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Network transport systems dependability analysis with critical situations discussion

Keywords

transport systems, quality, availability, critical situations, dependability, functional and reliability models

Abstract

The paper describes the analysis and discussion of the transport network systems in case of the critical situation that happens during ordinary work. The formal model is proposed –the point of view combines hardware and software resources as well as task definition and dispatcher role. The types of failure, procedures and methodology to reduce the consequences of the system faults are pointed and categorized. The functional and reliability measures are defined. The approach to modeling is based on the system behavior 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.

1. Introduction

The most often discussed methods of transport are focused on commodity movement according to declared routes, using autonomous equipment (vehicles) characterised by the capacity and based on prepared schedule. The presented class of transport systems is called discrete transport system (*DTS*). We can find an example of *DTS* as a commodity transportation realised by trucks. The schedule of such *DTS* can be not very precise against to coaches, passenger airplanes or trains. Of course there are situations where the schedule ought to be very precise – productive systems working without storehouses – for example – with remote co-operating parties [14], [27]. It is not trivial to model the transportation system properly for quality and efficiency estimation. The discrete transport system definition presented below includes all elements which have effect on service quality served by a supplier according to fixed strategy, real functional and reliability parameters of equipment. Such defined model combines both dependability and functional features. It allows to model discrete transport systems and to analyse the efficiency of the system if the number as well as quality of vehicles changes. We can also test how the system works if the number and location of recipients vary or different types of service strategy are available, or we notice failures [10], [16]. If we think about the transportation system as combination of equipment, infrastructure and human dispatcher we need to substitute the ordinary reliability models by functional and dependability models to check the system reaction for failures as well as to find the system efficiency changes after the dispatcher decisions [6], [26]. It is necessary for functional and dependability models to expand the definition of proper (reliable) state of system. The transportation system works correctly if tasks are realised according to the agreement – it means the commodity is transported on schedule, with declared volume. Failures of vehicles and infrastructure deteriorate the efficiency of the system, but if transportation tasks are realised according to the agreement we can say that the system works correctly. In the real transportation systems it is possible to substitute some functions by similar functions operating by various configurations, using different infrastructure features and redefined schedule [7], [17]. This way the system realises the task based on set of resources called functional configurations. The resources allocation is realised in dynamic way – modifications are driven by the stream of tasks, failures and dispatcher decisions [4], [9]. Complexity of this solutions force lower level of its description but in a same time high level perspective on what is going on in the system. Regardless of the level of abstraction many of parameters should be defined or measured to find the most accurate solution. Since some of them are uneasy to measure we propose to use softcomputing [16] to model the system, since this kind of model can be very useful for further analysis of the system. In result we provide an approach or even an idea of the tool for network system administrator. We call the approach as the functional-reliability models of network system exploitation. In this part we shortly describe elements of transport system Next sections provide the details of the softcomputing approach necessary to reliability and functional description and analysis of the discrete transport system. The results show the essential practical data in the function of the reliability parameters of the system. Paper ends with some general conclusion and remarks for the future works.

2. Discrete Transport System

The Discrete Transport System (*DTS*) is understood as a system of transport resources (e.g. vehicles), transport infrastructure (e.g. roads) and a management system (e.g. a dispatcher supported by a computer system). In this way dependability (functional – reliable) properties of the *DTS* depend not only on technical infrastructure of the system but also on dispatcher decisions [23], [25]. Dispatcher decisions may be a reaction on traffic situations (e.g. a traffic jam, a temporary limitation of vehicle speed on the fixed segment of a road), on infrastructure faults (e.g. a truck with cargo is failed and it has to be repaired), on functional system faults (e.g. a point storehouse is overfilled or already sent parcels are not collected yet) [11], [22], [27]. The dispatcher decisions are taken on the base of such different criteria as financial costs, system performance parameters, availability of renewal teams, possibility to access other routes, acceptability of parcel delaying, etc. The Discrete Transport System *DTS* is defined as [26]:

$$DTS = \langle TI, RES, TT, MS \rangle \qquad (1)$$

where:

TI – technical infrastructure of the system,
RES – system resources,
TT – transport tasks,
MS – management system which is called dispatcher.

