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Dependability of a discrete transport system

Keywords

dependability, transport system, performability, dependability system model

Abstract

A discrete system performing transport tasks (carriage of goods between the starting and ending points) using the vehicles of limited capacity and reliability is analyzed. The quality of transport tasks depend on the availability of transportation means (cars, roads, etc.), their functional properties (services) and reliability (faults and renewals) and of the system organization (dispatchers / system managers). Unfriendly system events affecting the realization of transport tasks are classified. A dependability model of the discrete transport system is considered as an unreliable service network. Outlined the idea of a maintenance policy system and a problem of synthesis of the discrete transport system.

1. Introduction

Functional and dependability modeling of transport systems is a fundamental problem of quality assessment of system works.
The proposed definition of a discrete transport system includes components that determine the quality of services, a strategy of service and reliability parameters of the equipment, roads, drivers, etc. The model takes into account both the functional and reliability properties of system elements [11].
Performance of the discrete transport system depends on numbers and quality of transport fleet, customers (numbers, locations and requirements), as well as the used strategies support both customers and potential system failures.
Of course, only part of the system parameters can be treated as deterministic variables but most of them are random variables - particularly the variables describing the processes of damage and repair.

2. A system

2.1. Technical infrastructure

A *technical infrastructure* of a discrete transport system TrI_{DTS} is understood as a system of transport resources (e.g. vehicles, reloading machines, service men) and transport infrastructures (e.g. roads with their traffic characteristics, terminal and trans-shipment stations).
The technical infrastructure of the discrete transport system is modeled as a tuple:

$$TrI_{DTS} = \langle TrIn, TrR \rangle \tag{1}$$

where:
TrIn – transport infrastructure
TrR – transport resources.

The *transport infrastructure TIn* of the discrete transport system is modeled as a directed graph

$$TrIn = \langle stations, roads \rangle = \langle Pl, Ro \rangle \tag{2}$$

where:
$Pl = \langle P_1, P_2, P_3, ... \rangle$ - set of reloading stations (places),
$Ro = \langle P_1 P_2, P_1 P_3, ... \rangle$ - set of roads connecting reloading places.

A *station* (reloading place) is a node of the transport infrastructure system (a node in the *TrIn* graph) in which such functions as uploading, reloading or unloading cars with goods may be realized. The reloading place may be equipped with a storehouse (with limited capacity) and supported by reloading machine, cranes, fork-lift tracks etc.

Roads Ro are modeled as directed arcs connected to nodes of the *TIn* graph. Engineering parameters of the road are integrated into one representative measure called *average speed* of transport resource on this road segment (e.g. $v_{P_1 P_2}$). 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 $v_{P_1 P_2} \neq v_{P_2 P_1}$.

2.2. A discrete transport system

The *Discrete Transport System DTS* is defined here as:

$$DTS = \left\langle TrI_{DTS}, TrT, TrSN, MS \right\rangle \tag{3}$$

where:

TrI $_{DTS}$ – technical infrastructure of the system (1),
TrT– transport tasks,
TrSN – transport service network,
MS– management system.

The *technical infrastructure TrIn* is allocated by the management system *MS* for transport tasks *TrT* realization on the base of available road nets *Ro* and functional services *TrSN*.

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

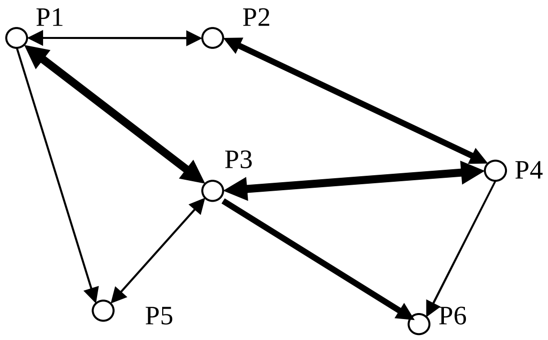


Figure 1. Example of the transport infrastructure - stations with transport means, storehouses and service units; roads characterized by integrated average speeds

The *transport services network TrSN* is a system of business services that are used for execution of user (client) tasks. The services nets are built based on the technical infrastructure and the technological services which are involved into a transport 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 a *choreography* and this term will be modified into a *transport choreography* here [14].

