Multi-Layered Architecture of Decision Support System for Monitoring of Dangerous Good Transportation

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Abstract. The consideration of this study is attached to the representation of knowledge content of dynamic application domain of transportation related to the risk evaluation of possible abnormal situations of dangerous good transportation. Multi-layered conceptual architecture is assembled by the models of knowledge representation at higher level including conceptual models of information structures, dynamic process analysis, and problem solving tasks in transportation processes of dangerous goods. The model represents behavioral analysis of target system based on Petri nets. The paper presents the technological platform how aggregate sensor components integrated with mobile technology can support the on-line processing of real data for localization and monitoring of transport objects and allow on-line recognition of abnormal situations. The representational platform describes a general component model that is a basis for expressing properties of knowledge of domain for informational structure specification.

Keywords. Decision support system (DSS), mobile control system, mobile sensor, intermodal transportation

Introduction

Over the past few years, a large number of researches had emerged approaching the use of mobile and other information management technologies in intermodal transportation area. While there is much literature about the logistic chain analysis [1, 5] and the intermodal transportation management itself [2, 3, 4] comparatively little has been written on this subject in relation to mobile sensor based technology implementation in intermodal container transportation.

Lee and Chan (2009) proposed a RFID-based reverse logistics framework and introduces genetic algorithm to optimize the locations of collection points for product returns in order to maximize the coverage of customers, which allow economically and ecologically reasonable recycling [8]. Jedermann *et al*. (2006) analyzed new sensor, communication and software technologies which were used to broaden the facilities of tracking and tracing systems for food transports, where an embedded assessing unit detected from sensor data collected by a wireless network potential risks for the freight quality and estimated the current maturing state of agricultural products which were supported by measurements of the gaseous hormone ethylene as an indicator for the ripening processes [9].

This research is inspired by e-Safety Initiative [22, 24]. We can find works related with hazardous materials transportation analysis [13, 14, 15, 16, 18, 19, 33]. Related

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works evaluate sensor readability [6] and integrate UHF RF powered chips by using sensors for wireless monitoring [5]. Our proposed multi-layered conceptual architecture assembles the technological platform of aggregating sensor components which are working by mobile technology and supports the on-line processing of real data for localization and monitoring of transport objects. The models of knowledge representation for the on-line recognition of abnormal situations are included in the decision support system (DSS) under development by conceptual models of information structures, dynamic process description and decision making tasks.

The representational platform describes a general component model that is a basis for expressing properties of knowledge by using Petri nets which consideration aimed at helping in management processes of multi-modal transportation. The analysis of transportation processes as complex technology has been proposed by means of imitation modeling [11, 25]. The attention is paid to the representation of dynamic and static aspects of a target system. The approach of using integrated conceptual models such as semantic models for representing information structures and fuzzy logic Petri nets [10] for functional analysis is focused on the consideration of temporal aspects of domain. However, multimodal transportation conditions, information security and other risk issues are less analyzed making them the primary objectives of the proposed transportation management mobile control system. In this paper, we study an emerging field of intermodal transportation and offer a combined RFID and mobile sensor based mobile control system, to ensure seamless end-to-end tracking and visibility from global to local level in intermodal transportation management by evaluating the potential risks involved in transportation of dangerous goods.

The aims of this research concern the construction of knowledge base for risk description of transportation dangerous goods and relation it with decision making deriving actions according to the data from sensors working on-line as the monitoring subsystem of transport objects. The tasks of this research are:

- to choice the knowledge representation techniques for description of risk of transportation using recognition mechanism using information about transport mean mobility and sensor parameters;
- to integrate the risk management component into the decision support of transportation processes;
- to present the architecture of the decision support system working as monitoring on-line system using mobile technologies;
- for assuring a high level of information and transportation security, and improving the efficiency of the communication to upgrade the capability of the general information system by integrating the mobile interaction system, using SIP (Session Initialization Protocol).

For the construction of knowledge base we are choosing Petri nets for the description of imitational model of transportation system. Petri nets are used to describe decision making processes and SIP communication protocol. For the semantic representation of data we are used class diagrams based on object oriented model of UML. For risk representation and possibilities of evaluation the levels of risk we describe the set $S = \{ s_k \}$ of types of scenarios of accident events of transportation which we can to recognize. Scenarios are described using the probability of evolving of such type s_k of scenarios.

