generated packet), yielding a maximum channel access delay of 10 ms. The staircase appearance of the curves is due to the number of slots in each SI. It should be noted that the channel access delay encountered in STDMA is neither affected by the channel model nor the network load. Consequently, the same channel access delays are also found for the LOS/OLOS model when STDMA is used. For CSMA using the LOS/OLOS channel model, the channel access delay is depicted on Figure 11. On Figure 12, the Nakagami and LOS/OLOS models are compared for CSMA. It can be concluded that the channel access delay is affected by the channel model in use and that the LOS/OLOS model implies longer channel access delays. This is due to the fact that the LOS/OLOS channel model has a successful packet reception range that is slightly longer than in the Nakagami case, implying that each station has slightly more stations within its radio range. These additional stations keep the channel occupied more often, forcing more stations into the back-off procedure and thereby increasing the channel access delay. When evaluating the channel access delay for CSMA and STDMA it can be concluded that while the minimum delay is smaller for CSMA than for STDMA, the worst case delay is random for CSMA. For STDMA, the worst case channel access delay is known and independent on network load and channel type.

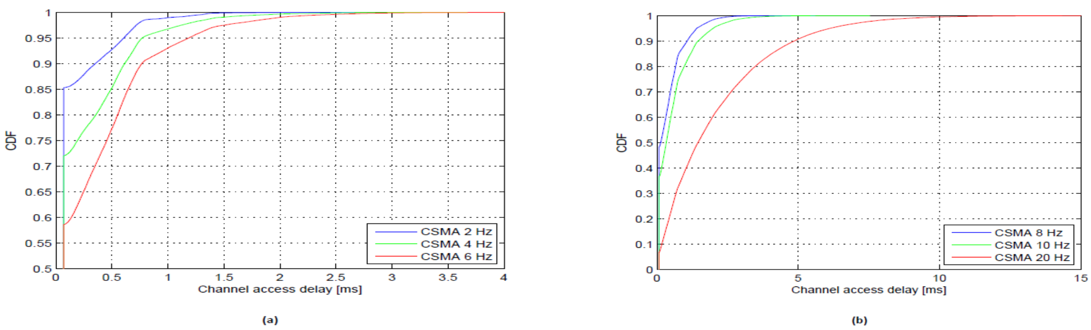


Figure 9. Channel access delay for CSMA when using the Nakagami model; (a) update rate of 2/4/6 Hz, and (b) update rate of 8/10/20 Hz

Figure 13(a)-(b) shows the packet reception probability for CSMA and STDMA, respectively, with the update rates: 2/4/6/8/10/20 Hz and the Nakagami channel model. The blue upper bound curve, denoted “Genie” on Figures 13-16, is the single transmitter case, i.e., no MAC method is needed as there is only one transmitter in the system and no interferers, implying that this is an unattainable upper bound for any network with more than one transmitter. Note that the update rate does not affect the packet reception probability per se, but since more transmissions take place, the probability of interferers is higher, which affects the probability of successful reception. From Figure 13, it can be concluded that STDMA has a higher packet reception probability for all considered rates, i.e., closer to the “Genie” compared to CSMA.

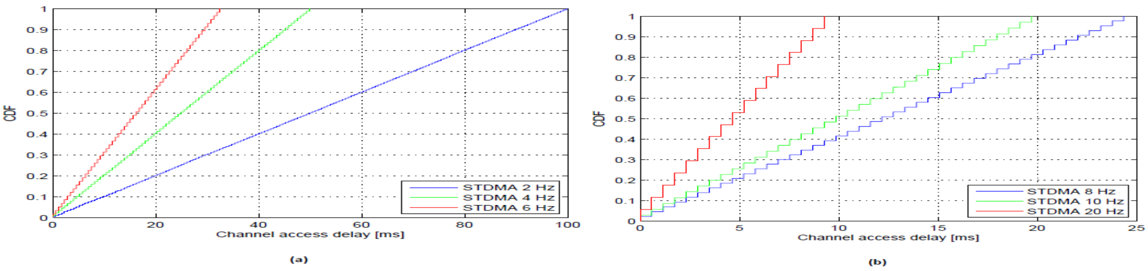


Figure 10. Channel access delay for STDMA; (a) update rate of 2/4/6 Hz, and (b) update rate of 8/10/20 Hz

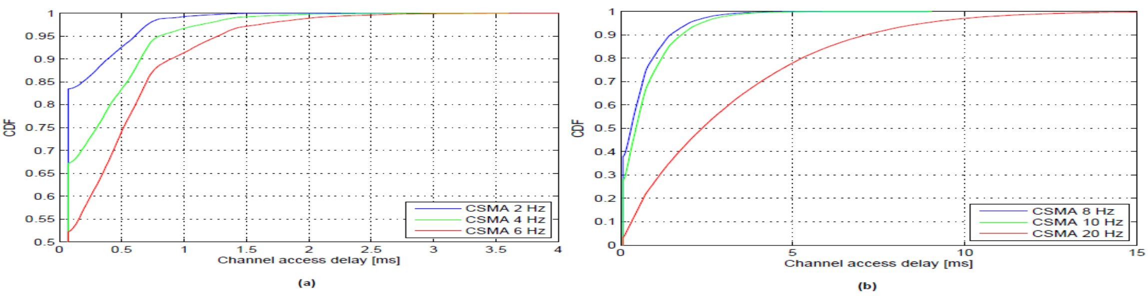


Figure 11. Channel access delay for CSMA when using the LOS/OLOS model for the following update rates;
(a) 2/4/6 Hz, and (b) 8/10/20 Hz

On Figure 14 the two MAC schemes are shown together for all considered rates. When RX is close to TX (< 100 meters) both MAC methods perform equally well. However, when the TX-RX distance increases, STDMA achieves a higher packet reception probability. At a TX-RX distance of 300 meters and an update rate of 6 Hz (Figure 14 (c)) and 8 Hz (Figure 14(d)), there is roughly a 20% performance gain with STDMA as compared to CSMA. For an update rate of 20 Hz, which can be regarded as an overloaded scenario, there is too much interference in the system for any of the two protocols, and the gap to the “genie” is considerable. In CSMA, the overloaded scenario causes stations within radio range to transmit simultaneously resulting in decoding failures at the receivers. The simultaneous transmissions occur since many stations are forced into back-off, and their back-off counters run the risk of reaching zero at the same time. For STDMA, the overloaded scenario implies that many slots are used by more than one station, resulting in a higher probability of decoding errors at the receivers and yet these slots are perceived as busy due to signal strengths above the *CSth*. Thereby stations are sometimes forced to select a slot within its SI that is perceived as busy but with missing position information, i.e., the protocol cannot take advantage of its ability to schedule transmissions in space.

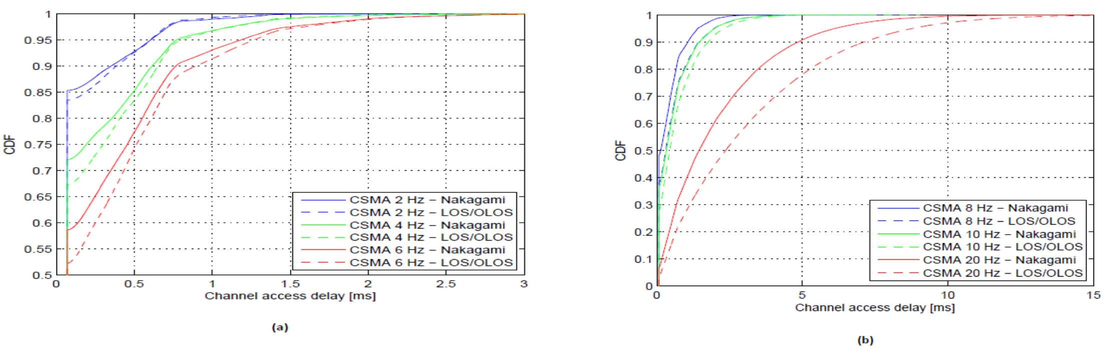
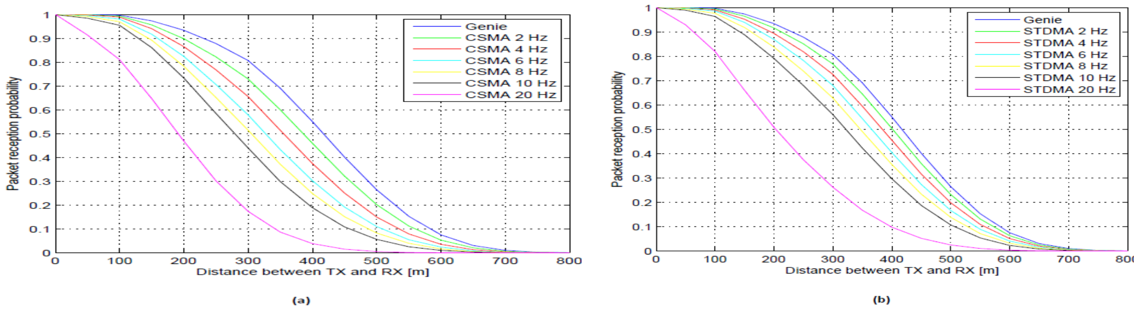


Figure 12. Channel access delay for CSMA when using the LOS/OLOS model and the Nakagami model
for the following update rates; (a) 2/4/6 Hz, and (b) 8/10/20 Hz

4.2 Packet reception probability



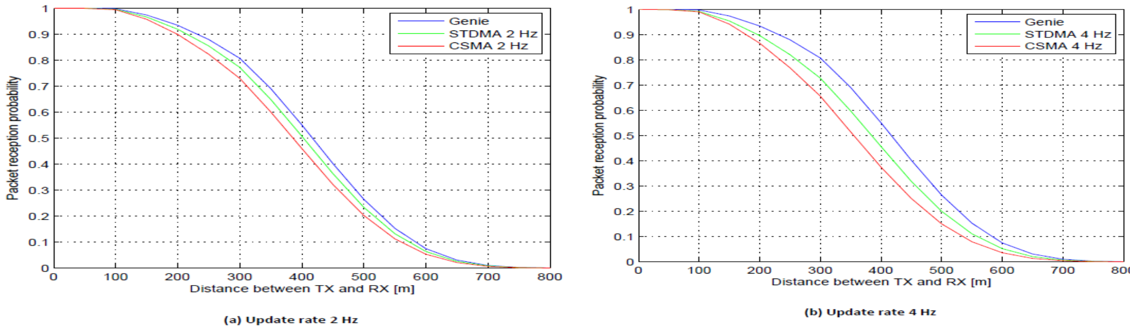


Figure 13. Packet reception probability for update rates of 2,4,6,8,10,16,20 Hz using the Nakagami model; (a) CSMA, and (b) STDMA

On Figure 15 the packet reception probability for CSMA and STDMA when using the LOS/OLOS model is depicted. It can be seen that the LOS/OLOS model has about 400 meters longer communication range than the Nakagami model, i.e., the packet reception probability approaches 0 for receivers approximately 400 meters further away.

On Figure 16 a comparison between CSMA and STDMA for different update rates is shown when using the LOS/OLOS model. The results show that STDMA performs better than CSMA for all settings also for this channel model. At a TX-RX distance of 300 meters, on Figure 14(c) update rate of 6 Hz and on Figure 14(d) update rate of 8 Hz, STDMA has almost a 20% better performance than CSMA. Consequently, STDMA is more reliable than CSMA.

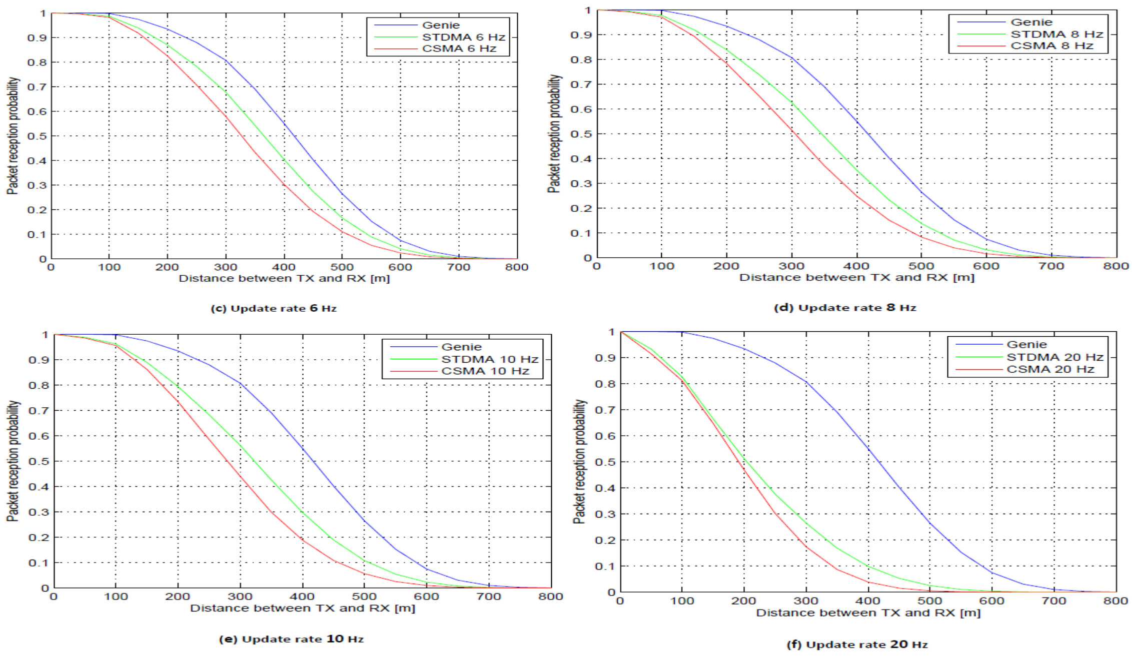


Figure 14. Packet reception probability for CSMA and STDMA when using the Nakagami model for different update rates of; (a) 2 Hz, (b) 6 Hz, (c) 8 Hz, (d) 10 Hz, (e) 16 Hz, and (f) 20 Hz.