The *technical infrastructure TI* of the discrete transport system is modelled as a directed graph [21], [26]:

$$TI = \langle reloading\ \ places, roads \rangle = \langle RP, R \rangle \qquad (2)$$

where:

$$RP = \langle A, B, C, \ldots \rangle \qquad (3)$$

- set of reloading places (Fig. 1),

$$R = \langle AB, AC, BC, \ldots \rangle \qquad (4)$$

- set of roads connecting reloading places.

A *reloading place* is a node of the discrete transport system (a node in the *TI* graph) in which such functions as parcels collecting in storehouses, reloading parcels from one transport resources to other one or to a storehouse may be realised. The reloading place may be equipped with a storehouse (with limited capacity; e.g. C_A, C_B, etc.) and needs such "mechanical tools" as cranes or fork-lift track.

Roads are modelled as directed arcs connected to nodes of the *TI* graph. Engineering parameters of the road are integrated into one representative measure called *average speed* of transport resource on this road segment (e.g. v_{AB}). Of course the average speed depends of cargo, transport means type, direction of traffic, day time or month time etc. Sometimes it is possible that $v_{AB} \neq v_{BA}$, but we can also assume the speed values are equal ($v_{AB} = v_{BA}$).

System resources of the *DTS* are understood as collections of transport means, drivers and service teams which the dispatcher may use for transport tasks realisation and for removing some disturbances in the system work. A system resource is described by its functional (e.g. load capacity of a truck), technical (e.g. fuels expendable per kilometre) and reliability parameters (e.g. mean time between failures or mean time renewal) which may have deterministic or probabilistic nature. Drivers create a specific class of the system resource [14], [24], [26].

A *transport task TT* 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 transport 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.

Faults and renewals of a discrete transport system. There are considered many disruptions in execution of the discrete transport systems. The failures of the *DTS* resources *RES*, e.g. physical failures of trucks or technical infrastructure *TI* (e.g. roads or reloading devices) need to use adequate such the *DTS* system means as service teams, garages, spare elements or substituted routes. Generally, in these situations *"technical" system renewal* processes are started on with assumption of the limited resources [24], [26]. Other sources of the *DTS* system disruptions we can find in organisation and management matters:

1) overloading of the technical infrastructure (roads, reloading machines, etc.),
2) traffic accidents or jams,
3) dispatcher faults – he or she is not able to keep up the dynamic changes of the situation in the working *DTS* system.

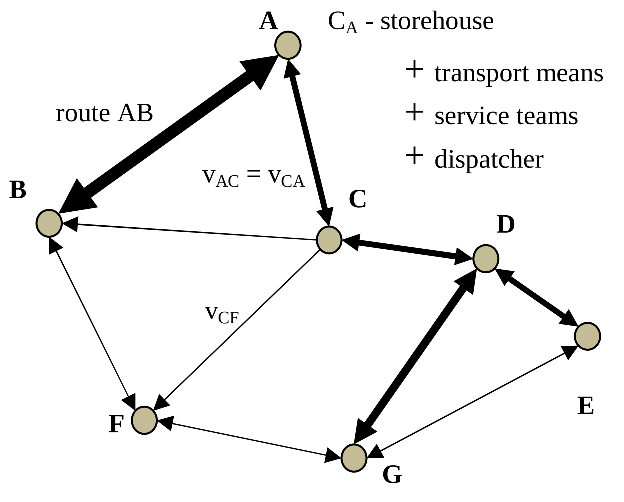

Figure 1. Discrete Transport System – an idea

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.