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 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 (MS) is helped by computer tools that improve an allocation process of system resources to tasks of transport, a creation time-tables of system traffic (planned and reserved for emergency conditions), a design of maintenance policies prepared to use both for in normal and extraordinary situations of the transport 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 too.

It is possible to define many classes of dispatchers of the discrete transport system. A passive dispatcher realizes transport 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. System dependability

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) [1],[2], [16].

Contemporary systems, such as transport systems, are very often considered as networks of services. The system 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) [8, 16].

The system realise 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 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 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 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.

4. Dependability of discrete transport systems

4.1. Discrete transport system events

Different events of discrete transport system operations are considered;

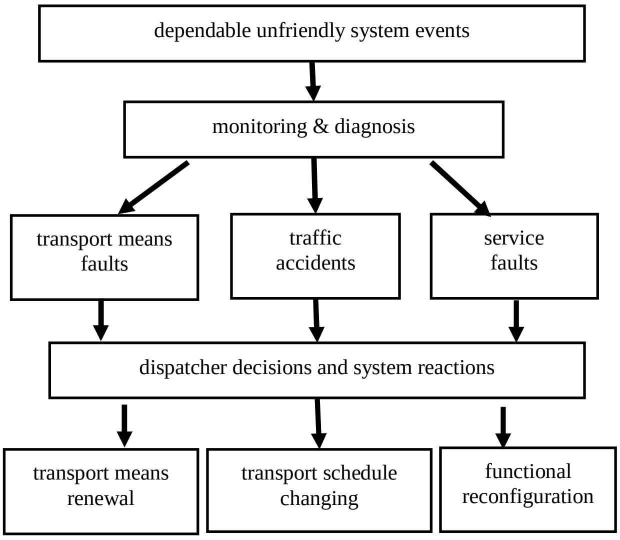
- “normal” functional events described by such time parameters as the start or / and the end of the task, a moment of a system resources allocation , a time of occurrence of a new task, an (prognoses or real) task execution time, etc.,
- unfriendly incidents that are disturbed efficient system execution; 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”.

A classification of dependable incidents and system reactions is presented on the Figure 2.

A 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 transport processes.



Fiure 2. A classification of unfriendly events of a discrete transport system

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 (e.g. 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 *TrR*, e.g. physical failures of trucks or technical infrastructure *Ro* (e.g. 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 trucks.

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 (they are 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.

4.2. Maintenance policies [12]

The maintenance policy is based on two main concepts; detection of unfriendly events and system reactions to them. Response provides a framework for counter-measure initiatives to respond in a quick and appropriate way to detected incidents.

It is hard to predict all incidents in the system, so system reactions are very often "improvised" by the system, by its management system, 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 had occurred, available system resources and the renewal possibilities (e.g. accessibility of service teams or spare devices). The renewal policy should be formulated on the basis of the required levels of system dependability and on the economic conditions (first of all the cost of downtime and lost profits).

Maintenance rule $(mr_j\,;\ j=1,2,...)$ is a chain of decisions about allocation of system resources that are undertaken to keep the system operational after an incident. These rules are very often connected with small fragments of the system, for example; replacement a vehicle by other one or a small delay of a departure time of a truck. These local operations may have impacts on the whole system, e.g. if a road is down by traffic jam for a few minutes, then rates of traffic of the system may violently change.

Cost of maintenance rule. The cost of the j-th maintenance rule ($c_{mr\,j}$) is defined as the sum of all considered costs of ventures made to ensure the required level of operation of a renewed part of the system. These costs may be evaluated in many ways; as cost of replacing broken vehicle for a new one, as servicemen costs, as time lost during renewal, etc.

For example, a cost of the maintenance rule may be evaluated as $c_{mr\,j} = Ac_{mr\,j} + Oc_{mr\,j}$ where $Ac_{mr\,j}$ means a cost of additional system resources (trucks, spare parts, servicemen, etc.) and $Oc_{mr\,j}$ - operational cost of implementing the maintenance rule.