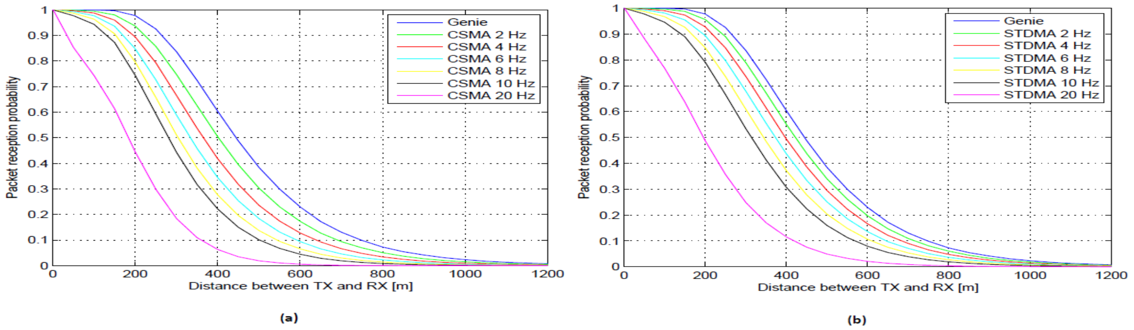
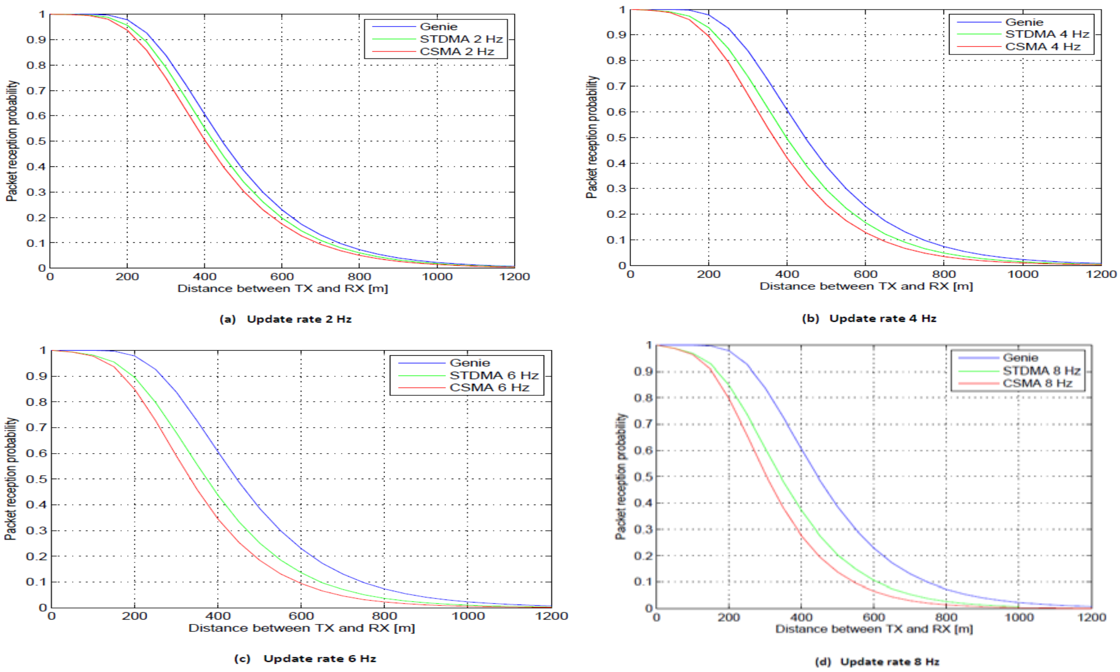


Figure 15. Packet reception probability for update rates of 2/4/6/8/10/20 Hz when using the LOS/OLOS model; (a) CSMA, and (b) STDMA

4.2 MAC-to-MAC Delay

MAC-to-MAC delay combines packet reception probability and channel access delay into one performance measure. The CDF for the MAC-to-MAC delay when using the Nakagami model for the update rates 2/4/6/8/10/20 Hz, is depicted on Figure 17. Since the MAC-to-MAC delay is a function of the update rate, the range of the abscissa is selected based on the specific update rate in use, i.e., the time between two packet generations (e.g., 1/(2 Hz) = 0.5 s). We use the convention that packet drops of any kind cause the MAC-to-MAC delay to be infinite. Packet drops can occur at the transmitter (for CSMA when channel access is not granted until the packet has expired) or at the receiver (for both CSMA and STDMA when decoding fails). However, on Figure 17, no packets have been dropped at the transmitting side. Therefore, the MAC-to-MAC delay is only infinite as a result of decoding failures. Every curve in the Figure represents all cases when the distance between transmitter and receiver is within a certain range, i.e., “STDMA 100-200 m” implies all receivers that are between 100-200 meters away from a transmitter.

The channel access delay for CSMA increases with increased update rate, quite in contrast to STDMA, where it instead decreases. On Figure 17(f), showing the highest update rate, the MAC-to-MAC delay reaches its maximum value after approximately the same time for both protocols for a TX-RX separation of 0-100 meters. The largest difference in performance between the MAC protocols is found on Figure 17(d) for an update rate of 8 Hz, where CSMA shows a lower MAC-to-MAC delay for the successfully delivered packets, but where STDMA manages to deliver more packets to higher layers implying that the CDF converges to a higher value. This illustrates the basic trade-off between delay and reliability. STDMA offers better reliability than CSMA at the expense of a longer MAC-to-MAC delay. For the shortest TX-RX separation the MAC protocols perform equally well, which is consistent with the finding for the packet reception probability curves.



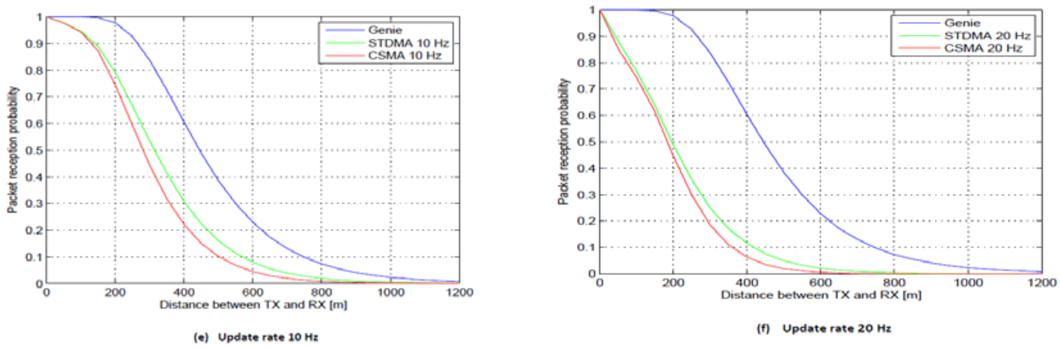
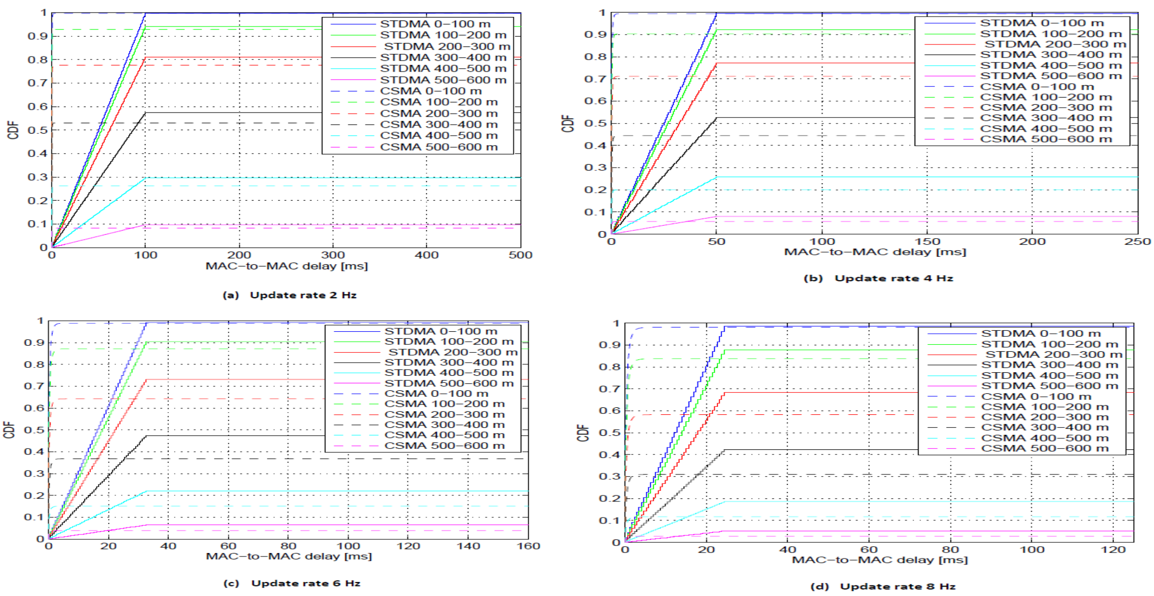


Figure 16. Packet reception probability for CSMA and STDMA when using the LOS/OLOS model for different update rates of; (a) 2 Hz, (b) 6 Hz, (c) 8 Hz, (d) 10 Hz, (e) 16 Hz, and (f) 20 Hz.

The MAC-to-MAC delay for the LOS/OLOS model is depicted on Figure 18 for both MAC schemes. STDMA and CSMA performs equally well for a TX-RX separation less than 100 meters. For longer distances, STDMA performs better than CSMA, i.e., the delay CDF flattens out at higher value. The largest difference in performance between CSMA and STDMA is also here found for an update rate of 8 Hz; see Figure 18(d). For every update rate, the largest difference between the two protocols is for a TX-RX separation of between 200-400 meters. We can conclude that CSMA has a lower minimum MAC-to-MAC delay, but that with STDMA, a higher percentage of all packets have a finite MAC-to-MAC delay.

4.3 City Scenario

The Palm-Beach Road (Nerul to Vashi) city scenario is chosen because here the highest relative speeds (i.e., min 60 km/h to max 100 or above km/h) in vehicular environments are found and hence it should constitute the biggest challenge for the MAC layer. The vehicles are entering each lane of the city road according to a Poisson process with a mean inter-arrival time of 3 seconds (consistent with the 3-second-rule used in Sweden, which recommends drivers to maintain a 3 second spacing between vehicles). The speed of each vehicle is modelled as a Gaussian random variable with different mean values for each lane; 60 km/h and 100 km/h a standard deviation of 1 m/s. For simplicity we assume that no overtaking is possible and vehicles always remain in the same lane. There is no other data traffic in addition to the heartbeat broadcast messages. The channel model is a simple circular transmission model where all vehicles within a certain sensing range will sense and receive packets perfectly. The simulated sensing ranges are 500 m and 1000 m. We have tried to focus on how the two MAC methods perform in terms of time between channel access requests until actual channel access within each vehicle node. Three different packet lengths have been considered: 500, 500 and 1000 byte. The shortest packet length is just long enough to distribute the location, direction and speed, but due to security overhead, the packets are likely longer [28]. The transfer rate is chosen to be the lowest rate supported by 802.11p, namely 3 Mbps. Since all vehicles in the simulation are broadcasting, no ACKs are used.



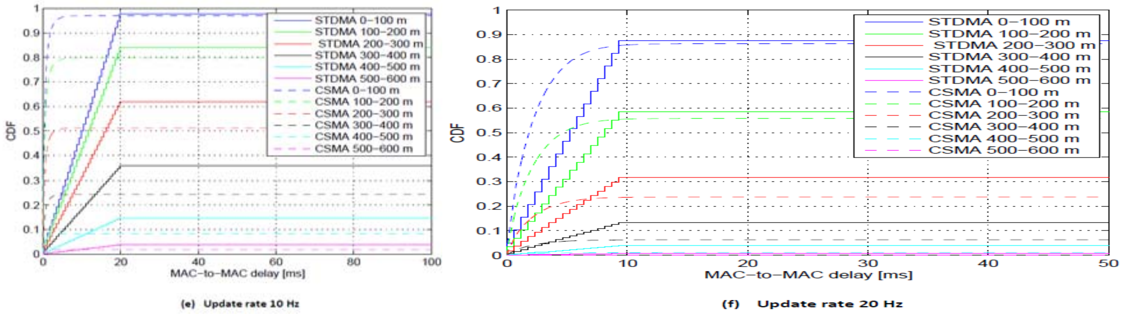


Figure 17. CDF for the MAC-to-MAC delay for CSMA and STDMA when using the Nakagami model for the following update rates: (a) 2 Hz, (b) 4 Hz, (c) 6 Hz, (d) 8 Hz, (e) 10 Hz, and (f) 20 Hz.

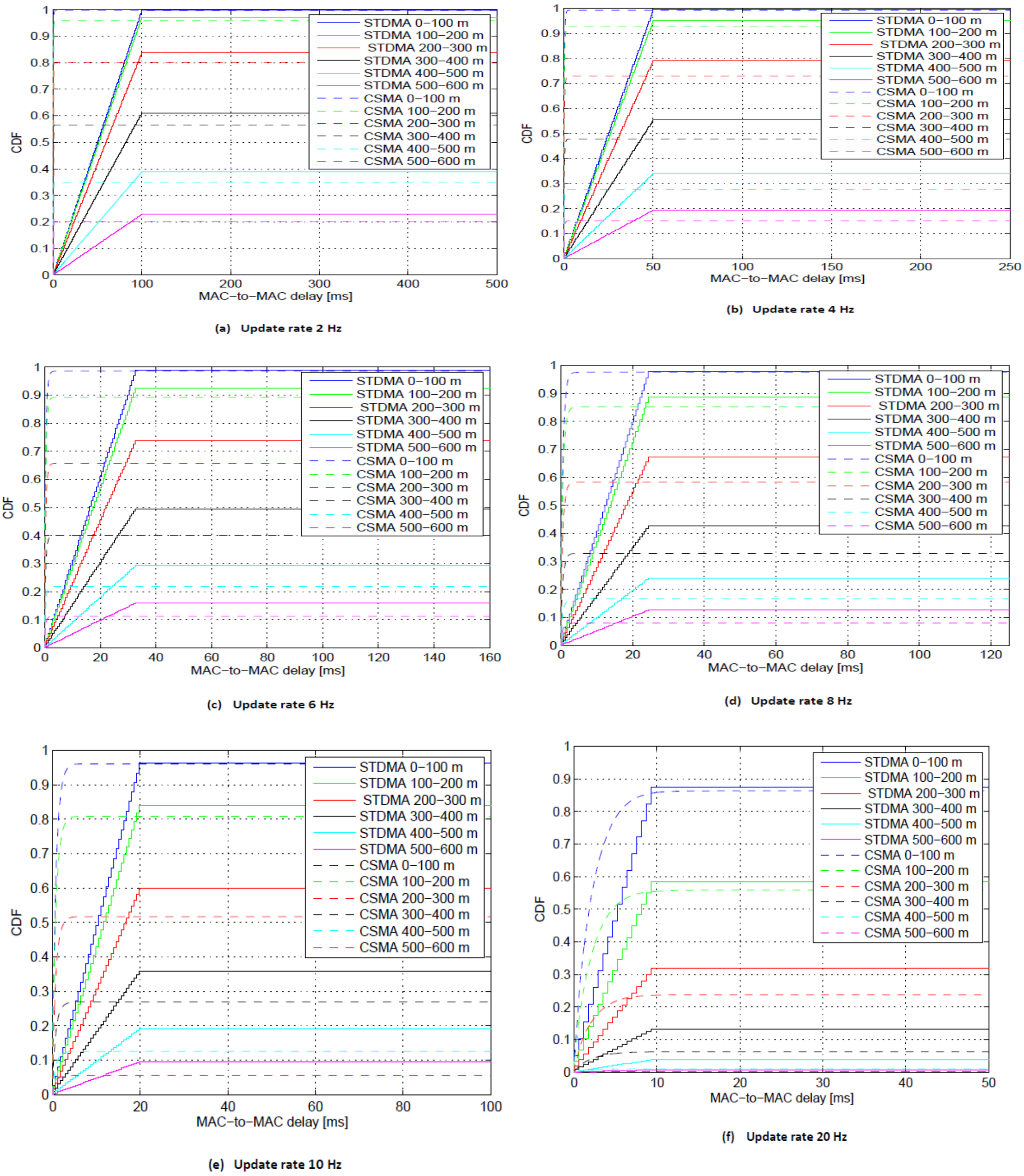


Figure 18. CDF for the MAC-to-MAC delay for CSMA and STDMA when using the LOS/OLOS model for the following update rates: (a) 2 Hz, (b) 4 Hz, (c) 6 Hz, (d) 8 Hz, (e) 10 Hz, and (f) 20 Hz.