The *dispatcher* organises a work of the *DTS* system - available system resources are assigned to realised tasks. The dispatcher administers logistics of a transport firm based on the signed agreements specifying conditions of correct realisation of a task or sets of tasks [23], [25]. Dispatcher decisions are taken based on needs of assumed transport 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 supported by the computer aided tools to improve an assignment of system resources to transport tasks, to compose system traffic time-tables (planned and reserved for emergency conditions), to provide maintenance policies ready to use both for normal and disrupted situation in the system work. Because there are a lot of people involved into the system work the dispatcher should take his/her decisions taking into account not only computer system support results, but also based on his/her experience and his/her intelligence [6], [10], [18]. It is possible to define many classes of dispatchers, who are working in harmony with agreement between an transport employer and an owner of the discrete transport system. A *passive dispatcher* realises transport tasks agree to previously defined conditions and schedules. He or she 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 selected task or its sets. He or she may works agree with such strategy as FIFO, LIFO, FILO etc. 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 are prepared a priori, the real dependability properties (performance and reliability parameters) of the considered *DTS* system are closer to expected. Dependability measures of discrete transport systems are defined as global values (e.g. system efficiency, financial profit or loss) or as more detail measures such as a probability of isolated task execution or a set of tasks realised in a determined time interval [24], [26]. Functional and reliable properties of a discrete transport system have an effect on dependability measures at two fundamental levels:

1. it is possibility to create a functional configuration of the task or the set of tasks, that means it is possibility to allocate needed system resources for the transport task (or tasks) execution,
2. it is possibility that the transport task is correctly realised, that means allocated resources correctly work during assumed time and the assumed cargo is delivered according to assumed time-table.

The resources of all real systems are limited, so the system dispatcher has a significant impact on solving above given problems. His/her decisions concerning allocation technical infrastructure, transport means, service teams or reconfiguration of the system have to be taken up quickly and adequate to the situation [4], [9], [16].

