# ITS Safety Ensuring Through Situational Management Methods

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**Abstract.** The paper is devoted to solving the problem of complex organizational and technical systems' (COTS) safety improvement with the use of methods of situational management. The possibility to manage COTS with the use of decision support system, the intelligent core of which contains the object model of the precedent describing unwanted processes in the COTS, is considered. The object-oriented hierarchy model of the vehicle as a complex dynamical system is developed. To improve reliability and safety of the COTS the database of precedents is established. Precedents in this database are presented according to the developed model by which the analogues search procedure is performed and the best managerial decision is chosen.

**Keywords:** Autonomous vehicle · Intelligent transport system
Road transport · Road safety · Situational management

## 1 Introduction

Modern human civilization entered the third Millennium characterized by the processes of globalization and urbanization that is accompanied by the growth of transportation demand. This consequently requires increasing sustainability and safety of transportation system. The three-pronged strategy of UNEP in the area of transport, a sector, which accounts for approximately one quarter of all energy-related greenhouse gas emissions is "Avoid – Shift – Clean".

The development of "unmanned vehicles" was the logical trend of realization of the way "Intelligent transport systems (ITS)" as a systemic strategy. ITS, according to the European Union, can create clear benefits in terms of transport efficiency, sustainability and safety, at the same time, contributing to the development of the EU internal market and competitiveness. Currently the service Real-time Traffic and Travel Information (RTTI) promotes the significant growth of population mobility. In the longer term, it is expected that the full potential of the systems that are based on the principle of cooperation between road users and infrastructure elements will be revealed. If necessary, these systems will be supplemented by the Global Navigation Satellite System (GNSS).

SAE International's new standard J3016 Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, delivers a harmonized

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classification system and supporting definitions that identify six levels of driving automation from “no automation” to “full automation”. System refers to the driver assistance system, combination of driver assistance systems, or automated driving system. Traditional ADAS technology allows you to identify certain objects, to carry out the basic classification, to notify the driver of dangerous situations and, in some cases, slow or stop the vehicle. Transition from the creation of driver assistance systems to the development of semi-autonomous vehicles is a global trend that is explained by the desire of developers to ensure sustainability and safety of the transport system [1].

All intelligent components of onboard vehicle systems for decision-making must process large amounts of information in a short time. This requires high-performance supercomputers and algorithms working with big data. One of the main news CES 2016 exhibitions was “supercomputer” Drive PX2 with artificial intelligence from NVIDIA that delivers overall performance of 8 TFLOPS and can become a basis for creation the vehicle computer, which can be trained to understand better the behavior of other vehicles on the road. These on-board computers use deep-learning algorithms and contain a software development kit called DriveWorks. It is a powerful platform for building applications for object detection, positioning and programming trajectory of movement.

Microsoft tries to find a different solution. Microsoft’s CHAD (connected highly automated driving) system collects data from smartphones and connected traffic lights. Thus, the vehicle gets more information about the surrounding objects than from the most advanced sensors and cameras. The main objective of unmanned vehicles is the improvement the reliability, safety, efficiency and sustainability of the transportation system. Wherein the most optimistic forecasts are given, because today the great number of road accidents are connected with the violation of traffic rules, i.e., due to “human factor” [2, 3]. A Rand Corporation report, “Autonomous Vehicle Technology: A Guide for Policymakers,” says that “without driver error, fewer vehicle crashes will result,” putting the kibosh on fears over vehicle and pedestrian safety concerns. However, it notes also that “aggressive policymaker intervention with respect to regulations or liability is premature and would probably do more harm than good,” at least for now.

The most obvious is the fact that removing the “human factor” from the vehicle control system creates the social tensions by reducing the number of drivers. In addition, “the opportunity to do some things during the trip” advantage, according to doctors, can lead to growth of indispositions in connection with a motion sickness. To avoid this, the technical solutions are necessary, which can be expensive [4].