On Figure 19 – the best and worst performance experienced by a single user is depicted together with the average for all users in the system. In the worst case, a vehicle node achieves successful channel access only 16% of the time i.e., 80% of all generated packets in this vehicle node are dropped. When the sensing range is 500 meters, a vehicle node will complete for the channel with approximately 230 other vehicle nodes. On Figure 20 – the results from a sensing range of 500 m are depicted, and the worst-case vehicle nodes are experiencing data packets drops 55%. In this scenario, approximately 115 vehicle nodes are competing for channel access.

Table 3. Contains a summary of the simulation parameter settings for City scenario.

Parameter	Value
Start-point of Highway Road	Nerul
End-Point of Highway Road	Vashi
Simulation Time	30 mins. (In-time 8.30 am & Out-time 10.00 am)
Length of Highway Road	10 Km
Traffic direction	2 ways
Number of Lanes in each direction	6 lanes (3 in each direction)
Vehicle type	Cars, Private vehicles etc.
Number of Vehicle Nodes on Highway	1200
Speed of Vehicle nodes	60 – 100 km/h,
Communication Protocol	802.11p and STDMA
Traffic type	UDP
Packet sending frequency	5 Hz, 10 Hz
Packet length	300 bytes (Ratio 40% vehicles), 500 bytes (Ratio 30% vehicles) and 1000 bytes (Ratio 30% vehicles).
Transfer Rate	3 Mbps
Slot time, T_{slot}	9μs
SIFS, T_{SIFS}	16μs
CWmin	3
CWmax	Not used
Communication Range	500 meter, 1000 meter
Back-off Time, $T_{Backoff}$	0,9,18,27 μs
AIFS (listening time before sending) CSMA parameter	34 μs (highest priority)
STDMA frame size	1 s
No of slots in the STDMA frame	1165 slots (300 byte packets), 718 slots (500 byte), 418 slots (1000 byte)

Figure 21 (a & b) – for different sensing ranges. Simulation statistics were collected from middle of the of the city scenario with the vehicle traffic. Dropped packets are considered to have infinite delays. Three plots in the figure represent CDF for the node performance in best average and worst case for different sensing range. In best case only 4% of generated and send packets are dropped while in worst case 60% packets are dropped for sensing range of 500 meters and 50% packets are dropped in average case for sensing range of 1000 meters. Lose of many consecutive packets, which will make the node invisible to the surrounding vehicles for a period of time. CDF for number of consecutive packet drops is on Figure 21. STDMA algorithm grants packets channel access since slots are reused if all slots are currently occupied within selection interval of the node. Node will choose the slot that is located furthest away hence there will be no packet drops at sending side when using STDMA and channel delay is small. Figure 23 – the CDF channel delay for STDMA for all nodes will choose a slot for transmission during selection interval therefore CDF for Tacc in STDMA is sending at unity after a finite delay compared to CDF for Tacc in CSMA. Figure 24 – the CDF for the minimum distance between two nodes, which utilizing the same slot within the sensing range is depicted for different packet lengths. In CSMA/CA, all channel requests did not make it to a channel access and then nodes drop packets. In CSMA/CA there is risk when nodes gets the channel access someone else also sends the packet and collision occurs. This is due to the fact that nodes can experience the channel idle at the same time, or ongoing transmission is not detected. Figure 25 – the CDF for minimum distance between two nodes in CSMA/CA city scenario sending at the same time for three different packets lengths with different ratio as shown in Table 3 above.

5. CONCLUSIONS

In future traffic safety system can be classified as real-time systems which mean that the data traffic sent on the wireless channel has a deadline. The most important component of a real-time vehicle-to-vehicle communication system is the MAC protocol method. In this paper, two MAC methods have been evaluated according to their ability to meet the real-time communication deadlines. The MAC of the vehicular communication standard IEEE 802.11p CSMA was examined through simulation, and the results indicate severe performance degradation for a heavily loaded system, both for individual nodes and for the system. The simulations show that 802.11p is not suitable for periodic location messages in a Mumbai-Pune Highway Road and Palm-Beach Road city scenario, if the network load is high since some nodes will drop over 85% to 90% of their data packets. Location messages will be a central part of vehicle communication systems and much traffic safety application will depend on locations. In addition, when the network load increases, the benefits of scheduling transmissions in space comes into play. With CSMA, transmissions may overlap in time, both completely and partially due to unsynchronised transmissions taking place outside the sensing range of concurrent transmitters. Also partially overlapping transmissions are likely to cause decoding failures at receivers situated in between the concurrent transmitters (the hidden terminal problem). Further, when the network load increases, CSMA stations within radio range of each other are more likely to transmit at the same time due to reaching a back-off value of zero at the same time. This occurs since CSMA stations within radio range of each other are synchronized to some extent, through the channel sensing procedure, and therefore stations tend to initiate their back-off counters at the same time, when a busy channel becomes free. The selection of back-off values is not scheduled in space and thus two or more stations can be geographically co-located when reaching a back-off value of zero, reducing the packet reception probability for many receivers.

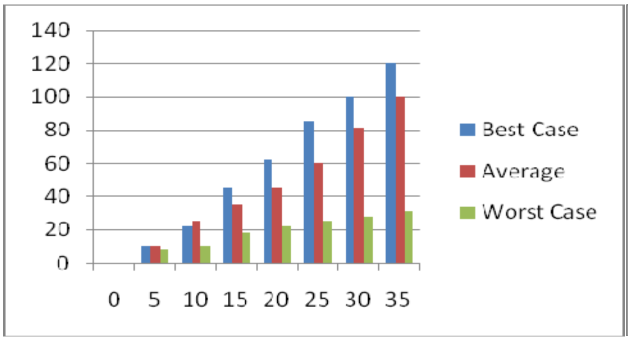


Figure 19. Channel access delay in CSMA with a sensing range of 500m, report rate 10HZ and packet length 500 byte

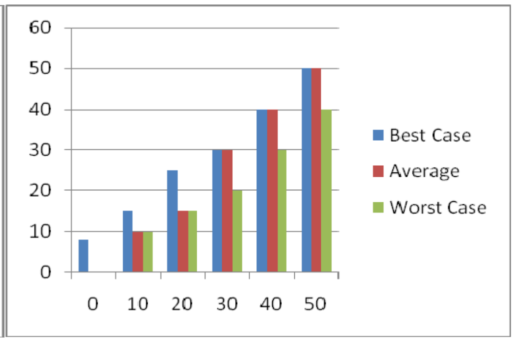


Figure 20. Channel access delay in CSMA with a sensing range of 1000m, report rate 10HZ and packet length 1000 byte

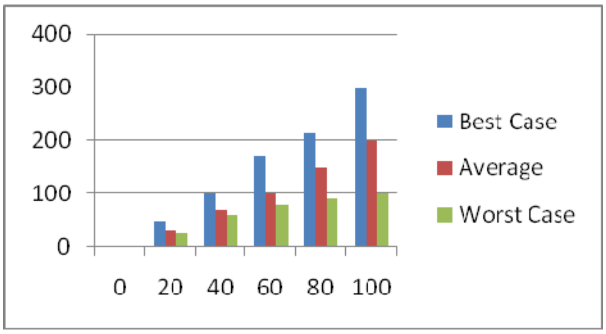


Figure 21(a). Sensing Range 500 meters

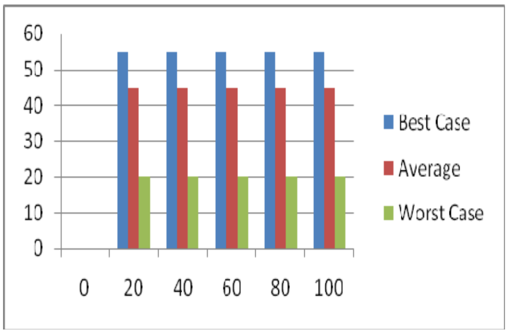


Figure 21(b). Sensing Range 1000 meters

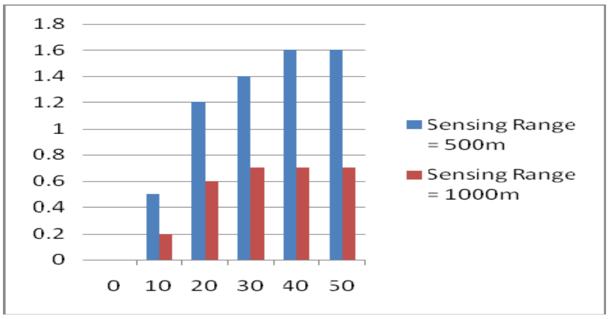


Figure 22. Number of Packets dropped due to no channel access

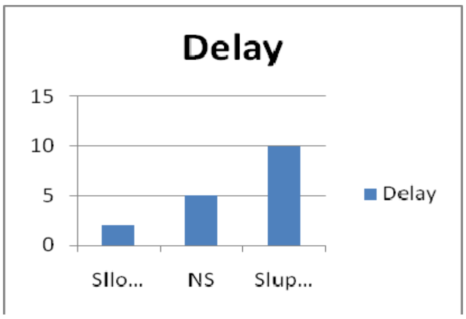


Figure 23. CDF for channel access delay in STDMA

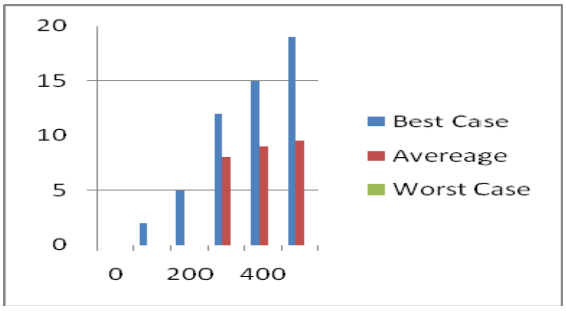


Figure 24. Utilizing the same time slot in STDMA to find minimum distance between two nodes

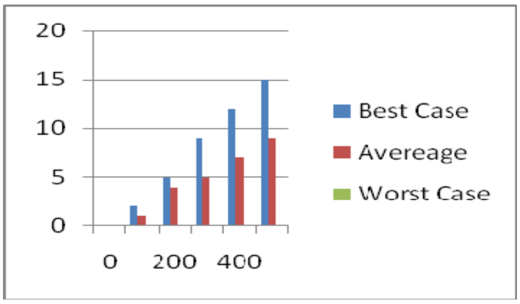


Figure 25. Sending at the same time in CSMA/CA using 300 bytes packets.10 Hz, sensing range 1km

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POTENTIAL OF PREDICTION QUANTIFICATION AND TRENDS IN TRANSPORT REQUIREMENTS AS TOOL OF TRANSPORT MANAGEMENT AND DEVELOPMENT

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The basic aim of managers in transport is to preserve and expand their share of the transport market. This should be done through prioritising quality and customer service, preservation and expansion field of transport enterprise activity to transport market on the basic of priority orientation to quality and customer, maintaining transport networks and applying the latest knowledge from research. It should also involve making a contribution to favourable indicators of economic activity, and a consideration of environmental change. This paper deals with customer requirements, the possibility of quantifying customer requirements and the recognition of future trends on the basis of assessments of recent quantitative results and the application of managers' knowledge and techniques.

Keywords: transport, prediction, region, transport performance, number of passengers**,** mass public transport (MPT)

1. Introduction

Transport is a phenomenon that consists of a large number of successive sub-events forming a complex whole. Human activities are always a key to this activity, because transport (except for planning, design, organization, management) involves controlling the movement of vehicles in space and time [3].

The competitiveness of a service provided by a transport enterprise is likely to improve if the enterprise is interested in meeting basic customer needs regarding safety, quality, reliability and cost. For this reason it is important that the carrier should concentrate on the continuous monitoring of customers' requirements and indicators of transport performance at and between different locations.

2. Quantified Performance of Mass Public Transport (MPT)

Passenger transport is a necessary consequence of the spatial distribution of activities and consequence of the adoption, use and settlement of the development environment. Passenger transport enables vital communication links generated by the interaction of the basic functions of the city (residence, workplace, cultural centre) to be maintained [2, 7].

Transport requirements of the population have significant effects on the way people live. The function of public transport is to provide transport connections to meet public demand as far as is practicable. At the same time, it is important that public transport organisations should be as efficient as possible to limit the demand for regional resources [6].

The quantification of customers' requirements in regard to transport processes can be realised by transport indicators (number of passengers and transport performance). Trends can be identified by the progression of indicators that change with respect to time function and dependence on parameters. These represent trend tendencies.

The Slovak Republic can be divided into the following regions (Fig. 1):

= Bratislava region,
= Trnava region,

= Trencin region,
= Nitra region,
= Zilina region,
= Banska Bystrica region,
= Kosice region,
= Presov region.

Figure 1. Regions of the Slovak Republic [9]

The Slovak Republic is located in Central Europe with surface area of 49 035.56 km^2. The number of inhabitants is 5 410 836 (of which females 51.3 %). The capital city is Bratislava with 415 589 inhabitants. The Slovak Republic consists of 8 regions. In 2012, the most inhabitants lived in Presov region (817 382 – 15.1 % of the total population). On the contrary, the least inhabitants lived in Trnava region (556 577 – 10.3 % of the total population). Banska Bystrica region is the largest from all of them with surface area of 9 454.32 km^2 and with the lowest population density per km^2 (69.6). Conversely, the smallest region is Bratislava region (2 052.62 km^2), in its turn there is the highest population density per km^2 (298.5). The average population density per 1 km^2 in the Slovak Republic is 110.3.

Table 1. The Basic Data about Slovak Regions

Region	The number of inhabitants	Area in km^2 by region	Population density per km^2
Bratislava	612 682	2 052,62	298,5
Trnava	556 577	4 146,40	134,2
Trencin	593 159	4 501,98	131,8
Nitra	688 400	6 343,78	108,5
Zilina	690 121	6 808,58	101,4
Banska Bystrica	658 490	9 454,32	69,6
Kosice	794 025	6 754,51	117,6
Presov	817 382	8 973,37	91,1
Total	**5 410 836**	**49 035,56**	**110,3**

Data are on 31.12.2012 [8]

The number of passengers using public transport for their everyday trips has been decreased during the last years in the Slovak Republic. This development is very similar to the development in most of the countries in Europe in the last decades [7].

The trend regarding the number of passengers in several regions of the Slovak Republic for the period 2001-2012 is shown in Table 2. From a long-term perspective, the trend in the number of passengers shows a decrease almost every year for every region (or about the same value), with the exception of the Trencin region in the year 2005 and the Nitra region in the year 2008.