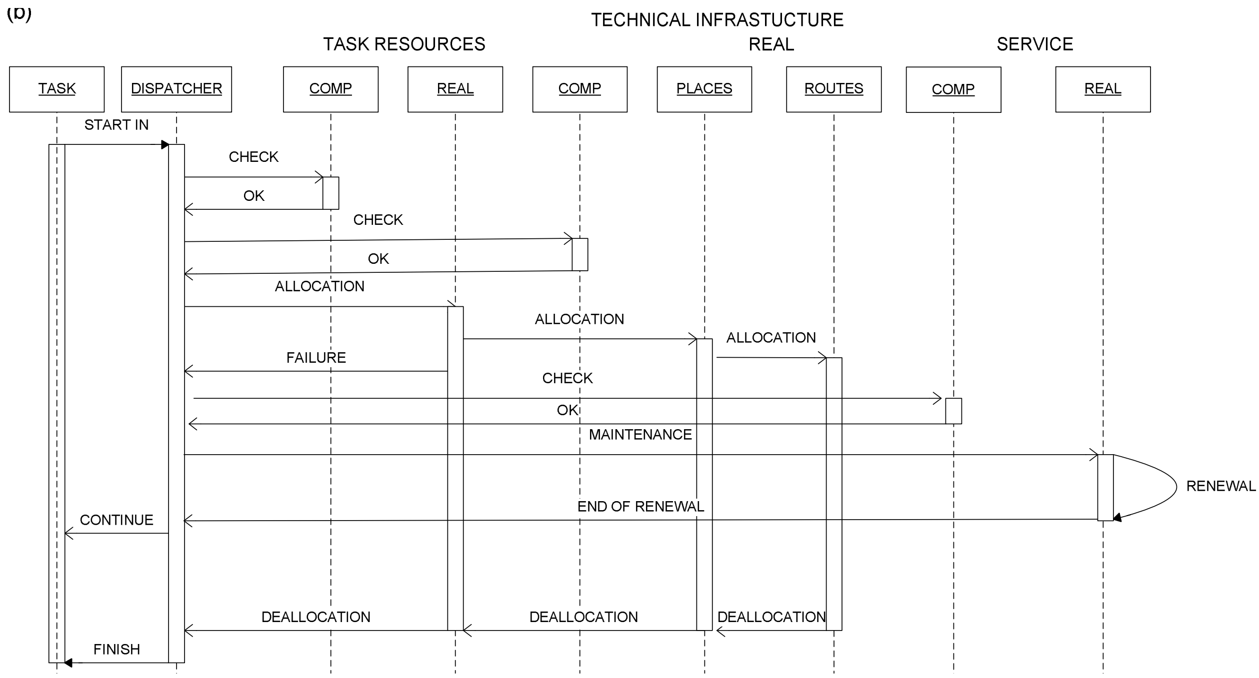

Figure 2. Dispatcher model in UML representation

3. Functional and reliability discussion

Dependability measures of discrete transport systems are defined as global values (e.g. system efficiency, financial profit or loss) or as more detail measures such as a probability of isolated task execution or a set of tasks realised in a determined time interval [7], [9].

Functional and reliable properties of a discrete transport system have an effect on dependability measures at two fundamental levels:

1. to create a functional configuration of the task or the set of tasks, to allocate needed system resources for the transport task (or tasks) execution,
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4. Transport system measures

It is considered a discrete transport system (*Figure 3*). A supplier of medium located at the node Z should deliver adequate quantity of medium to consumer (nodes $N_1, \ldots, N_N$) in time period $(0, t)$. The supplier possess K identical trucks with u capacity of each. It is assumed that routes and distances ($l^{(n)}$, $n=1 \ldots N$) are constant during time realisation of the contract [5], [7]. The correct agreement realisation means we guarantee for n-th recipient the medium in time-period $[0, T^{(n)}]$. The commodity is used by the recipient and we cannot agree for the shortage of it to the end of time when the agreement is valid. So the dispatcher ought to set such chronicle of deliveries to fix the commodity at the recipient at $t = 0$ and to minimise the commodity overload at the end of agreement period. It means the deliveries should start and stop properly.

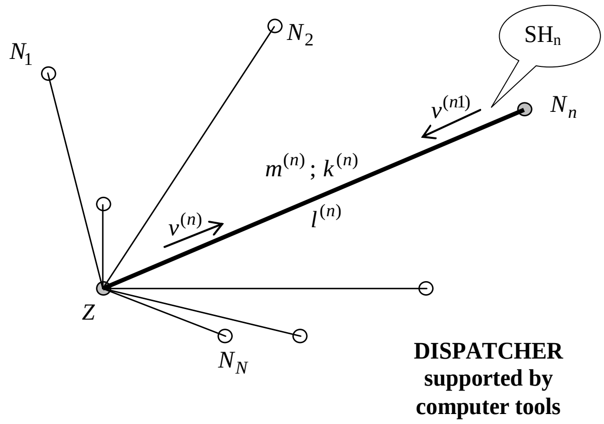

Figure 3. The considered *DTS*

Tasks – J. The commodity is delivered to recipient storehouse by vehicles with capacity u operating circular between the supplier and recipient. The vehicle failure elongates the time necessary for task realisation by time-period of maintenance. The delivered commodity is used by linear model $w^{(n)}t$ where $w^{(n)}$ is the parameter of commodity consumption in time unit. The agreement guarantees that deliveries satisfy the average commodity consumption with fixed overload – we introduce the parameter of protected level of reserves α [%].We do not care about the limited capacity of the recipient storehouse [14].

The transportation task is divided into three stages based on actual state of recipient storehouse: introducing deliveries, normal deliveries and reserves consumption (*Figure 4*).