1. The Architecture of Decision Support System with Embedded Subsystems for Monitoring and Localization of Moving Objects

The main design principles of DSS framework is presented by means of conceptually layered framework, with a view to associate the functionality of implemented components of the subsystems in the existing framework of the DSS (Figure 1). The system is dividing into various layers. We depict different context models used for representing, storing and exchanging sensing for contextual information representation needed for support decisions.

The real-time working subsystems (monitoring of data part) are embedded in the target system as a concurrent computing system related with the monitoring of sensors (Figure 1).

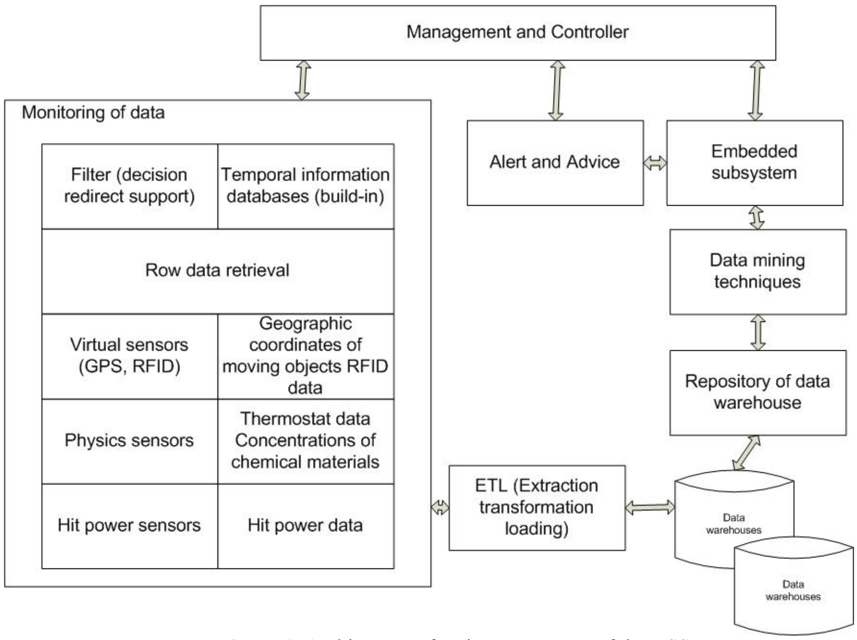

Figure 1. Architecture of main components of the DSS

The monitoring subsystem connected with the expert subsystem must detect the faults of process performance. The time for obtaining a solution is often strictly limited. These conditions impose strict deadlines on the obtaining a decision and maintaining the functioning correctness. The system behavior defines a set of temporal dependencies, dynamic evaluation of situations, adaptively control feedbacks and complexity management, which must be implemented in the embedded DSS, according to related works [11, 12, 21]. The system works as a multiple agent based system.

The monitoring component of the system integrates several sensor systems which observe the transportation means and indicate possible conditions of the state. Such sensors are aimed at localization of the object, observing the main physical parameters inside the object, which can characterize multiplex state evaluation. The main types of sensors are represented in Figure 1. Such data became row data for transforming them the data warehouses. The metadata represented in the conceptual schema of the repository of data warehouses are introduced in our system for a better understanding of data semantics and contextual information. The extraction transformation loading (ETL) engine is used for revealing and storing such row data into the data warehouses. Data mining techniques are introduced in the DSS as the components for extraction of the main rules and patterns of the situation recognition which can help to integrate multi-dimensional parameters into decision support processes and control processes of the accident event situation.

2. Description of Functional Requirements and Risk of Transportation System

The integration possibilities of knowledge representation techniques: semantic model constructions, macro Petri nets with imitational interpretations of processes are considered. Such common interaction model is illustrated in Figure 2. The whole modelling system of multi-modal transportation was divided into three subsystems: ”Environment”, “Node” and “Chain”. The structural scheme of component application for multi-modal transportation system is presented in Figure 2.