Table 2. Number of Passengers in the Enterprises, which are Specialised in Road Transport (Thousands of Passengers)

	Number of passengers (thousands of passengers)								
Region / *Year*	**Bratislava**	**Trnava**	**Trencin**	**Nitra**	**Zilina**	**Banska Bystrica**	**Kosice**	**Presov**	***Total***
2001	22 743	47 832	95 495	85 399	89 076	104 041	52 895	68 964	***566 445***
2002	22 549	45 047	90 024	75 503	86 408	98 533	49 858	68 691	***536 613***
2003	20 220	40 354	81 651	65 293	79 103	95 775	45 501	65 809	***493 706***
2004	19 014	37 772	77 397	62 815	73 437	87 886	42 621	60 830	***461 772***
2005	18 229	37 549	85 019	61 436	69 187	79 999	41 219	56 818	***449 456***
2006	17 658	36 783	65 209	58 066	66 704	63 824	41 657	53 369	***403 270***
2007	17 094	35 145	62 301	58 101	62 926	59 487	40 488	49 095	***384 637***
2008	16 934	33 071	59 151	60 106	58 975	53 745	37 667	45 870	***365 519***
2009	15 722	29 027	53 177	54 651	52 904	46 020	32 037	39 604	***323 142***
2010	15 748	28 437	51 506	53 866	50 332	45 020	29 336	38 472	***312 717***
2011	15 564	27 450	48 242	50 175	49 745	42 692	29 341	36 370	***299 579***
2012	14 543	26 441	44 747	48 138	50 918	41 367	28 046	35 028	***289 228***
									4 886 084

Source: The Statistical Office of the SR

The greatest decrease in the number of passengers was in Banska Bystrica region. There was a decrease in the number of passengers over the period from 104.041 millions passengers to 41.367 thousand passengers. This is a substantial (60.2 %) decrease between the years 2001 and 2012. Conversely, the lowest decrease in the number of passengers was in Bratislava region, (36.1 %) from 22.743 thousand passengers in 2001 to 14.543 millions passengers in 2012. The average decrease in the number of passengers for all the regions during the period 2001-2012 is 48.9 %, from 566.445 millions passengers in 2001 to 289.228 millions passengers in 2012 (Fig. 2).

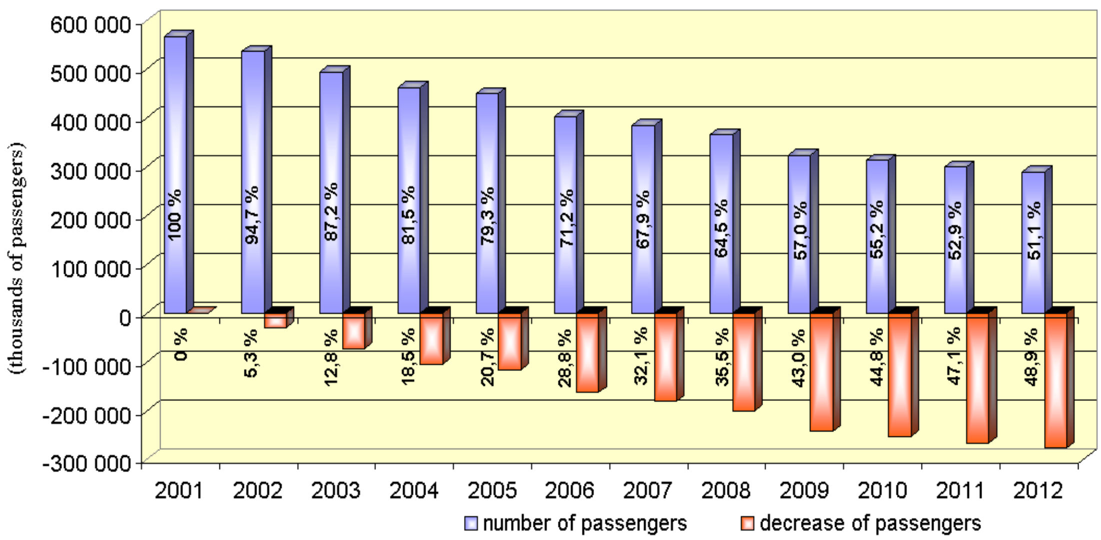

Figure 2. Trend in Number of Passengers in Enterprises, which are Specialised in Road Transport in Regions of the Slovak Republic

To ensure a serviceable transport system in the regions, regional transport systems operate with different capacities for different means of transport and deal with different passenger demand. It is necessary to monitor also the actual transport performance in millions of passenger-kilometres rather than the number of passengers. There is a comparison of trends in transport performance over several years of monitoring time shown in the Table 3. The greatest decrease in transport performance was in the Presov region. The decrease in Transport performance decreased from 1 205 millions of passenger-kilometres in 2001 to 536 millions passenger-kilometres in 2012. This is a substantial decrease of 55.5 %. The lowest decrease in transport performance was in the Bratislava region: 24.6 %, from 566 millions passenger-kilometres to 427 millions of passenger-kilometres. The average decrease in transport performance for all the regions during the period 2001-2012 is 44.5 %, from 8 253 millions passenger-kilometres in 2001 to 4 584 millions passenger-kilometres in 2012.

Table 3. Number of Transport Performance in the Enterprises Specialised in Road Transport (Millions of Passenger-kilometres)

Region	*Transport Performance (millions of passenger-kilometres)*											
	2001	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*
Bratislava	566	820	483	511	469	479	478	449	360	364	411	427
Trnava	729	716	665	661	675	771	780	676	521	513	524	506
Trencin	992	974	934	1 006	1 019	971	1 084	706	586	666	645	666
Nitra	1 316	1 411	1 289	1 271	1 192	1 267	1 212	997	785	723	748	712
Zilina	1 055	989	1 096	863	872	818	937	747	620	567	602	615
Banska Bystrica	1 307	1 136	1 082	1 159	1 193	1 232	1 208	954	567	578	603	606
Kosice	1 083	988	1 073	914	942	950	952	836	501	457	528	516
Presov	1 205	1 202	1 135	1 497	1 163	1 177	945	1 081	598	568	550	536
Total	***8 253***	***8 236***	***7 757***	***7 882***	***7 525***	***7 665***	***7 596***	***6 446***	***4 538***	***4 436***	***4 611***	***4 584***

Source: The Statistical Office of the SR

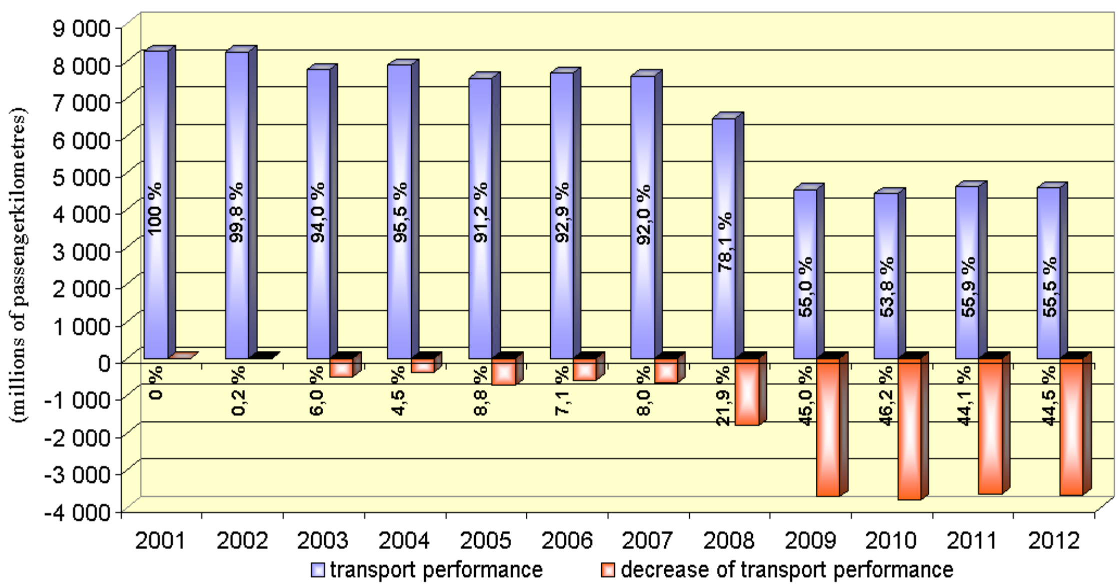

Figure 3. Trends of Transport Performance in Enterprises Specialised in Road Transport in Regions of the Slovak Republic

Figure 3 shows the recorded trend of transport performance in several regions of the Slovak Republic over the years 2001-2012. While the number of passengers carried by organisations specialising in road transport in regions of the Slovak Republic decreased overall, transport performance showed a slight upward trend in some years (for example years 2004, 2006 and 2011), a significant decrease was occurred in 2009. In 2012, the transport performance for the regions of the Slovak Republic was at of 55.5 % of the level recorded in 2001.

3. Determination of Trend Performance MPT

The modelling of transportation and transport processes in a major territory unit (region or district) uses the same methods as in towns. On the other hand there are some differences, which must be considered. First of all, there are the size of the modelled area and the volume of requirements for the input data regarding the distribution of activities in the area, and regarding the transport networks. Next, there are the specific characteristics of behaviour of people living in towns or in the country, or in different parts of the area. There are regions where industry, agriculture or recreational use prevails, and they have different social and economic conditions [4].

The succession of steps that allow a forecast in the trend of transport indicators to be determined is represented in the next figure. Input information for choosing the appropriate model for trends and predictions for the selected region (Zilina region) introduces quantified customer requirements to the transport process (indicators of MPT performance). These take into consideration the spatial distribution of the Slovakian territory and the time aspect (time period: years 2001-2012).

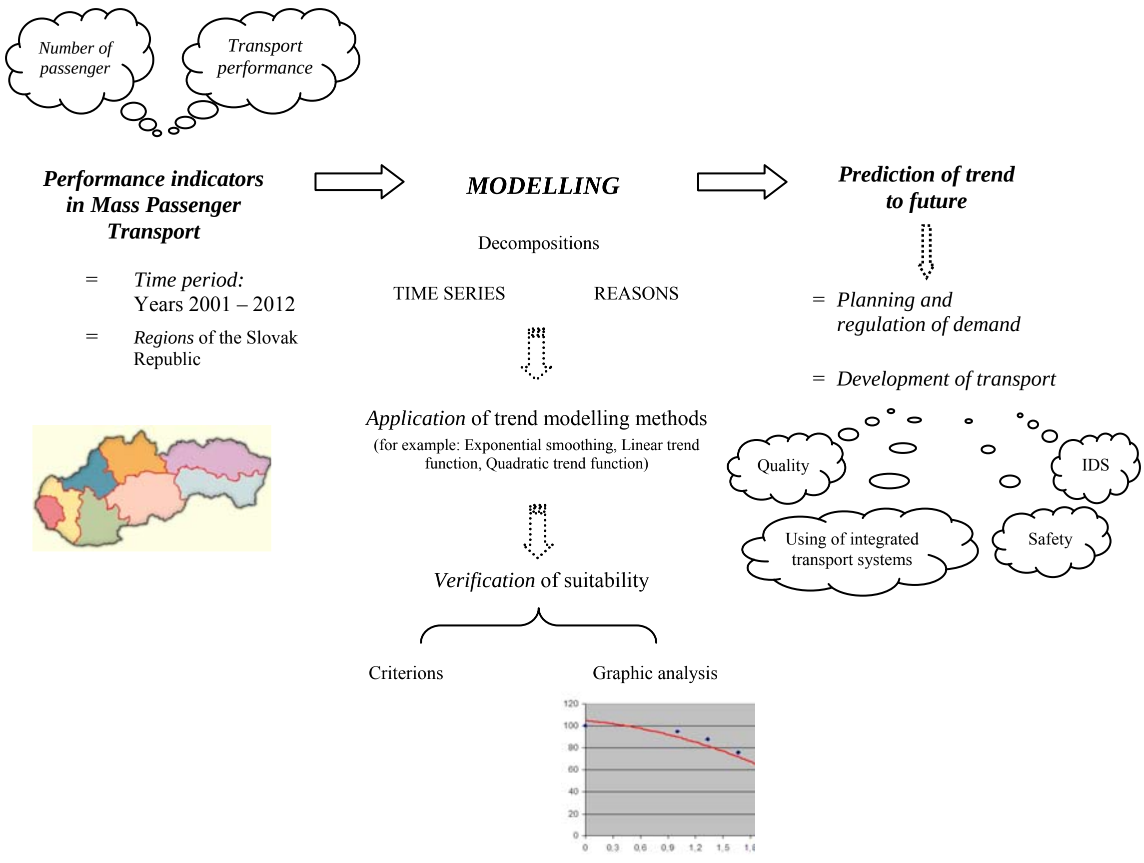

Figure 4. Succession of Steps for Determination of Trend Performance MPT

The correct identification of input information creates the basis for modelling, which is a tool of systemic analysis of complicated problem solving. This can include also the determination of development of investigating indicators prediction. Model choice is influenced by the time series analysis of input information on the basis of decomposition. The main reason for decomposition is the revelation of relations and trend tendencies. The forecast is likely to be more accurate if seasonal variation is removed. The main condition is to represent every single value of the time series that can be represented as a summation or product of its components by single models of the time variable.

Table 4. View of Selected Prognostic Methods

Methods	***Form***	***Characteristic***
Exponential smoothing	$S_t = \alpha \sum_{k=0}^{N-1} \beta^k y_{t-k}$ $\hat{y}_t = a_{0,(t-1)} + a_{1,(t-1)}.\tau$ where $\tau = 1$	= form for exponential average = exponential smoothing is suitable for modelling of time series with fluctuations. The greatest weight is attributed to the youngest observation. = weight decreases exponentially with time. The rate of smoothing is dependent on the size of the smoothing factor α. *Brown's double exponential smoothing* and *Holt exponential methods* are suitable for the local linear trend in time series,
Linear trend function	$T_t = A_0 + A_1.t$	= are regression models, where the independent variable is time, respectively its modification. = trend functions are appropriate for a uniform values over the time series, = where A_0, A_1 are parameters of the regression relationship
Quadratic trend function	$T_t = A_0 + A_1.t + A_2.t^2$	= are regression models, where the independent variable is time, respectively its modification. = trend functions are appropriate for a uniform values over the time series = where A_0, A_1, A_2 are parameters of the regression relationship

The choice of the optimal method in terms of exactness of processing and accuracy is conditioned not only by theoretical knowledge of the selected method but also by a considerable amount of experience and subjectivity. Achieved outcomes should be the starting point for the process of making important decisions in a firm [5].

The application of selected methods represents a choice of appropriate trend function for a given time series on the basis of realized decomposition and estimated attributes of development with respect to examined problems. Model parameters will be estimated from the value time trend. In case we should initiate presumption parameters, the complete condition of importance can be used to determine the forecast.