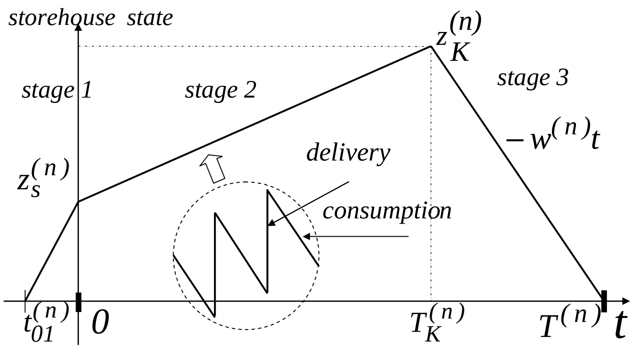

Figure 4. Storehouse state of *n*-th recipient

Vehicles – H. The system includes *K* vehicles with capacity *u* of each. The vehicle with load for *n*-th recipient moves with constant average speed $v^{(n)}$ and returns in empty state with speed $v^{(n1)}$. The average speed covers a time period of additional operations as: loading, unloading, breaks for driver, etc. The vehicles can fail and are repairable. The time to failure and time of repair are described by exponential distribution with parameters: λ_F and μ_F.

Infrastructure – $I_{TR} = \{i_{TR}^{(j)}; j = 1, 2, ...\}$. Routes and storehouses create the system infrastructure with fixed paths of delivery and distances ($l^{(n)}$, $n = 1 ... N$). There are no alternative paths, the route parameters allow to travel with maximum average speed for each vehicle. The routes not fail, there are no traffic problems. We also relax the problem of limited capacity of the recipient storehouse [5], [11], [14].

Dispatcher – D. The system is driven by static dispatcher working according to ready to use plan for time-period of agreement. The plan considers already defined hazards and proper solutions. The dispatcher decisions are taken by following rules:

- single agreement needs $k^{(n)}$ vehicles for *n*-th recipient,

$$K = \sum_{n=1}^{N} k^{(n)}$$

- the commodity is transported from supplier to recipient, return journey vehicle realises in empty space,
- vehicles started in unified time-periods called cycles and they realised transport tasks: commodity delivering, return in empty state to a base,
- each route is equipped by single maintenance group, the repair time combines the real repair time and necessary time to reach the failed vehicle, maintenance is realised according to FIFO approach,
- commodity consumption starts at the begin of agreement time-period – so it is necessary to store the volume of commodity and it is necessary to start vehicle fleet little bit before the agreement starting point.

The main goal is to estimate the number of necessary vehicles, the state of recipient storehouse and the proper moment to start the vehicles with the commodity - taking into account guaranteed average level of reserves in the recipient storehouse [9]-[10], [13].

Number of vehicles. The average number of vehicles with capacity *u* working for *n*-th recipient – based on model assumptions and logistic - we can estimate as follow:

$$k^{(n)} \cong \frac{w^{(n)}\left(1+\alpha^{(n)}\right)}{u}\left(\frac{l^{(n)}}{v^{(n)}}+\frac{l^{(n)}}{v^{(n1)}}\right) \tag{5}$$

Based on agreement conditions - penalty if the level of resources is lower than $(1 + \alpha^{(n)})\, w^{(n)}$) – the number of trucks we should round to the closer integer value. The final number of necessary vehicles to operate with all *N* recipients equals to:

$$K \cong \sum_{n=1}^{N} \frac{w^{(n)}\left(1+\alpha^{(n)}\right)}{u}\left(\frac{l^{(n)}}{v^{(n)}}+\frac{l^{(n)}}{v^{(n1)}}\right) \tag{6}$$

The equations above are true if there are no barriers related to vehicles. If we add this kind of limitations the problem how to allocate the system resources among the recipients is more sophisticated. The most typical solution is based on the supplier profits, operating costs and penalties if the agreement cannot be fulfilled. The equations (5) and (6) are absolutely correct if the vehicle fleet is perfectly reliable. If the time-period of agreement is significant the fleet can lost very good dependability parameters. This way it is possible that the system owner's profits are less than expected, he or she has to cover additional costs of vehicle maintenance and he or she has some problems to fulfil the agreement conditions. If we use the overflow number of vehicles the costs grow up, we can meet the problem of storehouse overload, or the queues of vehicles waiting for unloading procedure [10], [14].