The cost of additional system resources is evaluated as a sum of all costs that are incurred to make the maintenance rule possible (transport means, workshops, reloading machines, additional investments, staff hire, etc.). They are incurred

regardless whether the incident occurs or how often it occurs.
The operation cost of the maintenance rule may be considered as the cost of additional functions used during the network renewal and the unit costs of renewal procedures (cost of spare parts, cost of a service reloading operations etc.). The maintenance rules may be applied many times during operation time period $[0, T_E]$, so the real cost of the rule should be estimated as a mean value computed over the operation time $[0, T_E]$

$$\overline{c_{mr\,j}}(T_E) = \mathrm{E}_{T_E}\left[Ac_{mr\,j}(t) + Oc_{mr\,j}(t)\right] \qquad (4)$$

Local maintenance policy may be based on the analysis of the pairs: maintenance rule and cost of its execution

$$mp_j = \left\langle mr_j, c_{mr\,j} \right\rangle. \qquad (5)$$

Renewal of a system component may often be realized in more than one way, at different levels of cost. So, there is a set of pairs and the local maintenance policy is defined on this set. The choice may be determined by actual availability of spare parts or services, or on an arbitrary decision of a manager/dispatcher.

Transport maintenance policy system TMPS is a triple of sets:

$$TrMPS = \left\langle TrSI, MP, D_{MP} \right\rangle \qquad (6)$$

where:
$TrSI$ – unfriendly transport system incidents,
$MP = \left\langle mp_j,\ j = 1, 2, ... \right\rangle$ - maintenance policies,
D_{MP} - rules characterizing the impact of each maintenance rule on the overall transport system performance and system cost.

A very simple example of the system maintenance policy is demonstrated in Table 1, where all the foreseeable incidents are listed in the first column. For each incident, various feasible maintenance rules are listed in column 2, with corresponding local costs (column 3). The last column is the most important, since it gives grounds for adopting maintenance decisions based on the analyses of the whole system. For example, in a transport network, a chosen local maintenance policy may have a huge and diverse influence on various parts of the network, so locally the cheapest local maintenance policy does not have to yield the best global solution. The global maintenance policy has to depend on the dependability measures of the system and the impact of local maintenance policies on them.

Table 1. System maintenance policy [12]

Incidents	*Maintenance policy*		*System cost*
	rule	*cost*	
. . .			
k-1			
k	$mr_k(1)$	$c_{mr\,k}(1)$	
	$mr_k(2)$	$c_{mr\,k}(2)$	$d_{mr\,k(2)}(1)$
			$d_{mr\,k(2)}(2)$
			. . .
			$d_{mr\,k(2)}(u)$
	. . . $mr_k(j)$	. . . $c_{mr\,k}(j)$	
k+1			
. . .			
new incident	*empty at this moment*		*empty*

5. A services network model of the discrete transport system

5.1. Services networks

A *services network* is a system of functional services that are necessary for user (clients) tasks realisation process. The services networks re built 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 transport services and their implementation process will be hereinafter referred to as *transport choreography*.

We can build more general definition of the system (3) 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 discrete transport services network could be defined as

$$DTS = \left\langle TrT, TrSN(TrI_{DTS}), MS(TrMPS), C \right\rangle \quad (7)$$

where

TrT– a set of tasks generated by users and realised by the service network,
$TrSN\left(TrI_{DTS}\right)$ – a set of transport services carried out on the basis of the available technical infrastructure (1),
MS(TrMPS) - management system - allocates services (functionalities) and network resources to realized tasks, checks states of the services network and controls suitable system responses to detected and localized unfriendly events and minimises their negative effects. The control of the defense reactions of the system is understood as the choice of an appropriate maintenance policy (5),
C – a network chronicle, defined by a set of all essential moments in "life" of the network.

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 been 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 a transport network choreography. Modelling of this kind of systems is a hard problem for system designers, constructors and maintenance organizers, and for mathematicians, too.