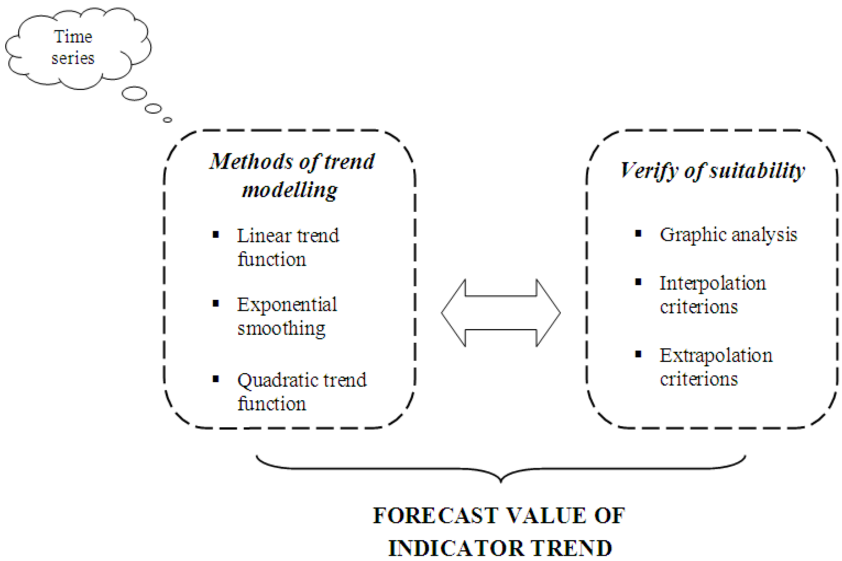

Figure 5. Succession of Steps for Forecast of Indicator Trend

The verification of the appropriateness of the applied methods is realized on the basis of an adjudication of selected criteria because of the reason of measure precision; smoothing finding or average value residues characteristics introduces value RMSE.

$$RMSE = \frac{1}{N}\sum_{t=1}^{N}\left(y_t - \hat{y}_t\right)^2 , \tag{1}$$

where: y_t ~ variance of real trend value,

$\hat{y}_t$ ~ smoothing - estimated trend value,

$RMSE$ ~ Root Mean Square Error.

Consecutively after evaluation of reached results quantities, value of future trend investigating indicators follows the period of the year 2013.

Table 5. Indicators of MPT of Zilina region at the Period of Years 2001-2013

Year	***Value of MPT indicator***		***Predictions of MPT indicator***	
	Number of passengers *(thousands of passengers)*	***Transport Performance*** *(millions of passenger-kilometres)*	***Number of passengers - by methods exponential smoothing*** *(thousands of passengers)*	***Transport Performance - by methods linear trend function*** *(millions of passenger-kilometres)*
2001	89 076	1 055	89 799.8	1 085.45
2002	86 408	989	84 405.1	1 035.02
2003	79 103	1 096	79 334.6	984.582
2004	73 437	863	74 568.6	934.145
2005	69 187	872	70 089.0	883.709
2006	66 704	818	65 878.5	833.273
2007	62 926	937	61 920.9	782.836
2008	58 975	747	58 201.1	732.4
2009	52 904	620	54 704.7	681.964
2010	50 332	567	51 418.4	631.527
2011	49 745	602	50 332.3	600.154
2012	50 918	615	49 745.1	**552.577**
2013	-	-	**50 917.9**	**505.01**

Values of ***transport performance*** time series reached relatively periodic trend in monitored period of years 2001-2012.

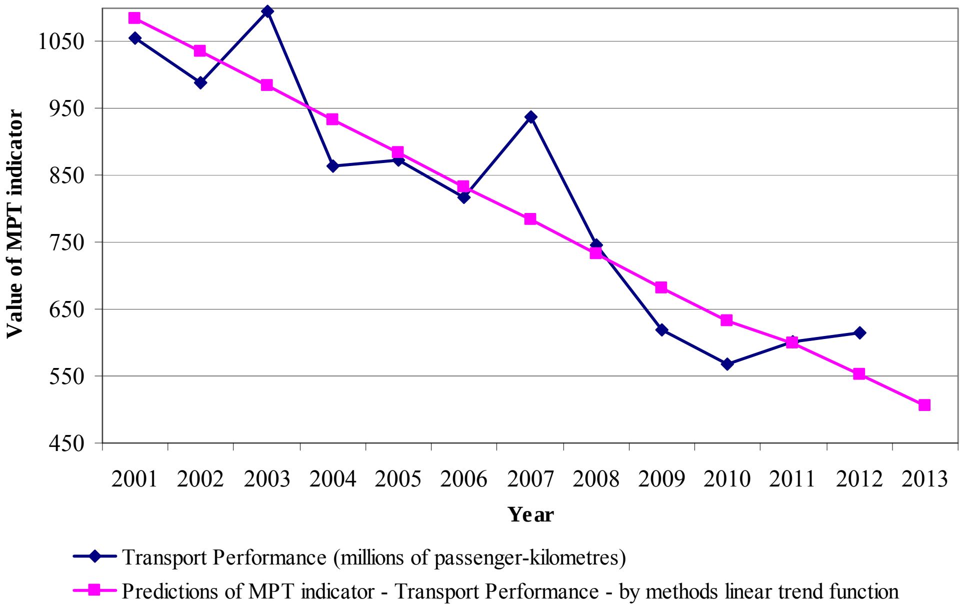

Figure 6. Predictions of MPT Indicator – Transport Performance of Zilina region

To initiate the regulated time period, the service methods were used on the basis of graphic analysis adjudication *Quadratic trend function, Holt's exponential smoothing* and *methods of Linear trend function* and methods of *exponential smoothing*. After the application of the time series, the verification of the appropriateness of single methods by selected criteria followed.

As the most appropriate method to describe the trend of the time series methods in the best way, *methods of Linear trend function* has been evaluated because, according to determined criteria, it recorded the lowest value of RMSE (75.6364) and all model parameters were important. Other applied methods had no important model parameters; and so it is not possible to recommend the application of these methods (*methods of Holt's e exponential smoothing* and *exponential smoothing*).

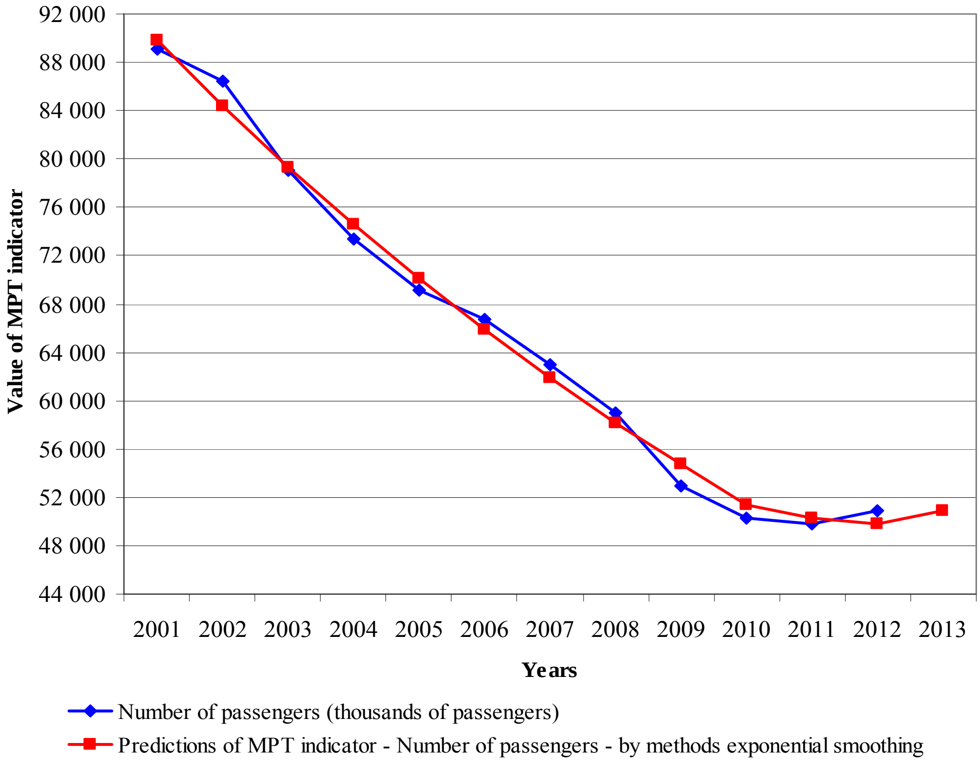

Figure 7. Predictions of MPT Indicator – Number of Passengers of Zilina region

Number of passengers by using the method of *exponential smoothing* the best results were achieved and the forecast values for the year 2013 were quantities of 50 917.9 thousands of passengers.

4. Conclusions

Transport is one of the basic sectors that significantly affect socio-economic development and increases in living standards. This makes it one of the key factors in the development of each society. It is not a goal in itself, but a means of economic development and a prerequisite to achieving social and regional cohesion [1].

Transport management concentrates on assessments of measures of the requirement for convenient transport, the requirements for a particular type of transport and transport service and maintaining or extending the existing market for transport.

In transport management it is necessary to create a modern structure and procedure for managerial work. The implementation of those appropriate prognostic methods and planning models allows the determination of the planned value of supply and demand by evaluating the time series trend, thereby introducing a possible way to realise stable and long-time results for the regional transport enterprise activities. In addition it could enable the application of intelligent transport systems, the integration of transport systems and improved safety and quality of service with higher value-added.

Accomplishment of fundamental functions and operations of populate regions and city depends on mass passenger transport that must ensure all necessary transport requirements. To forefront extends distinctively strongly urgency of good coordination of all operations in complete transport systems in conditions increasing transport requirements and demands to regions and cities development [3].

Essential is in the process coordination otherwise self-contained participants (municipalities, cities, interest groups, natural person, juristic person, etc.) and place/put/lay emphasis on creativity, communication ability, ideas richness, engagement, effort to solve problems, flexibility, persuasion and natural authority [1].

In regional management is necessary to create modern and elementary procedure and structure of managerial work. Just implementation of appropriate prognostic methods and planning models those allow determining planned value of supply and demand by evaluation of time series trend introduces to possible solution to reach stable and long-time results of region and transport enterprise activities and also to application of intelligent transport systems, integrate transport systems, safety and quality of services.

Regional management of area can allow to Slovak regions and municipality fast adaptation to conditions EU market as innovation and integrated management tool. Regional management can help to break through and assume to market with competitive supply that to Slovak gives new human and financial capital and ensures so long-term perspective and permanent sustainable development.

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BENCHMARKING AND ASSESSMENT OF GOOD PRACTICES IN PUBLIC TRANSPORT INFORMATION SYSTEMS

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The development of the Public Transport (PT) services in the last decade is characterized by wide implementation of various information systems and technologies, which cover different transport services, such as traffic planning, traffic network monitoring, management of operation of PT fleets, providing information to the passengers, ticketing payment, etc. The article considers the research part of a large EU-funded project POLITE aimed at public transport sector and increasing the awareness of infomobility services and PT attractiveness through the application of identified Good Practices and Best Practices. The objective of this paper is presentation of the methodology of benchmarking and assessment of Good Practices and choice of the best one on the basis of the multi-criteria comparative analysis. For assessment of Good Practices the AHP (Analytic Hierarchy Process) method is applied.

Keywords: public transport, infomobility, Good Practice, benchmarking, multi-criteria analysis, AHP method

1. Introduction

Multimodal integrated travel information, planning and ticketing services could play a significant role in improving modal integration, thus increasing the attractiveness of collective mobility and public transport (PT). One of the principal achievements of the latest decade is expanding direct access to the information services via the internet; the access is provided for all categories of users (passengers, managers, traffic controllers, agents, etc.), and the information services obtain such property as infomobility [2].

The term "infomobility" is not much used in the academic literature. One of the definitions is: "Infomobility systems provide access to information and services for the support of user mobility. Bidirectional communication between the client devices and the system that can travel by several different transportation means, ranging from cars to trains to foot" [3]. Another view was mentioned in T-TRANS report [8]: "Reliable, personalized, and "anytime-anywhere" based real-time travel and traffic information (RTTI) is a key element of intelligent mobility services envisioned for the future… The activities in the InfoMobility sector mainly focus on: Traffic and traveller information; Geo-localization; Freight and logistics, Access and demand management". In the work [7] infomobility is defined as "a theme increasingly debated due to its potentiality of making the mobility system more efficient and effective in meeting users' needs".

Considerable experience of the regional development activities in infomobility in PT has accumulated [1-3]. One of the possible ways of improving PT services is to identify and facilitate the transfer of existing practices that work successfully. Therefore the task of selection and transference of Good Practices (GP) in PT services is a very important and urgent.

This article presents the research part of a large EU-funded project POLITE aimed at public transport sector and increasing the awareness of infomobility services and PT attractiveness through the application of identified Best Practices and other recommendations [5]. The project runs from the beginning of the 2012 until the end of 2014 and focuses on the sub-theme "Energy and Sustainable Transport".

POLITE partners work together in the exchange and transfer of experiences and improvement of policies, knowledge and GP on infomobility services in their regions, with the goal of improving their PT information systems. Due to exchange and transfer knowledge POLITE partners are divided on two groups:

1. *Good Practice Sites:*
   - Province of Ferrara (PoF, Italy);
   - Reading Borough Council (RBC, United Kingdom);
2. *Transfer Sites:*
   - Calabria Regional Administration (CRA, Italy) – Leader partner;
   - Polis (Pol, Belgium);
   - Institute of Logistics and Warehousing (ILIM, Poland);
   - Transport Research Centre (CDV, Czech Republic);
   - Latvian Transport Development and Education Association (LaTDEA, Latvia).

POLITE addresses infomobility, specifically the problem of providing travellers with adequate and complete information on the PT services available in a region at different geographic levels. The project promotes public actions to enhance the awareness of travellers' choice and to increase the use of PT services [5]. The objective of this paper is to present the comparative assessment of GP in PT infomobility developed under project POLITE and presented and discussed with project partners at the May 2013 in Reading (UK).

2. Definition of the Problem

The research is focused on evaluation of GP and choice of the best one in PT information systems. Examples of considered systems are Real Time Passenger Information Systems, Smart Ticketing Payment Systems, Priority at Traffic Signals Systems, etc.

Several interrelated terms are used in the literature to refer to GP. Those terms sometimes overlap in some aspects and differ in others, refer to different things. Let us identify a Good Practice as "an initiative (e.g. methodologies, projects, processes and techniques) undertaken in one of the programme's thematic priorities, which has already proved successful and which has the potential to be transferred to a different geographic area. Proved successful is where the Good Practice has already provided tangible and measurable results in achieving a specific objective" [4].

The problem of searching for the GP and then selection of the best should be performed taking into account the variety of different criteria determining the efficiency of the information services: economic, technological, social, ecological, and so on. In the present article this problem is formulated as the multiple-criteria decision-making task.

As follows from the studies conducted in the project we can compare GP taking in account the number of their measures (or submeasures), which comprehensively cover the overall objectives of PT (see Fig.1).