Storehouses. The actual state of *n*-th recipient storehouse depends on the volume of delivery, commodity consumption in time unit ($w^{(n)}$) and time-period of the agreement. The volume of delivery is driven by: the number of used vehicles ($k^{(n)}$), vehicle capacity (u), distance from supplier ($l^{(n)}$), routes quality, average speed of vehicle ($v^{(n)}$, $v^{(n1)}$), reliability of vehicles ($\lambda_F^{(n)}$) and strategy of maintenance. The state of storehouse is estimated based on balance equation of average level of resources for *n*-th recipient:

$$E_t\left[m^{(n)}(t)\right] = u\,\frac{E_t\left[k^{(n)}\right]}{\frac{l^{(n)}}{v^{(n)}}+\frac{l^{(n)}}{v^{(n1)}}}\,t-\left(1+\alpha^{(n)}\right)w^{(n)}\,t \qquad (7)$$

where:

$E_t\left[m^{(n)}(t)\right]$ - expected value of resources for *n*-th recipient calculated for time-period agreement [*0*,*t*],

$E_t\left[k^{(n)}\right]$ - expected value of active vehicles for *n*-th recipient calculated for time-period [*0*, *t*].

Task – Stage 1. Before $t = 0$ – begin of agreement time-period – we have to collect in the storehouse the proper volume of commodity $m_S^{(n)}$ – equal to the consumption process in time-period [0, $t_S^{(n)}$]. The starting moment of the introducing deliveries can be estimated as follow:

$$t_{01}^{(n)} = ceil\left(\frac{l^{(n)}}{v^{(n)}}\right), \qquad (8)$$

Number of necessary vehicles to realise Stage 1:

$$k_1^{(n)} = ceil\left(\frac{\left(1+a^{(n)}\right)w^{(n)}t_S^{(n)}}{u}\right) \qquad (9)$$

where: *ceil* – the smallest integer value greater or equal to argument

Task – Stage 2. The state of commodity in the storehouse is analysed. The commodity is taken to provide the production process – for example – and the storehouse is refilled by cyclic deliveries. Number of deliveries can be estimated as follow:

$$d^{(n)} = ceil\left(\frac{\left(1+\alpha^{(n)}\right)w^{(n)}T^{(n)}}{u}\right) \qquad (10)$$

Number of deliveries meets the number of realised transportation tasks by vehicles characterised by capacity *u*. The key problem is to fix time-period of single cycle – it means the interval between starting points of the following deliveries [11]:

$$t_C^{(n)} = floor\left(\frac{u}{\left(1+a^{(n)}\right)w^{(n)}}\right) \qquad (11)$$

where: *floor* – the greatest integer value lower or equal to argument

Task – Stage 3. According to the agreement the volume of commodity in the storehouse should meets the consumption to the time-moment $T^{(n)}$. The dispatcher sometimes is not able to fit the delivery cycles precise enough to start the last delivery process properly earlier. The time overload (*Figure 5*) can be the time redundancy of *DTS*:

$$\tau_R^{(n)} = T^{(n)} + t_{01}^{(n)} - T_K^{(n)} \qquad (12)$$

The value of time redundancy can be tuned based on reliability parameters of the system elements [7]-[9].

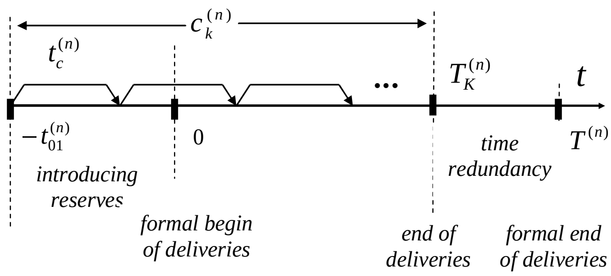

Figure 5. Time redundancy of *k*-th recipient

5. 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 model may be treated as decision variables. For example, a system 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 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 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 fulfill the functional requirements defined by users' tasks (the so-called. input tasks) – see functional – reliable models [12], [20], [26].