Moreover, the emergence of new types of vehicles with fundamentally new control systems could cause problems of safety and interaction with other road users. In the case of self-driving cars crashing, the resulting big data should be retrieved by the NHTSA and the car manufacturer without any bias, all to facilitate crash reconstruction and the necessary analysis. The NHTSA only says more research is needed on cyber-security issues before finalizing regulatory standards and is calling on self-driving car manufacturers to directly share vulnerability data with their rivals through a medium known as Auto-ISAC, acting as a clearinghouse for the cyber-security industry.

Today, researches are conducted in the direction of improved management (calculating trajectory, the optimal route) [5, 6], interaction between road users and infrastructure (V2V, V2I, I2I), interaction between vehicles and pedestrians [7]. In fact, intelligent robots that should choose the route to destination, bypass the possible obstacles, choose the optimal parameters of movement (speed, position in space, the acceleration when cornering) and prevent accidents are created. In general, they must be able to make decisions or plan their actions in the uncertain or difficult situations. Therefore, to ensure transport system's safety, methods of situational management have to be used.

## 2 Situational Management Methods in ITS

### 2.1 The Concept of an Expert System to Enhance the Safety in the Transport System

Complex organizational and technical systems (COTS) today are developing and increasing in their number that leads to expanding their capabilities and scope. At the same time, this fact deepens their vulnerability to the impact of different adverse factors. Ensuring the reliable and safe functioning of COTS is a difficult problem because it is hard to develop behavioral models of diverse research objects and to formalize scientific tasks. This is also caused by the lack of adequate regulatory basis and methodological framework as well as by continuous improvement of methods and means to implement impacts on COTS. The aforesaid leads to the fact that the prescriptive approach of "results-based management" is replaced by a more flexible and effective "situational management" based on real time decision-making. Situational management in this case involves a detailed analysis of all features of the situation and the development of its new rules for decision-making taking into account interests of all stakeholders.

The purpose of ITS is to reduce the influence of "human factor" in management functions. However, you should take into account that fundamental changes in the management system can lead to displacement of causality in the structure of the incidents. The transport system contains subsystems of different nature and with different parameters. These are: technical static subsystem (infrastructure); technical dynamic subsystem (the vehicle); live dynamic subsystem (pedestrians, passengers, drivers, managers). These subsystems interact with each other in accordance with the developed system of rules. If all the objects follow the rules, the system works normally. Failure cases depend on a variety of reasons. The probability of failure depends on the number of conflict points at which each subsystem operates in accordance with its decision. Programmers delegate management functions to intelligent modules, because they believe that the computer faster chooses the solution that is best in this situation. This statement is true in that case, if all actors adhere to the similar rules. Such situations should be incorporated in the control algorithm.

However, in reality, such combinations of external actions (called a "fatal coincidence") when you have to make unconventional decisions are possible. Such a situation can be associated not only with inadequate behavior of a person (intentionally or unintentionally violating the rules), but with the state of the technical system. Analysts fear that the increasing complexity design of vehicles makes them more vulnerable from the point of view of reliability. The surveys conducted among the population of different countries, showed that drivers want to be able to intervene in the management in the event of failure of any equipment. Therefore, if the designers make the control system more autonomous, they must include special management rules for the situation when the individual elements of the vehicle will lose functionality. This is the conclusion reached by the authors of the paper [8], who conducted tests of the behavior of flight crews in normal and emergency modes.

The hierarchy of vehicle, which belongs to a class of complex dynamic systems, is shown in Fig. 1a. Unwanted processes in the technical system emerging in the process of operation under the influence of external factors can lead to faulty state. In turn, faulty state can be both safe and dangerous. The boundary between them are the state limit for a security criterion. The dangerous state can be divided into stages: alarm stage (AS), critical situation (CS), extreme situation (ES) (Fig. 1b). Alarm situation is preceded by the stages of critical situations and extreme situations, herewith parameters of system state exceed the permitted, but there is no the loss of functionality yet. Usually, this is due to the accepted safety coefficients on these parameters. In some cases, an emergency situation is developing very quickly, due to poor governance and/or ineffective design solutions in terms of safety. If an emergency situation develops for a long time, it is possible to detect it early and take measures to prevent CS or ES. Decomposition of the ES development process at the stage of the design of the object contributes to the deeper analysis of scenarios, incidents and states of the process.