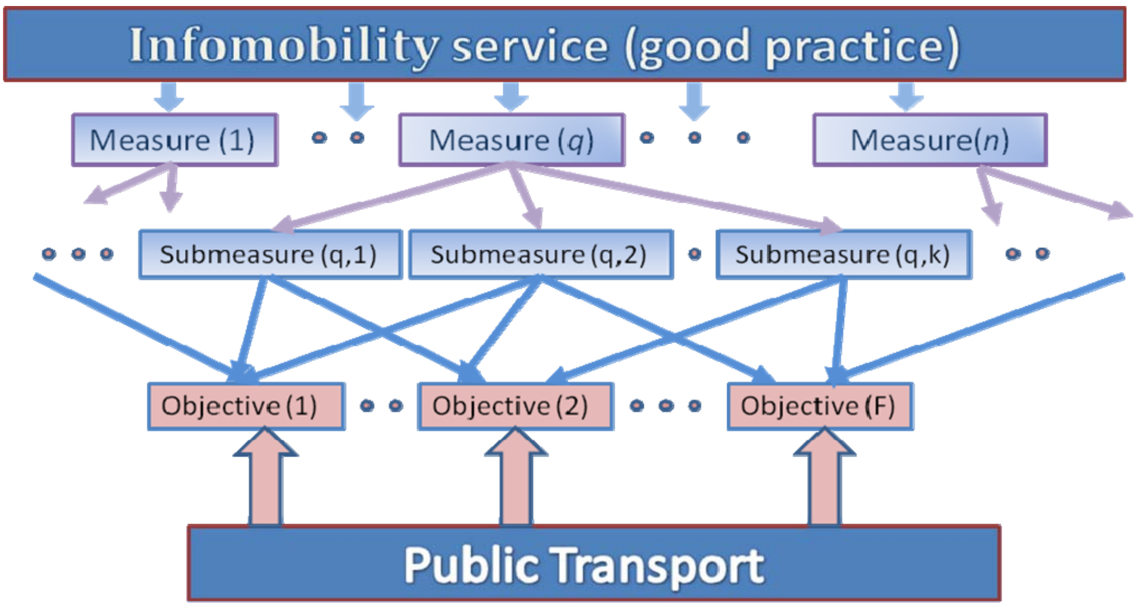

Figure 1. The scheme of infomobility services impact on PT efficiency

The determination of GP efficiency was used on the analysis of the measures, which cover the following objectives:

1. Improving city attractiveness;
2. Improving PT services;
3. Improving PT efficiency;
4. Increasing the PT mode share;
5. Decrease congestion;
6. Emissions and pollution reduction.

GP sites for project POLITE are likely to have implemented a system / systems or services, each of which are likely to cover a range of the 54 detailed submeasures grouped in the following 10 measures:

1. PT legislation and regulation;
2. PT reorganization into multimodal system;
3. Cooperation among administrations;
4. Intelligent transport system (ITS) technical standardization for interoperability;
5. Infrastructural measures;
6. Innovative information and communications technologies (ICT) for PT;
7. Modelling tools and measures;
8. PT traffic management measures;
9. PT information measures;
10. Advanced PT ticketing.

Comparative assessment of GP and choice of the best one are considered as the task of the multi-criteria comparative analysis. As follows from the studies conducted in the project, we can compare GP taking in account the number of measures (or submeasures), which comprehensively cover the overall objectives of PT. It should be noted that a comparative evaluation and choice of GP should be carried out for practices that have the same functional purpose, for example, for Real Time Passenger Information systems.

The suggested methodology of benchmarking and comparative assessment of GP involves the following stages:

Stage 1. Study of GPs descriptions and Questionnaires completed by POLITE partners.
Stage 2. GPs classification based on functional purpose.
Stage 3. Determination of objectives priorities (impotence) for each group of GP.
Stage 4. Choice of indices characterizing GP efficiency.
Stage 5. Comparative analysis of GP and the selection of the better one for each group of GP.

Let us consider these stages more detail.

3. Stage 1: Study of Good Practices

The POLITE project should strive to identify best practices where possible, however it should be recognised that the successful identification of GP fully meets the objectives of the POLITE project. GP were identified from either a desktop study, through a questionnaire, and from site visits. The methodology of identification of potential GP was presented in POLITE report "Definition of Infomobility Policy Themes for Exchange" [5].

The process for identifying the GP has been sub-divided into 7 steps set out below:

- Desktop identification of potential GP;
- Selection of the GP;
- Production of GP Questionnaire;
- Arranging site visits;
- Good Practice Questionnaire completion;
- Site visits;
- Summary report.

In the frame of project 32 GP from 10 EU countries were identified, 6 of them were selected for site visits. The distribution of GP between 10 countries is the following: Italy – 8 practices; UK – 6; Czech Republic – 5; Latvia – 4; Spain – 2; Poland – 2; Denmark – 2; Belgium – 1; Serbia –1; Switzerland – 1. Four leading countries are Italy, United Kingdom, Czech Republic, and Latvia.

The desktop reviews of GP and the detailed GP data through site visiting were described in GP Questionnaires completed by POLITE partners, and were analysed and presented in appropriate charts and tables [5]. The GP overview and their measures are presented in Table 1.

Table 1. Surveyed sites and Good Practices: overview and categories of measures

No	Good Practices	Measures: PT Legislation and Regulation	PT Operational Reorganisation into Multimodal Measure	Cooperation among administrations	ITS Technical Standardisation for Interoperability	Infrastructure Measures	Innovative ICT for PT	Modelling Tools and Measures	PT and Traffic Management Measures	PT Information Measures	Advanced PT Ticketing
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	Traffic monitoring and management: Floating Car Data (FCD) as traffic sensors. *Torino/ Italy*			X	X			X	X		
2	Stimer / Mi Muovo Project - Mobility Integrated Fare System in RER (Emilia-Romagna Region) - buses, trains and bike sharing. *Region Emilia-Romagna/ Italy*	X	X	X	X		X	X		X	X
3	Multi-channel Information system on mobility at regional scale. *Campania/ Italy*		X				X		X	X	
4	Sustainable Mobility Plan (SMP). *Santander/ Spain*	X	X	X		X	X	X	X	X	X
5	Traveller Information / Mobilitami. *Marche / Ancona and Senigallia/ Italy*						X				
6	Traffic Management. *Verona/ Italy*				X	X			X		
7	Intermodal infomobility platform and SMS ticketing. *Genova / Liguria/ Italy*		X			X				X	X
8	Traffic Management during big events. *Perugia/ Italy*		X			X			X		
9	SMS ticketing service. *Flanders/ Belgium*				X		X				X
10	Mobility and traffic management in firms. *Valjevo/ Serbia*		X						X		
11	Open Public Transport Data. *London/ UK*	X			X		X			X	
12	Real Time Passenger IS, Bus Priority at Signals, Public Transport mobile apps, City Access Control. Smart Card. *Cambridgeshire County Council/ UK*	X		X		X	X		X	X	X
13	Bus Lane Enforcement. *Reading Borough Council/ UK*	X		X	X		X		X		
14	Real Time Information System & Bus Priority at Signals. *Greater Bristol/ UK*	X		X		X	X	X	X	X	
15	Real Time Passenger Information System, Bus Priority at Signals, Disability Accessibility. *City and County of Swansea/ UK*					X	X		X	X	
16	Mobile travel information. *Aalborg/ Denmark*						X		X		
17	On-board bus travel information. *Aalborg/ Denmark*								X	X	
18	Real Time Passenger Information System (Mezi). *Bern/ Switzerland*									X	
19	Demand responsive transport (Tele-bus). *Kraków/ Poland*								X		
20	Advanced PT Ticketing (Skycash). *Poland*										X

Continuation

1	2	3	4	5	6	7	8	9	10	11	12
21	Multimodal Journey planner for the Czech Republic. *Brno/ Czech Republic*		X		X	X				X	X
22	Integrated public transport system and smart ticketing. *Ostrava and Silesian-Moravian region/ Czech Republic*	X	X	X	X	X	X	X	X	X	
23	Public Transport dispatching under KORDIS integrator/organizer: CED. *Brno and South Moravian region/ Czech Republic*		X	X	X	X	X	X	X	X	
24	Real Time Passenger Information System. *Central Bohemia region/ Czech Republic*		X	X	X	X	X	X	X	X	
25	Multimodal Integrated Transport. *Prague and Central Bohemia / Czech Republic*		X	X	X	X	X	X	X	X	
26	Unified intermodal cargo service. *Riga region/ Latvia*			X		X				X	
27	Interchange Principe Pio. *Madrid/ Spain*		X								
28	Integrated system of selling and reserving tickets. *Riga/ Latvia*	X			X					X	X
29	Atlas Public Transport Ticketing System in Riga. *Riga/ Latvia*										X
30	Interactive passenger service in train traffic. *Riga region/ Latvia*			X					X	X	
31	Premier Route Bus Corridor Network. *UK*			X		X	X		X	X	
32	Gestione Informata Mobilita' – G.I.M. *Province of Ferrara – Emilia Romagna Region/ Italy*		X	X	X	X			X		

Let us characterize the selected set of GP using such important features as objectives support, belonging to the public or the private sector, territorial and political levels. Visual performances of these characteristics are presented below on Figures 2-5.

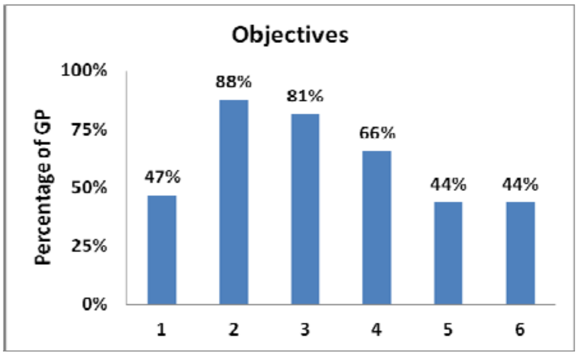

Figure 2. Objectives covering by GP

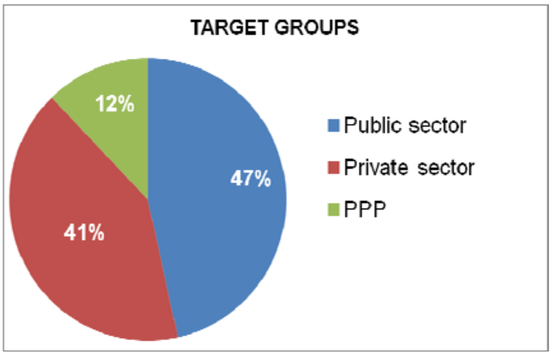

Figure 3. Distribution of GP target groups

As can be seen on Figure 2, the main objectives for considered GP of infomobility services are #2 "Improvement of PT Services" and #3 "Improving PT Efficiency". The objective #4 "Increasing PT Mode Share" is in the third place with 66%. The other three objectives: #1 "Improving City Attractiveness", #5 "Decreasing Congestion" and #6 "Decreasing Congestion" – are covered by a smaller number of GP (from 44% to 47%).

The pie chart "Target Groups", shown on Figure 3, illustrates that private and public sectors have almost the same position in informobility services area.

The pie chart "Policy – Territorial", shown on Figure 4, illustrates territorial level division. Regions and metropolis have the leading position with 30% and with 24%, accordingly. State and local divisions have almost the same value (18 and 20%, accordingly).

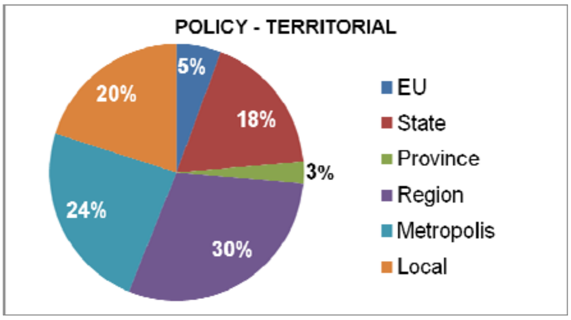

Figure 4. Territorial division of GP

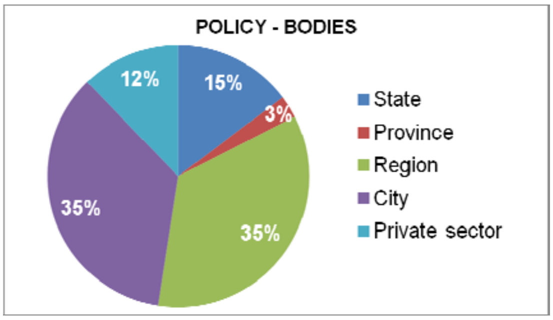

Figure 5. Political division of GP

The pie chart "Policy – Bodies", shown on Figure 5, describes political level of GP. At the first place there are two policy bodies: city level and region level with 35% both. Next policy body is the state (15%); the private sector has 12% and province – just 3%.

4. Stage 2: GP Classification Based on Functional Purpose

In the frame of project GP in informobility services were classified in the following five groups:

1. Public Transport and / or Multimodal Information Systems:
   - Bus Automatic Vehicle Location (AVL);
   - Real Time Passenger Information Systems (RTPI);
   - Real Time Traveller Information systems, bus stops, on bus, in public locations, on web, on mobile devices;
   - Journey Planning Systems (single mode / multimodal).
2. Public Transport Fleet Management Systems.
3. Public Transport Interchanges.
4. Public Transport Priority Systems:
   - Bus priority at signals;
   - Bus Gates / Bus Lanes;
   - Enforcement systems e.g. bus lane enforcement;
   - Access controls.
5. Public Transport Payment Systems
   - Pre Pay Contactless Smart Cards;
   - Innovative Incentive Scheme.

The classification of 32 GP under consideration is presented in Table 2. As can be seen from this table, the most representative group is "PT and/or Multimodal Information Systems", which included 10 practices. The comparative assessment and choice of GP is carried out separately for each group of GP.

Table 2. Distribution of GP

Group No	Name of Group	Membership of Group (GP numbers)
1	PT and / or Multimodal Information Systems	7, 11, 14, 16, 17, 18, 21, 24, 30, 31, 32
2	PT Fleet Management Systems	4, 6, 8, 10, 19, 26
3	PT Interchanges	1, 2, 3, 23, 25, 27
4	PT Priority Systems	5, 12, 13, 15
5	PT Payment Systems	9, 20, 22, 28, 29

5. Stage 3: Determination of Objectives Priorities for Group of GP

Let for the given group of GP the weights of objectives are defined by the vector $\boldsymbol{\beta} = (\beta_1, \beta_2, ..., \beta_6)$, where β_j is the weight of *j*-th objective; $\beta_j \geq 0,\ j = 1,2,...,6$ and $\sum_{j=1}^{6} \beta_j = 1$. Notice that for equal weights of all objectives we have: $\beta_j = 0.167$ for $j = 1,2,...,6$.

In this research to perform the calculations of the weights of objectives the pairwise comparison scale 1-9, proposed by T. Saaty in AHP method [6], is offered. This scale has the following weights *w*1 and *w*2 for two objectives (alternatives) A1 and A2:

*w*1=1; *w*2=1, if two objectives A1 and A2 are equal in importance;
*w*1=3; *w*2=1/3, if A1 is weakly more important than A2;
*w*1=5; *w*2=1/5, if A1 is strongly more important than A2;
*w*1=7; *w*2=1/7, if A1 is very strongly more important than A2;
*w*1=9; *w*2=1/9, if A1 is absolutely more important than A2,

and 2, 4, 6, and 8 are intermediate values between the two adjacent judgments. The importance of the objectives is evident from the evaluation of the priority vector [6].

The example of objectives weights for the group "PT Payment Systems", estimated by experts, is presented in Table 3. It is easy to notice that objectives "Improving PT Efficiency" with the weight 0.4368 and "Increasing the PT Mode Share" with the weight 0.2162 are more important for GP group "PT Payment Systems" than other four.