Optimization of system 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 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 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 constructor and the dispatching mechanisms should exercise adequate caution in these situations.

The set of system operation points forms a system 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 5* 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 quality is measured by the availability parameter.

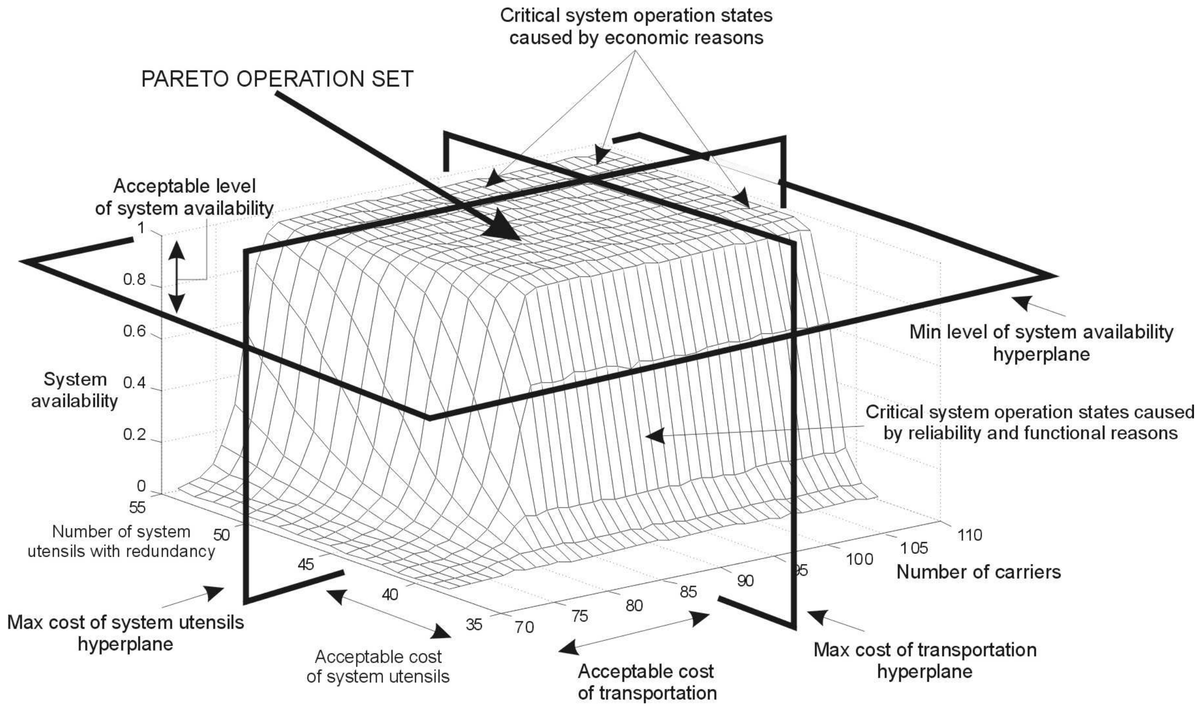

Figure 6. General idea of critical sets for network system

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 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 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 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 5*) corresponds to critical system operation states. The critical system state can be a simple consequence of change of "process parameters", such as raising the intensity of damage of the systems elements as a result of their use or the result of unfavorable 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.

6. 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)*. 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 analyze the system in case of reliability, functional and economic case. The metric could be analyzed as a function of different essential functional and reliability parameters of network services system. Also the system could be analyze in case of some critical situation (like for example a few day tie-up [24]).

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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