5.2. Tasks and services networks

It is proposed to focus the dependability analysis of the networks on the fulfilment of requirements defined by user task [14]. Therefore, it should take into consideration following aspects:

- specification of the user requirements described by transport task demands, for example expected volume of goods transported, desired time parameters etc.,
- functional and performance properties of the transport system and theirs components,
- reliable properties of the DTS 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 transport 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, 14,15, 16].

5.3. Dependability measures of the DTS systems

Full system dependability analysis of the discrete transport system includes:

- threats, failures, faults arising in technical infrastructures and in management systems;
- functional and performance properties;
- organizational measures restricting the consequences of threats, failures or faults.

Today's services networks perform concurrent and parallel sets of transport tasks.

Streams of transport tasks are executed in accordance with the service rules (policies). Such a services network is considered as a multi-channel network with fixed (deterministically assigned to a channel) resources or as dynamic allocation of network resources to the channels.

Concurrently executed tasks can be assigned to the transport priorities and a guaranteed minimum quality realization levels of the tasks, which has a substantial impact on the work of services network in case of limited resources.

Considering a system with *k* service channels (*k* = 1 ... K), where each channel is assigned to a set of transportation tasks $TrT^{(k)} = \left(TrT_i^{(k)}; i = 1,...\right)$ performed on the basis of the allocated infrastructure resources.

The service channels of the transport network are characterized by numbers of transport tasks carried out in a given period of time and a measure of task performance of the k-th channel is defined

$$w_{TrT}^{(k)}\left(\tau^{(k)}\right) = \frac{card\left\{TrT_R^{(k)}\left(\tau^{(k)}\right)\right\}}{card\left\{TrT_N^{(k)}\left(\tau^{(k)}\right)\right\}} \qquad (8)$$

where:

$\tau^{(k)}$ - analyzed *k*-th channel time,

$TrT_R^{(k)}\left(\tau^{(k)}\right)$ - a set of tasks completed by *k*-th channel in the time interval $\tau^{(k)}$

$TrT_N^{(k)}\left(\tau^{(k)}\right)$ - a set of tasks scheduled for execution in the *k*-th channel in the time interval $\tau^{(k)}$

$card\,\{...\}$ - the size of a task set.

The global task performance of the services network with *k* service channels is defined as the number of transport tasks completed by all active channels within a given period of time

$$W_{DTS} = \frac{card\left\{\bigcup_k TrT_R^{(k)}\left(\tau^{(k)}\right)\right\}}{card\left\{\bigcup_k TrT_N^{(k)}\left(\tau^{(k)}\right)\right\}} \qquad (8)$$

Transport tasks are carried out in each channel according to the work schedules, available services and resources and system eventsIn real situations allocation of resources to the tasks being carried out is based on a dynamic decision management system. Mathematical models of the systems are built on the base of a lot of simplifying assumptions, for example a permanent allocation of network resources to each channel; a fixed strategy of task realization; random variables are treated as variables with the exponential distributions, etc. In this way the created models are only a distant reflection from reality.

Taking into account the priorities of channels and/or tasks, or dynamic allocation of resources (channels with higher priority can "consume" resources from lower priority channels) lead to such complexity of formal mathematical models of the services network that the analysis of their properties can be realized only on the basis of "simplified" Monte Carlo simulation models.

5.4. Critical working point of discrete transport systems

The *working point* of a discrete transport system is defined by specific values of functional parameters (resulting from the existing transport infrastructure - load capacity and the available number of vehicles, passing speed limit, road quality, availability and quality of handling equipment, route selection, etc.) and reliability (mean time to truck failures, the number of repair crews, the frequency and duration of traffic jams on the road, 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 vehicle capacities to needs of the transport task but very often he has no possibility to choice of vehicles on the base of their reliability characteristics. You can choose a road of better throughput, but does not change the parameters of this road. The appropriate operating point of the transport system may been achieved through such the dispatcher actions of organizational nature as: choosing the number of vehicles and/or the number of repair crews, bypassing a blocked (overload by traffic) road, rescheduling courses, etc.

Dispatcher decisions concerning allocation of services (functionalities) and resources can treat (define) as the system reconfigurations necessary to accomplish the planned transportation tasks.