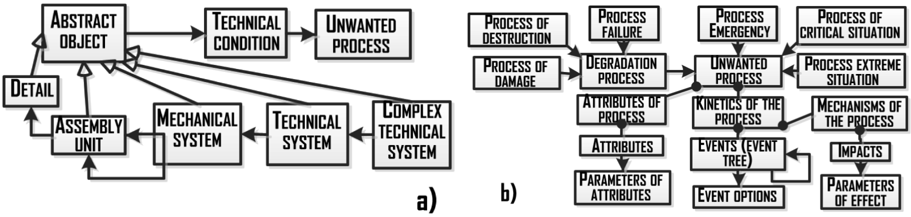

**Fig. 1.** (a) Object model of the vehicle's hierarchy; (b) Object model of unwanted processes in the vehicle

## 2.2 Implementation of the Situational Management Concept as the DSS

Currently, the generally accepted control theory is based on the concept of management under conditions of incomplete information about models of objects and/or about the effects of the external environment. In this case, the type of uncertainty of the object's mathematical model depends on a number of uncontrolled factors:

- parametric uncertainty (parameters of the controlled object and/or external effects are unknown quasistationary);
- signal uncertainty (model of the controlled object and/or external effects can be specified as a non-measurable function of time);

- functional uncertainty (unknown function of the object's state variables and/or object's input/output variables can be specified).

The specificity of modern COTS determines the need to manage them under conditions of external effects' signal uncertainty. Wherein, the set of possible actions and their parameters are considered to be known, but the time and the sequence of adverse factors' occurrence are unknown. In this case, the implementation of situational management is the most promising way. Synthesis of the management complex is associated with the need to determine the object, purpose, strategy, methodology and control algorithm. Currently, researches in the field of developing decision support systems (DSS) in the COTS management are being actively conducted. At the same time, orientation of these DSS toward solving weakly structured and unstructured problems that are characterized by the impossibility to use methods and models based on exact description of problem situations, is intensified. As a result, to make managerial decisions the following systems have been widespread: systems that use formalized experience and knowledge of specialists of relevant subject areas, systems based on the rule-oriented inference, frame models, semantic networks and cognitive maps. There is a number of methods that implement different features of the situational approach. A significant group of methods is focused on the formation of an artificial language to describe situations and interrelations between objects [9]. However, the construction of a semiotic model of the controlled object and processes occurring in it is not always justified. Another group of methods is based on the representation of the situation as a range of values of a fixed set of attributes. Under certain conditions, these methods can be reduced to each other, but they also have a number of significant differences.

The principles of situational management are widely introduced into classical models. As an example semantic situational networks [10], discrete situational networks, some types of derivations based on analogies can be mentioned. However, the lack of knowledge about the researched system, incompleteness, inaccuracy and insufficient reliability of the data that is the basis for decision making, as well as practical impossibility to clarify this data because of the lack of time make the implementation of the situational approach the most promising way when solving the considered class of problems based on the fuzzy logic methods.

The set of methods of the situational approach and fuzzy logic is known as the fuzzy situational approach (FSA). There are various methods implementing FSA. Most of them are based on the representation of situations as the set of fuzzy values of a fixed set of attributes. This group includes such methods as fuzzy inference, fuzzy classification, multi-criteria evaluation and the choice of alternatives, analysis of a set of situations in the form of graph structures, bayesian networks [11]. The set of these methods allows developing decision support systems based on FSA for various complex objects. A typical example is the onboard driver-assistance systems [12, 13]. However, COTS' management requires not only to identify the current situation and the appropriate set of management decisions, but also to determine rational ways to achieve the objectives of the system. To do this, it is necessary to predict the possible consequences of several moves ahead. This requires the use of additional methods.