Table 3. Paired comparison matrix for objectives and results of priority vector calculation for the group "PT Payment Systems"

Group of measures	Improving city attractiveness	Improving PT services	Improving PT efficiency	Increasing the PT mode share	Decrease congestion	Emissions and pollution reduction	**Priority vector (weights)**
Improving city attractiveness	1	1/3	1/7	1/5	3	5	0.0794
Improving PT services	3	1	1/3	1	5	7	0.1985
Improving PT efficiency	7	3	1	3	7	9	0.4368
Increasing the PT mode share	5	1	1/3	1	5	7	0.2162
Decrease congestion	1/3	1/5	1/7	1/5	1	1	0.0387
Emissions and pollution reduction	1/5	1/7	1/9	1/7	1	1	0.0304

6. Stage 4: Choice of Indices Characterizing Efficiency GP

The set of indices, characterized the degree of the GP objectives covering by 10 practice measures, is used as criteria of GP efficiency. The method of GP efficiency calculation is considered below.

Let n is the number of submeasures in the l-th measure;

m_j is the number of submeasures which cover j-th objective; $m_j = \sum_{i=1}^{n} k_{i,j}$; $j = 1,2,...,6$,

where $k_{i,j} = \begin{cases} 1, & \text{if } i-\text{th submeasure covers } j-\text{th objective,} \\ 0, & \text{if } i-\text{th submeasure does not cover } j-\text{th objective} \end{cases}$ $i = 1,2,...,n$; $j = 1,2,...,6$.

Coefficient r_j characterizes proportion of measure's submeasures, which cover j-th objective

$$r_j = \frac{m_j}{n} ;\ j = 1,2,...,6 .$$

Index p_j characterizes the degree of j-th objective covering by considered measure and is calculated by the following formulae:

$$p_j = \begin{cases} 0.5 + 0.5\dfrac{m_j - 1}{n-1}, & \text{if } m_j > 0; \\ 0, & \text{if } m_j = 0. \end{cases} \tag{1}$$

The criterion P_l of *l*-th measure efficiency characterizes the degree of all 6 objectives covering by the measure with number *l*, and is determined by formulae:

$$P_l = \sum_{j=1}^{6} \beta_j p_j, \quad l = 1,2,...,10. \tag{2}$$

Vector $\mathbf{P} = (P_1, P_2, ..., P_l, ..., P_{10})$ is the criteria of GP efficiency and is used in GP comparative assessment process.

The paired comparison of GP with numbers *i* and *j* for the measure with number *l* is determined by index $\delta_l = P_l^{(i)} - P_l^{(j)}$. The values of paired comparison criterion are determined for the scale 1-9 using the value of index δ_l according Table 4.

Table 4. The scale for criterion of measure calculation in the paired comparison of PT

Difference $\delta_l = P_l^{(i)} - P_l^{(j)}$	**Values of criterion of the measure with –**	
	greater coefficient of efficiency $P_l^{(i)}$	**smaller coefficient of efficiency** $P_l^{(j)}$
$\delta_l < 0.1$	1	1
$0.1 \le \delta_l < 0.2$	2	1/2
$0.2 \le \delta_l < 0.3$	3	1/3
$0.3 \le \delta_l < 0.4$	4	1/4
$0.4 \le \delta_l < 0.5$	5	1/5
$0.5 \le \delta_l < 0.6$	6	1/6
$0.6 \le \delta_l < 0.7$	7	1/7
$0.7 \le \delta_l < 0.8$	8	1/8
$\delta_l \ge 0.8$	9	1/9

The considered approach fulfils the evaluation of the efficiency of GP in different groups with the account of the groups' specific.

7. Stage 5: Comparative Analysis of Good Practices and the Selection of the Better One for Each Group of GP

The Good Practices' measures used in criteria of efficiency **P** (2) are distributed in four groups: Organization and Legislation; Infrastructural Actions; Information Actions; Modelling. The created hierarchical structure of the criteria is shown on Figure 6. This structure has two levels of the hierarchy. The results of testing different methods of the multi-criteria analysis [9] make it possible to determine the Analytic Hierarchy Process (AHP) [6] as the most suitable one for comparative evaluation of GP and choice the Best Practice. The AHP method allows arranging the GP in the order of their efficiency and showing their difference in the given vector of criteria **P**.

Using AHP method we estimated the efficiency of GP in each group of infomobility services. As an example of GP comparative assessment let us consider the evaluation of GP of the group "PT Payment Systems". This group contains five practices for assessment presented in Table 5.

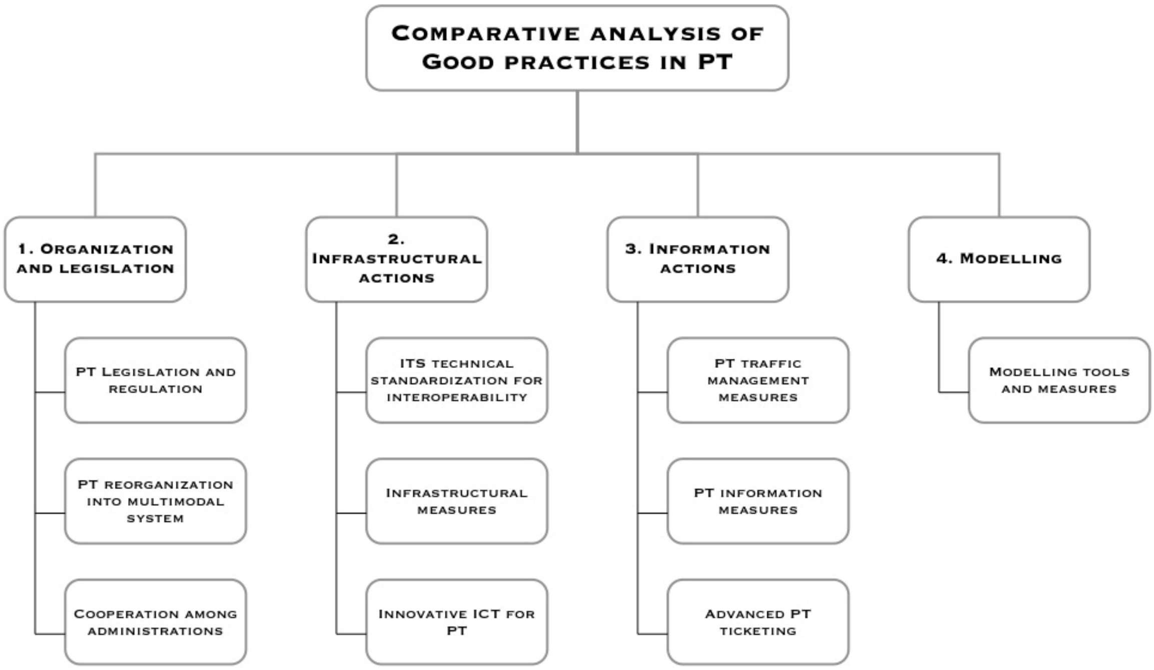

Figure 6. Hierarchical structure of the criteria (indices of measures)

Table 5. Description of GP in group "PT Payment Systems"

No	Name of Partner	Description of Good Practice
9	PoF	SMS ticketing service, *Flanders, Belgium, (Questioner)*
20	ILIM	Advanced PT Ticketing (SkyCash), *Warszawa, Poland, (Questioner)*
22	CDV	Integrated public transport system and smart ticketing, *Ostrava and Silesian-Moravian region, Czech Republic, (Site visit)*
28	LaTDEA	Integrated system of selling and reserving tickets, *Riga, Latvia, (Questioner)*
29	LaTDEA	Atlas Public Transport Ticketing System in Riga, *Riga, Latvia, (Questioner)*

The results of calculation of the criteria of each GP measures efficiency (the degree of all objectives covering by each measure) $P_l, l = 1,2,...,10$, using formulas (1), (2), are presented in Table 6.

Table 6. The criteria of each GP measures efficiency, $P_l, l = 1,2,...,10$

GP No	PT Legislation and regulation	PT reorganization into multimodal system	Cooperation among administrations	ITS technical standardization for interoperability	Infrastructural measures	Innovative ICT for PT	Modelling tools and measures	PT traffic management measures	PT information measures	Advanced PT ticketing
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
22	0.66	0.89	0.72	0.71	0.60	0.85	0.81	0.52	0.53	0.85
28	0.50	0.57	0.43	0.43	0.51	0.67	0.45	0.46	0.55	0.64
29	0.37	0.39	0.00	0.00	0.00	0.40	0.34	0.38	0.00	0.85

Paired comparison matrix for the groups of measures (an upper level) estimated by experts and results of priority vector calculation are shown in Table 7.

Table 7. Paired comparison matrix for groups of measures and results of priority vector calculation, GP group "PT Payment Systems"

Group of measures	Organization and legislation	Infrastructural actions	Information actions	Modelling	**Priority vector (weights)**
Organization and legislation	1	1/5	1/7	1	0.0685
Infrastructural actions	5	1	1/3	5	0.2830
Information actions	7	3	1	7	0.5800
Modelling	1	1/5	1/7	1	0.0685

Paired comparison matrices estimated by experts and results of priority vectors calculation for measures of the each group (a second level) are presented in Tables 8-10.

Table 8. Paired comparison matrix and priority vector for measures of the group "Organization and Legislation"

Measure	PT Legislation and regulation	PT reorganization into multimodal system	Cooperation among administrations	**Priority vector (weights)**
PT Legislation and regulation	1	1/5	1/7	0.0719
PT reorganization into multimodal system	5	1	1/3	0.2790
Cooperation among administrations	7	3	1	0.6491

Table 9. Paired comparison matrix and priority vector for measures of the group "Infrastructural Actions"

Measure	ITS technical standardization for interoperability	Infrastructural measures	Innovative ICT for PT	**Priority vector (weights)**
ITS technical standardization for interoperability	1	5	3	0.6586
Infrastructural measures	1/5	1	1	0.1562
Innovative ICT for PT	1/3	1	1	0.1852

Table 10. Paired comparison matrix and priority vector for measures of the group "Information Actions"

Measure	PT traffic management measures	PT information measures	Advanced PT ticketing	**Priority vector (weights)**
PT traffic management measures.	1	1/7	1/9	0.0592
PT information measures	7	1	1	0.4507
Advanced PT ticketing	9	1	1	0.4901

The paired comparison of GP with numbers *i* and *j* for the measure with number *l* is determined by index: $\delta_l = P_l^{(i)} - P_l^{(j)}$. The values of paired comparison criterion are determined for the scale 1-9 using the value of index δ_l according the Table 4. Table 11 gives an example of the results of pairwise comparisons and a normalised evaluation of the measure "PT Legislation and Regulation" from the measures' group "Organization and Legislation". Similar calculations were made for each of 10 measures.

Table 11. Matrix of measure “PT Legislation and Regulation” evaluations

GP No	9	20	22	28	29	Priority vector
9	1	1	1/7	1/5	1/4	0.0533
20	1	1	1/7	1/5	1/4	0.0533
22	7	7	1	2	3	0.4464
28	5	5	1/2	1	2	0.2727
29	4	4	1/3	1/2	1	0.1743

Proceeding from the received evaluations of the priority vectors of two levels of the criteria hierarchy, we have calculated the final matrix of the evaluation of the global priority vector for the GP in the group “PT Payment Systems” shown in Table 12 and on Figure 7.

The results of the evaluations allow the GP to be arranged in the order of their efficiency, and show their difference in the given set of criteria. Practice No 22 “Integrated Public Transport System and Smart Ticketing (CDV)” has the highest value of priority 0.4417 and will be selected as the better one from the considered five practices. This practice has the highest values of priorities vectors for all groups of measures. Practice No 29 takes the second place, and practice No 28 is on the third place.

Table 12. Results of GP evaluations for the group of practices “PT Payment Systems”

	Organization and legislation	Infrastructural actions	Information actions	Modelling	**Priority vector**
Weights / **GP No**	**0.0685**	**0.2830**	**0.5800**	**0.0685**	
9	0.0552	0.0575	0.0789	0.0451	0.0689
20	0.0552	0.0575	0.0539	0.0451	0.0544
22	0.5433	0.5189	0.3782	0.5587	0.4417
28	0.2558	0.2924	0.2686	0.2112	0.2706
29	0.0905	0.0736	0.2204	0.1400	0.1645

8. Conclusions

The considered research is focused on the application of Information Technologies for Public Transport. Good Practice sites for POLITE are likely to have implemented a system/systems or services each of which are likely to cover a range of the 54 detailed measures. Examples of such systems are a Real Time Passenger Information system, a Smart ticketing payment system or Public Transport priority at traffic signals.

Present article solves the issue of benchmarking and assessment of the GP on infomobility services. This problem has been formulated as the multiple-criteria decision-making task. For assessment of GP the AHP (Analytic Hierarchy Process) method is applied. The AHP method allows arranging the GP in the order of their efficiency and showing their difference in the suggested set of criteria.

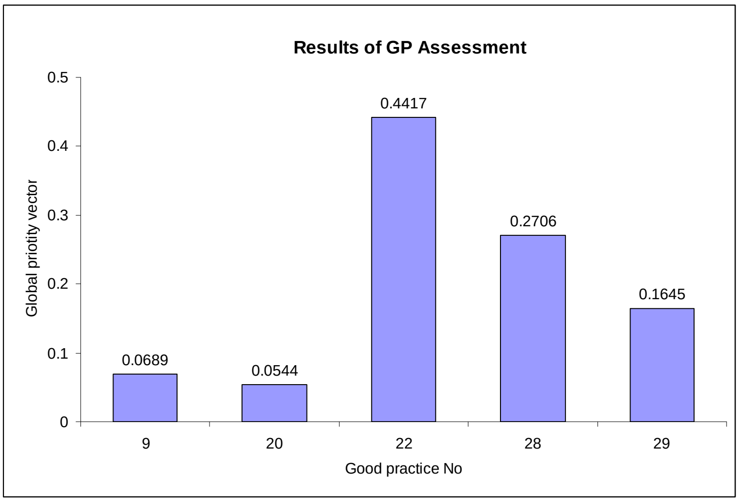

Figure 7. Results of GP evaluations for the group of practices “PT Payment Systems”

Results of GP assessment presented in this article are used as input to Transfer-oriented sessions in which project participants together with authorities, in a 3 steps path, mutually learn on how to improve infomobility policies. As well the results will be discussed during Good Practice Round Tables in 2014. At the end POLITE will result in improved policies, plans and programmes regarding Public Transport information systems in partners' sites, through experiences exchange and strengthening of competencies.

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CUMULATIVE INDEX

TRANSPORT and TELECOMMUNICATION, volume 14, no. 4, 2013 *(Abstracts)*

The paper describes the analysis and discussion of the network systems in case of the critical situation that happens during ordinary work. The formal model is proposed – based on the two types of real sophisticated network systems – with the approach to its modelling based on the system behaviour observation. The definition of the critical situation sets are created by reliability, functional and human reasons. No restriction on the system structure and on a kind of distribution describing the system functional and reliability parameters is the main advantage of the approach. The proposed solution seems to be essential for the owner and administrator of the transportation systems.