The *dependability analysis* of discrete transport systems is carried out to assess the degree of risk associated with the implementation of transport 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 discrete transport systems is based primarily on such a selection of services and resources to fulfill the functional requirements defined by users in their transport tasks (the so-called. input tasks) - see functional - reliable models [3], [11], [15], [16]. 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 discrete transport system synthesis are determined by nominal values contained in the intervals of tolerance, so acceptable, though unlikely, is a scenario corresponding an operation point defined by the worst of circumstances (for example, the simultaneous maximum demand of transport tasks, the maximum number of long-term traffic jams, outbreaks of influenza among drivers, 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 discrete transport system may be used as a basis for estimating the risk of system faults.

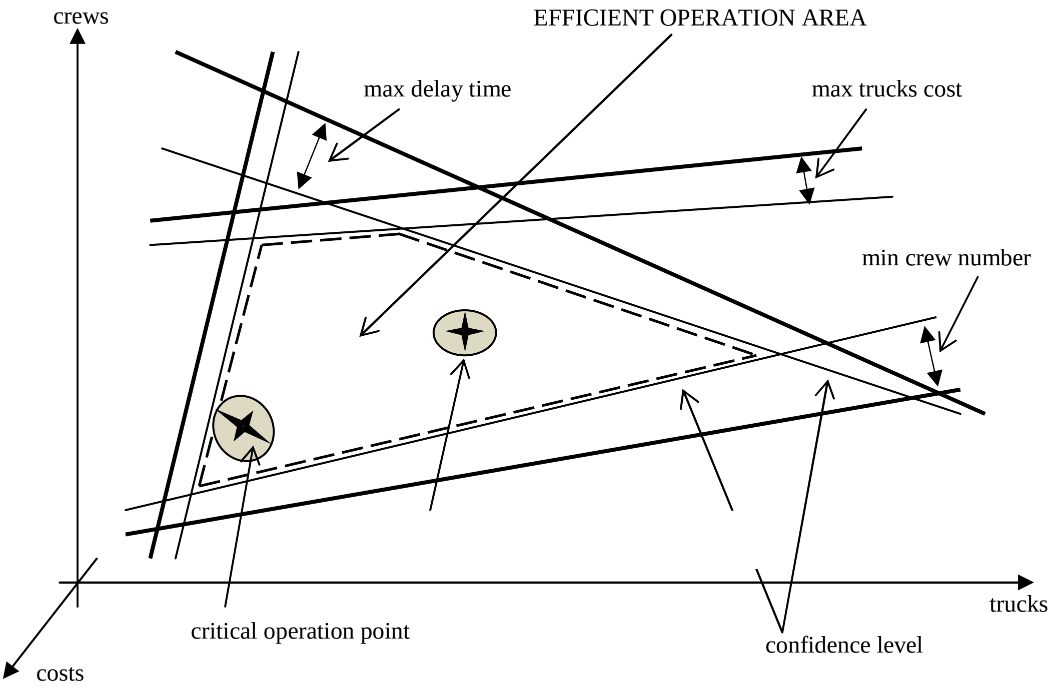


Figure 3. An illustration of an efficient operation area of the discrete transport system

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 dispatcher 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 discrete transport system can be formulated as to ensure the global task performance (9) for a specified number of vehicles, 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 transport system in the plane of the number of vehicles and repair teams. The boundaries of the efficient operation area shall be determined on the basis of the acceptable costs of transport tasks, the maximum allowable repair time, cost of used vehicle fleet and they can be set for the expected values (thick lines) or for the assumed level of confidence (thin lines). You will 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 to one vehicle) 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 roads) leads to "disaster" of the system (e.g. interruption of the supply chain in a just at time production 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 state can be a simple consequence of change of "process parameters", such as raising the intensity of damage to vehicles λ (t) as a result of their use or the result of unfavorable combination of circumstances (adverse realization of random variables). For example, without necessarily changing λ, too many vehicles 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 (situation with a small risk?).

5. Conclusions

The proposed dependability model of the discrete transport system can allow a more complete analysis of functional and reliable properties of components, structures, services and processes of the DTS. The proposed model can be particularly useful in studies on the impact of transport logistics system performance.