Situational advisory systems with the use of fuzzy situational networks (FSN) are based on the representation of a set of typical states of the system as graph nodes, and graph branches correspond to managerial decisions. Herewith, the knowledge base does not explicitly include ready-made solutions that match situations with managerial decisions. The sequence of managerial decisions that transfer the system from the current state to the state described by the target situation, which is best in the sense of the selected system of estimates, is determined by output over the network.

DSS based on the FSN are successfully used for individual industrial facilities, small enterprises or strategic management tasks. However, the use of FSN in DSS when managing the COTS (especially in the case of operational management tasks) is limited by a number of factors. To solve the problems discussed above, the general structure of the modules of the basic control system of the COTS is presented in Fig. 2. The functions of each module and its use in the system are considered below.

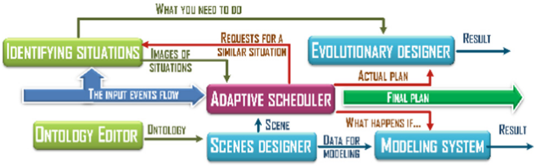

**Fig. 2.** The interaction between modules of the basic control system of the COTS

*Identifying situations*. This module identifies typical situations that arise when events happening and develops a forecast and recommendations on rational management for the transition of the COTS to a stable state. It allows including in the loop of the system's operation the automatic learning and to use the results of system's learning to improve the quality and effectiveness of management. This module can use clustering technology that is one of the data mining approaches, associated with the knowledge detection in data flows. Cluster analysis allows detecting latent trends, which are almost impossible to find in another way, in the data on the state of COTS. It also allows presenting them in a convenient form that helps to make the best decisions.

*Adaptive scheduler* processes the flow of incoming events: the emergence of non-regular situations, the introduction of new resources, changes in the state of the environment, etc. As a result of event processing, the real-time management option close to the optimal or allowable is forming.

*Ontology Editor* allows entering and changing the common ontology of COTS, describing the knowledge model of the subject area, which is then used in the scenes designer to describe the configuration of the COTS. It allows separating knowledge of the subject area from the text of the programs, which also creates a basis for the further development of the system and the expansion of its functions without reprogramming.

*Scenes designer* allows you to edit the initial configuration of the COTS and to determine it. In this case, you need to import data from various sources (existing databases, Excel files, etc.). It is based on a common knowledge base (ontology) describing the activities of the COTS using the ontology editor.

*Evolutionary designer* develops proposals to improve the network configuration in terms of increasing or decreasing a certain number of resources.

*Modeling system* is a software module that allows you to simulate situations on the principle "What If…?". At any time, the current state of the COTS and the forecast of its change for the next period of time can be uploaded to this system in order to then simulate what will happen in the case of an event.

## 2.3 Situational Management of the COTS Based on Ontological Engineering

Situational management in the modern interpretation is the following. Current situation C is understood as the totality of the current state object (state vector X) and its external environment (vector of perturbations F). Then C = <X, F>. The term "fully situation" means: S = <C, G>, where C – current situation, G – the purpose of the management, which can be represented as the target situation Gg. Then S = <C, Gg>. Assuming that the current situation belongs to some class $Q'$ and the targeted (defined) situation Gg – class $Q''$, it is necessary to find such a management (vector of management actions U), which belongs to the set of admissible controls $\Omega_u$ and provides the required conversion from one class of situations to another:

$$C = Q' \overset{U\in\Omega_u}{\longrightarrow} G_g \in Q'' \tag{1}$$

Ontology engineering involves the identification of: the main classes of entities (basic concepts) in the description of real interacting processes; relations between these classes, as well as the set of properties that determine their change in behavior and interaction. Goals of ontological engineering are: increasing of the level of integration of information required for managerial decision-making; improving the efficiency of the information search; providing opportunities for collaborative knowledge processing on the basis of common semantic descriptions of knowledge spaces. Metaontology of the situational management and ontology of situational analysis is shown in Fig. 3 [14].