Keywords: network systems, critical sets, reliability, dependability modelling

The paper discusses the discrete transportation system's (DTS) availability problem in case of the critical situation, which happens during its ordinary work. The formal model of the transportation system suitable for modelling based on the system behaviour observation is proposed. Monte Carlo approach is in use for a simulation. The system's availability is calculated as global metric to find if the system is able to realise the loaded set of tasks. The critical situation discussed there is caused by reliability, as well as by functional and human reasons. No restriction on the system's topology and on a kind of distribution describing the system's functional and reliability parameters is the main advantage of the approach. The proposed solution seems to be essential for the owner and administrator of the transportation systems.

Keywords: reliability, discrete transportation system, Monte-Carlo simulation, critical situation sets

Critical state of operation is reached by a system when it is exposed to an unexpected coincidence of faults (such as periodic rapid increase of the service demand, unavailability of a significant proportion of vehicle operators, simultaneous breakdown of all or a large part of the vehicle fleet). This leads to complete disruption of the transportation system, which persists even after the faults are removed. The duration of critical state of operation is defined as the time needed to resume normal operation after such an incident. It is shown that this time can be predicted using the simulation tools. Furthermore, a contingency plan is proposed, based on relocation of some resources between independent parts of a hierarchically organized transportation system. This contingency plan is analysed to determine the optimal percentage of resources to be relocated and the duration of this relocation.

Keywords: discrete transportation, reliability analysis, simulation tools, risk management

In the context of a harmonized transnational transport system the green corridor concept represents a cornerstone in the development and implementation of integrated and sustainable transport solutions. Important properties of green corridors are their transnational character and their high involvement of public and private stakeholders, including political level, requiring new governance models for the management of green corridors.

Stakeholder governance models and instruments for green corridor governance are going to be developed and tested in different regional development projects in order to safeguard a better alignment of transport policies at various administrative levels and a strengthening of the business perspective. A crucial role in this context belongs to involvement of public and private stakeholders in order to safeguard efficient corridor performance.

The paper presents recent research results about green supply chain management in the frame of network and stakeholder model theory and its application to the stakeholders of green transport corridors.

Keywords: green supply chain management, green transport corridors, stakeholder governance

Khairnar, V. D., Kotecha, K. Simulation Based Performance of Mumbai-Pune Expressway Scenario for Vehicle-to-Vehicle Communication using IEEE 802.11p, *Transport and Telecommunication*, vol. 14, no. 4, 2013, pp. 300–315.

Traffic safety applications using vehicle-to-vehicle (V2V) communication is an emerging technology and promising area within the ITS environment. Many of these applications require real-time communication with high reliability; to meet a real-time deadline, timely and predictable access to the channel. The medium access method used in 802.11p, CSMA with collision avoidance, does not guarantee channel access before a finite deadline. The well-known property of CSMA is undesirable for critical communications scenarios. The simulation results reveal that a specific vehicle is forced to drop over 80% of its packets because no channel access was possible before the next message was generated. To overcome this problem, we propose to use STDMA for real-time data traffic between vehicles. The real-time properties of STDMA are investigated by means of the highway road simulation scenario, with promising results.

Keywords: CSMA, STDMA, V2V, VANET

Ondruš, J., Dicová, J. Potential of Prediction Quantification and Trends in Transport Requirements as Tool of Transport Management and Development, *Transport and Telecommunication*, vol. 14, no. 4, 2013, pp. 316–324.

The basic aim of managers in transport is to preserve and expand their share of the transport market. This should be done through prioritising quality and customer service, preservation and expansion field of transport enterprise activity to transport market on the basic of priority orientation to quality and customer, maintaining transport networks and applying the latest knowledge from research. It should also involve making a contribution to favourable indicators of economic activity, and a consideration of environmental change. This paper deals with customer requirements, the possibility of quantifying customer requirements and the recognition of future trends on the basis of assessments of recent quantitative results and the application of managers' knowledge and techniques.

Keywords: transport, prediction, region, transport performance, number of passengers**,** mass public transport (MPT)

Yatskiv, I., Kopytov, E., Casellato, D., Luppino, G., McDonald, R. Benchmarking and Assessment of Good Practices in Public Transport Information Systems, *Transport and Telecommunication*, vol. 14, no. 4, 2013, pp. 325–336.

The development of the Public Transport (PT) services in the last decade is characterized by wide implementation of various information systems and technologies, which cover different transport services, such as traffic planning, traffic network monitoring, management of operation of PT fleets, providing information to the passengers, ticketing payment, etc. The article considers the research part of a large EU-funded project POLITE aimed at public transport sector and increasing the awareness of infomobility services and PT attractiveness through the application of identified Good Practices and Best Practices. The objective of this paper is presentation of the methodology of benchmarking and assessment of Good Practices and choice of the best one on the basis of the multi-criteria comparative analysis. For assessment of Good Practices the AHP (Analytic Hierarchy Process) method is applied.

Keywords: public transport, infomobility, Good Practice, benchmarking, multi-criteria analysis, AHP method

TRANSPORT and TELECOMMUNICATION, 14. sējums, Nr. 4, 2013 (Anotācijas)

Mazurkevičs, J. Tīkla sistēmas analīze kritisko situāciju gadījumā, *Transport and Telecommunication,* 14. sēj., Nr. 4, 2013, 262.–271. lpp.

Rakstā tiek aprakstīta analīze un diskusija par tīkla sistēmām kritiskajās situācijās, kuras var izveidoties vienkāršos darba apstākļos. Rakstā tiek piedāvāts formālais modelis, – pamatojoties uz divu veidu īsti sarežģītām tīkla sistēmām – ar pieeju tās modelēšanā, balstoties uz sistēmas uzvedības novērošanu. Kritisko situāciju kopas definīcija ir izveidota uzticamības, funkcionālo un cilvēcisko iemeslu dēļ. Sistēmas struktūrai un izplatīšanas veida aprakstam nav ierobežojumu, aprakstot sistēmas funkcionālos un uzticamības parametrus, kas ir galvenā pieejas priekšrocība. Piedāvātais risinājums, šķiet, ir svarīgs transporta sistēmu īpašniekam un pārvaldītājam.

Atslēgvārdi: tīkla sistēmas, kritiskas kopas, uzticamība, uzticamības modelēšana

Mazurkevičs, J., Valkovjaks, T. Diskrētās transportēšanas sistēmas pieejamības problēma kritisku situāciju kopas gadījumā, *Transport and Telecommunication,* 14. sēj., Nr. 4, 2013, 272.–281. lpp.

Rakstā tiek izskatīta diskrētās transportēšanas sistēmas pieejamība kritisko situāciju gadījumā, kas notiek vienkāršos darba apstākļos. Transportēšanas sistēmas formālais modelis, kas ir derīgs modelēšanai, pamatojoties uz sistēmas uzvedības novērošanu, tiek izskatīts dotajā rakstā. Simulācijās ir izmantota Monte Karlo pieeja. Sistēmas pieejamība tiek aprēķināta kā globālais rādītājs, lai uzzinātu, vai sistēma spēj realizēt ielādes uzdevumu kopumu. Kritiskas situācijas diskusijai ir par iemeslu uzticamība, kā arī funkcionālie un cilvēciskie iemesli. Sistēmas struktūrai un izplatīšanas veida aprakstam nav ierobežojumu, aprakstot sistēmas funkcionālos un uzticamības parametrus, kas ir galvenā pieejas priekšrocība. Rakstā piedāvātais risinājums, liekas, ir svarīgs transporta sistēmu īpašniekam un pārvaldītājam.

Atslēgvārdi: drošība, diskrētas transporta sistēmas, Monte-Carlo simulācijas, kritisko situāciju kopas

Kabans, D., Valkovjaks,T. Resursu pārvietošana hierarhiski pārvaldītā transporta sistēmā kritiskos apstākļos, *Transport and Telecommunication,* 14. sēj., Nr. 4, 2013, 282.–291. lpp.

Darbības kritisks stāvoklis tiek sasniegts ar sistēmu, kad tā ir pakļauta negaidītu bojājumu sakritībai (piemēram, periodiski straujš pakalpojumu pieprasījumu pieaugums, nepieejamība transportlīdzekļu operatoru ievērojamai daļai, vienlaicīga visu vai lielas daļas transportlīdzekļu parka salūšana). Tas noved pie pilnīgas transporta sistēmas sagrāves, kas saglabājas pat pēc tam, kad defekti ir novērsti. Kritiskā stāvokļa darbības ilgumu definē kā laiku, kas nepieciešams, lai atsāktu normālu darbību pēc šāda incidenta. Ir pierādīts, ka šis laiks var būt prognozēts, izmantojot simulācijas rīkus. Turklāt ārkārtas rīcības plāns ir ierosināts, pamatojoties uz dažu resursu pārvietošanu starp neatkarīgām hierarhiski organizētām transporta sistēmas daļām. Šis ārkārtas plāns tiek analizēts, lai noteiktu optimālo resursu procentuālo daļu, kurai ir jāpārceļas, un šīs pārvietošanas ilgums.

Atslēgvārdi: diskrēti pārvadājumi, drošuma analīze, simulācijas rīki, riska pārvaldība

Hunke, K., Prauze, G. Zaļā koridora darbības vadīšana, *Transport and Telecommunication,* 14. sēj., Nr. 4, 2013, 292.–299. lpp.

Saistībā ar saskaņotu starpvalstu transporta sistēmu zaļā koridora koncepcija ir stūrakmens integrētu un ilgtspējīgu transporta risinājumu izstrādē un īstenošanā. Zaļo koridoru svarīgas īpašības ir to starpvalstu raksturs un publiskā un privātā sektora ieinteresēto pušu plašā iesaistīšanās, tostarp politiskā līmenī, kas prasa jaunus pārvaldības modeļus zaļo koridoru vadīšanai.

Ieinteresēto pušu pārvaldības modeļi un instrumenti zaļo koridoru vadīšanai tiks izstrādāti un pārbaudīti dažādos reģionālās attīstības projektos, lai nodrošinātu labāku transporta politikas saskaņošanu dažādos pārvaldes līmeņos un nostiprināšanu no biznesa viedokļa. Izšķiroša loma šajā sakarā pieder publiskā un privātā sektora ieinteresēto pušu iesaistīšanai, lai nodrošinātu efektīvu transporta koridora darbību.

Rakstā tiek parādīti jaunākie pētījumu rezultāti par zaļās piegādes ķēdes vadību tīkla un ieinteresēto personu modeļa teorijas ietvaros un tās piemērošanu zaļo transporta koridoru ieinteresētām pusēm.

Atslēgvārdi: zaļās piegādes ķēdes vadīšana, zaļie transporta koridori, ieinteresēto personu veidota pārvaldība

Hainare, V. D., Koteča, K. *Mumbai-Pune* ātrgaitas ceļa scenārija sakaru simulācija transportlīdzeklis-transportlīdzeklim, izmantojot IEEE 802.11p, *Transport and Telecommunication,* 14. sēj., Nr. 4, 2013, 300.–315. lpp.

Satiksmes drošības programmas, izmantojot transportlīdzeklis-transportlīdzeklim (V2V) komunikāciju ir jauna tehnoloģija, un daudzsološa joma ITS vidē. Daudziem no šiem pieteikumiem nepieciešama reālā laika komunikācija ar augstu uzticamību; sasniegt reālā laika termiņu, savlaicīgu un paredzamu piekļuvi kanālam. Vidējas piekļuves metode, ko izmanto 802.11p, CSMA ar izvairīšanos no sadursmes, negarantē piekļuvi kanālam pirms galīgā termiņa. Labi zināma CSMA īpašība nav vēlama kritisko sakaru scenārijiem. Modelēšanas rezultāti liecina, ka konkrēts transportlīdzeklis ir spiests pamest vairāk nekā 80% no tā paketēm, jo nebija piekļuve kanālam, pirms nākamā ziņa tika radīta. Lai pārvarētu šo problēmu, mēs piedāvājam izmantot STDMA reālā laika datu plūsmu starp transportlīdzekļiem. Reālā laika STDMA īpašības tiem pētītas ar ātrgaitas ceļa simulācijas scenārija palīdzību, ar daudzsološiem rezultātiem.

Atslēgvārdi: CSMA, STDMA, V2V, VANET

Ondrušs, J., Dicova, J. Kvantitatīvās noteikšanas un tendenču prognozēšanas potenciāls transporta prasībās kā līdzeklis transporta vadībā un attīstībā, *Transport and Telecommunication,* 14. sēj., Nr. 4, 2013, 316.–324. lpp.

Transportā vadītāju pamatmērķis ir saglabāt un paplašināt savu daļu pārvadājumu tirgū. Tas būtu jādara, izmantojot prioritāti kvalitātē un klientu apkalpošanā, transporta uzņēmuma darbības transporta tirgū saglabāšanas un paplašināšanas jomā, prioritātes orientācijas pamatā virzībā uz kvalitāti un klientu, saglabājot transporta tīklus un izmantojot jaunākās zināšanas no pētījumiem. Tajā būtu jāiesaista arī ieguldījumu veikšana labvēlīgas ekonomiskās aktivitātes rādītājos, un arī vides pārmaiņu apsvērumi. Šis raksts izskata klientu prasības, klientu prasību kvantitatīvās noteikšanas iespēju un nākotnes tendenču atzīšanu, pamatojoties uz neseno kvantitatīvo rezultātu novērtējumu, un vadītāju zināšanu un metožu piemērošanu.

Atslēgvārdi: transports, prognozes, reģions, transporta darbības rezultāts, pasažieru skaits, masu sabiedriskais transports

Jackiva, I., Kopitovs, J., Kaselato, D., Lupino, Dž., Makdonalds, R. Salīdzinošā analīze un labas prakses novērtēšana sabiedriskā transporta informācijas sistēmās, *Transport and Telecommunication,* 14. sēj., Nr. 4, 2013, 325.–336. lpp.

Sabiedriskā transporta pakalpojumu attīstība pēdējos desmit gados raksturojas ar plašu dažādu informācijas sistēmu un tehnoloģiju ieviešanu, kas aptver dažādus transporta pakalpojumus, piemēram, satiksmes plānošanu, satiksmes tīkla uzraudzību, sabiedriskā transporta flotes darbības vadību, nodrošinot informāciju pasažieriem, informāciju par biļešu maksājumiem, u.c. Raksts izskata lielu ES finansētā projekta POLITE pētniecības daļu, kuras mērķis ir sabiedriskā transporta nozare un informētības palielināšana par infomobilitātes pakalpojumiem un sabiedriskā transporta pievilcību, piemērojot definēto Labo Praksi (*Good Practice*) un Vislabāko Praksi (*Best Practices*). Šī raksta mērķis ir salīdzinošās analīzes metodikas prezentācija un Labās Prakses novērtēšana, un vienas no vislabākajām izvēle, pamatojoties uz multi-kritēriju salīdzinošo analīzi. Lai novērtētu Labo Praksi, tiek pielietota Analītiskā Hierarhijas Procesa (AHP) metode.

Atslēgvārdi: sabiedriskais transports, infomobilitāte, Labā Prakse, salīdzinošā analīze, multi-kritēriju analīze, AHP metode

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