Computer systems supporting the work of the dispatcher should designate efficient operation areas (together with their critical efficient operation subareas) of the transport system, to monitor the processes of system parameters changes and prompt decisions in extreme cases to prevent a system crash. In everyday practice, the dispatcher expects tips for choosing an appropriate maintenance policy, or responding to specific "minor" unfriendly events leading only to raise the system operating costs. This implies a need to develop appropriate dependability mathematical models of considered systems, defining appropriate measures of performability and the development of computer tools of evaluation of these measures which are functions of random and deterministic variables defined in the respective ranges of tolerance.

Computer simulation methods allow to circumvent many of the mathematical restrictions on ownership of real transport systems, but a generalization of the simulation results requires a lot of costly and lengthy research.

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References

[1] Avižienis, A., Laprie, J. & Randell, B. (2000). Fundamental Concepts of Dependability. *In: 3rd Information Survivability Workshop* (ISW-2000), Boston, Massachusetts, USA.

[2] IFIP WG10.4 on Dependable Computing and Fault Tolerance, http://www.dependability.org/

[3] Inżynieria komputerowa. Praca zbiorowa pod red. W. Zamojski. WKŁ, 2005

[4] Josuttis, N. (2007). SOA in Practice: The Art of Distributed System Design. O'Reilly.

[5] Walkowiak, T. (2011). Simulation approach to Web system dependability analysis. *Summer Safety and Reliability Seminars, SSARS 2011*, Vol. 1, 197-204.

[6] Walkowiak, T. & Mazurkiewicz, J. (2008). Availability of Discrete Transport System Simulated by SSF Tool. *Proceedings of International Conference on Dependability of Computer Systems*, Szklarska Poreba, Poland, June, 2008. Los Alamitos: IEEE Computer Society Press, 430–437

[7] Walkowiak, T. & Mazurkiewicz, J. (2008). Functional Availability Analysis of Discrete Transport System Realized by SSF Simulator. *Computational Science – ICCS 2008, 8th International Conference*, Krakow, Poland, June 2008. Springer-Verlag, LNCS 5101, 2008. Part I, 671–678.

[8] Walkowiak, T. & Mazurkiewicz, J. (2009). Analysis of Critical Situations in Discrete Transport Systems. *Proceedings of International Conference on Dependability of Computer Systems*, Brunow, Poland, June 30-July 2, 2009. Los Alamitos: IEEE Computer Society Press, 364–371.

[9] Volfson, I.E. (2000). Reliability Criteria and the Synthesis of Communication Networks with its Accounting. *J. Computer and Systems Sciences International*, Vol. 39 (6), 951-967.

[10] Xiaofeng, T., Changjun, J. & Yaojun, H. (2005). Applying SOA to intelligent transportation system. *IEEE International Conference on Services Computing* Vol. 2, 101 – 104.

[11] Zamojski, W. (2005). *Model funkcjonalno-niezawodnościowy systemu komputer-człowiek.* Praca zbiorowa pod redakcją Wojciecha Zamojskiego Inżynieria komputerowa. WKiŁ, Warszawa 2005.

[12] Zamojski, W., Caban, D. (2006). Introduction to the dependability modelling of computer systems. *Dependability of Computer Systems DepCoS - RELCOMEX '06*, 100 – 109.

[13] Zamojski, W. & Caban, D. (2007). Maintenance policy of a network with traffic reconfiguration. *Dependability of Computer Systems DepCoS - RELCOMEX '07*, 213 – 220.

[14] Zamojski, W. & Walkowiak, T. (2010). Services net modeling for dependability analysis. *In-Tech.*, 1-17

[15] Zamojski, W. (2009). Dependability of services networks. *3d Summer Safety and Reliability Seminars SSARS 2009*, 387 – 396.

[16] Zamojski, W. & Mazurkiewicz, J. (2011). From reliability to system dependability – theory and models. *Summer Safety and Reliability Seminars, SSARS 2011*.

[17] Zheng, Z. & Lyu, M.R. *Collaborative Reliability Prediction of Service-Oriented Systems.*