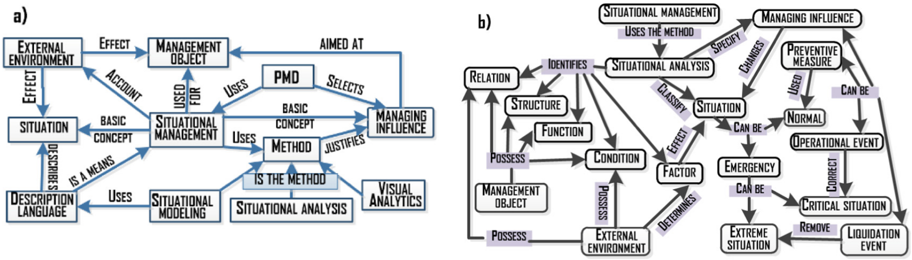

**Fig. 3.** Metaontology situational management; (b) Ontology of situational analysis

Situational management requires a formed space of knowledge. We understand pragmatics as practical aspects of development and the use of field, i.e. the transition from expert knowledge to their models. Precedents can be used for this purpose.

### 2.4 Precedents

Components of the model of precedent include: component of the problem description and component of the problem solution: $Precedent = \langle Problem, Solution \rangle$. Component of the problem description of the precedent contains properties of the object that reflects its state at some points in time. That is, fixed properties, which was formed at the time of manufacture and operation obtained during the technical assessment, as well as in the study of emergency, critical and extreme situations: **Problem** = $\left\langle O^{stat}, O^{dyn} \right\rangle$, where $O^{stat}$ - static information model of the object (represents the information that is defined at design stage); $O^{dyn}$ - dynamic information model of the object (information reflects the operational stage). **Static model:** $O^{stat} = \left\langle AF^{D}, PO^{D} \right\rangle$, where $AF^{D}$ - design affecting factors; $PO^{D}$ - design properties of object: $PO^{D} = \langle N_U, T_{CH}, T_R, T_C, P_{SS}, P_{SR}, TC^{Pr} \rangle$, where $N_U$ - the number of unique elements in the object; $T_{CH}$ - technical characteristics; $T_R$ - technical requirements; $T_C$ - technical conditions; $P_{SS}$ - properties of security system; $P_{SR}$ - properties of reliability system; $TC^{Pr}$ - the primary technical condition of the object, $TC^{Pr} = \{M_i\}$, $M_i$ - i - mounting heredity, D - design index.

**Dynamic Model:** $O^{dyn} = \left\langle T, AF^{PE}, PO^{P} \right\rangle$, where T - discrete time points in the life cycle of the object; $AF^{PE}$ – operational external affecting factors; $PO^{P}$ - operational properties of object (this set has a similar structure with design properties); $TC^{O}$ - operational technical condition of the object, $TC^{O} = \{UP_l\}$, $UP_l$ - l-unwanted process of object; $TC^{O} = \{TC_k, TC_k \rightarrow TC_{k+1}\}$, → - causal-implication relations; k - index of the stage of unwanted process (emergency, critical situation, extreme situation), $k = 1,3$. At the time the facility begins functioning $T_0$ its design and operational technical condition coincide, which is expressed by the identity $TC^{O} \equiv TC^{PR}$.

$$UP_1 = \left\{ UP_{lk} | UP_{lk} = \langle M_{1k}, Kn_{lk}, A_{lk} \rangle, M_{lk} = \left\langle AF^{PE}, PO^{P} \right\rangle, UP_{lk} \rightarrow UP_{lk+1}, M_{1k} \rightarrow \{Kn_{lk}^{mt}\}_{m,} \{Kn_{lk}^{mt}\}_{m} \rightarrow \{A_{lk}^{mt}\}_{p} \right\} \tag{2}$$

where $UP_{lk}$ – k-stage an l-unwanted process; $M_{lK}$ – mechanism k-stage an l-unwanted process (the set of properties of the object n factors affecting it); $Kn_{lk}$ – kinetics k-stage an l-unwanted process (set of events describing hazardous processes and phenomena); $A_{lk}$ – attributes k-stage an l-unwanted process; $Kn_{lk}^{mt}$ – m-event k-stage an l-unwanted process at time t; $A_{lk}^{mt}$ – p-attribute k-stage an l-unwanted process at time t; l – index of the unwanted process; m – index of the kinetics unwanted process; p – index of the attribute unwanted process; → – causal-implication relations. Component of precedent describing solution of the problem, includes: $Solution = \langle Reason, Managing\ actions \rangle$, where the *Reason* – the description of the whole set of interrelated reasons for the occurrence of any dangerous condition; *Managing actions* – description of the sequence of control decisions that have been taken to prevent, contain, eliminate and reduce the effects AS, CS or ES for the task of decision-making. Thus, the precedent contains the following information: the name of the object and its hierarchical affiliation (CTS - TS - MS); actual operating conditions; the observed parameters and their outward manifestation; the sequence of states that led to each threat situation including the properties of these situations; the causes of situations; irregularities and imperfections made at all stages of the life cycle of the object; the decision on managing the unwanted condition, the effects of unwanted processes, etc. The accident is considered as a sequence of stages (AS, CS, ES), where each stage is described by a set of events. Each event is characterized by values of many parameters and by functions of their change. Descriptions of events can be repeated at different time moments and can differ by parameters' values. In fact, the precedent describes the accident scenario.

Implementation of the precedent approach is performed by creation the analogues search procedure in the database of precedents which are presented according to the developed model. The analog means a precedent, whose description is similar to description of the considered problem situation, i.e. contains similar attributes (properties). The similarity is estimated by comparing the descriptions of the precedents in order to identify qualitative differences (absence of certain attributes in the description) or quantitative differences (different values have the same name attributes). To improve the efficiency of the search procedure (reducing its computational power) indexing of precedents is used. Thus, each precedent has its own set of indices describing different properties: structural affiliation of the object, its current technical condition, etc.

The search for analogues is performed by iterating and comparing the sets of indexes of precedents corresponding to a particular condition. The search can be carried out progressively (by stages), using various groups of indices, thus there is a gradual reduction of the dimensionality of the search space (through the use of the results of the previous stage of the search as a sampling input of the current stage) and increasing of its accuracy. Subjective preferences of the expert in calculating measures of similarity are considered as the rating the importance of a characteristic in the description of certain technical condition. The importance of indicators is specified either by the user (through the linguistic scale) or by analyzing the base of precedents. It corresponds to the frequency of occurrence of attribute in the description of problem situations taking into account the hierarchy of attributes which described object-oriented model. There is a corresponding set of indices describing different properties to improve the efficiency of the search procedure for each precedent: structural affiliation of the object, its current technical condition, etc. The search result is the set of analogues, ordered in accordance with the measure of similarity (proximity) of descriptions where indicate the degree of uncertainty (incompleteness) of the estimates of similarity.

## 3 Conclusions

Transport systems' intellectualization could give a synergistic effect, because their sustainability could have social and managerial effects, be profitable in the context of economy as well as of safety both for the system itself and for the environment. At the same time, the complication of vehicles makes them more vulnerable in terms of reliability. Therefore, it is necessary to identify potential risks, to predict the likelihood of their occurrence and to determine the possible consequences. In addition, ways to prevent risk situations and to reduce the severity of the consequences in case of risk situations should be developed. For these purposes, a good solution is the application of situational management and precedent expert systems, reflecting decisions by analogy, i.e. according to reports of critical situations, which are a potential threat for this object.

Traditional methods of reliability and safety evaluation do not fully take into account all the characteristics of COTS, such as structural construction of the system, the influence of individual elements on the whole system's operation, assessment of the significance and impacts of elements to the structural reliability and safety of the system, etc. Thus, logical-probabilistic methods and methods of situational management are the most effective analyze COTS and can be implemented to ensure the reliability and safety of the transport system and its elements, especially such as autonomous vehicles.

Objects of COTS are usually characterized by a large number of states, different operating modes and variants of the use, the complexity of the structural organization and the ability to operate in different states with different efficiency. Therefore, it is necessary to use information and communication technologies for the most complex calculations and when developing complex mathematical and statistical models.

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