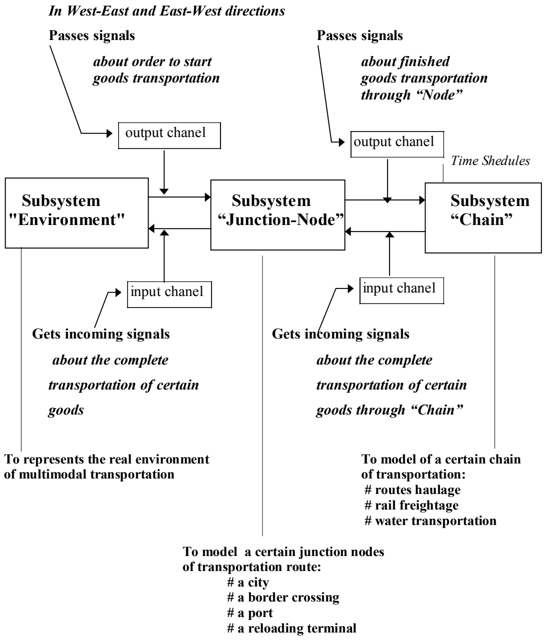

Figure 2. The structural scheme of interaction of aggregate components for intermodal transportation representation

Decision making is performed considering a lot of various factors: evaluating technical infrastructure of multi-modal transportation and organizational aspects, comparing reports with the real situation.

The subsystem "Environment" is dedicated to model the real environment of multi-modal transportation. It has two output channels with the first and the last junction-nodes of the "Node" subsystem, through which the "Environment" passes the output signal about the order to start goods transportation accordingly to the West-East or East-West direction.

The route is divided into road stretches and each is characterized by different characteristics. Risk is related with scenarios of accident events, influenced by types of dangerous goods, and surroundings. The approaches of multiple complex description of scenarios influence the classification them by types and can be based on the ontology of this phenomenon. Federal and provincial legislation provide for the regulation of an extensive list of products, substances or organisms classified as dangerous. The products fall into one of nine classes: explosive, flammable, radioactive, etc. The model is focused on evaluation of a proper frequency of accidents, following [15, 16].

The set $S = \{ s_k \}$ represents types of scenarios of accident events of transportation which we can to recognize, where $k = \overline{1,n}$.

Following the recommendations of approaches by [15, 17, 24], the expected number of fatalities as a consequence of an accident occurred on the road stretch r and evolving according to a scenario s_k, can be expressed as:

$$B_r = \sum_{k=1}^{n} f_r N_{r,s_k} P(s_k) \qquad (1)$$

where f_r is the frequency of accident in the r-th road stretch [accident·year^{-1}], N_{r,s_k} is the number of fatalities according to a scenario s_k in the r-th road stretch [accident fatalities^{-1}], $P(s_k)$ is the probability of evolving scenarios of type s_k, following the accident (i.e. collision; roll-over; failure, etc.).

The transportation network can be considered as a number of junctions (nodes) linked one to another by a number of arcs (Figure 3).

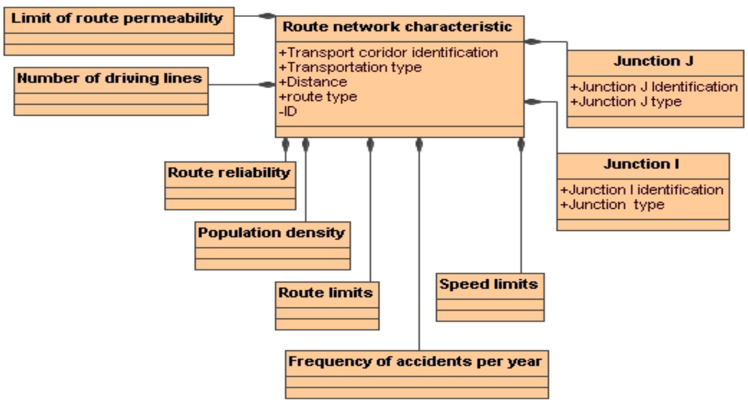

Figure 3. The example of class diagram for conceptual representation of main parameters of route stretch characteristics

The junctions represent the cross roads, towns, tool-gates, storage areas, etc. in the transportation network. An arc between two junctions can be characterized by a different number of road stretches and the expected number of fatalities for the arc is:

$$B = \sum_{r} \sum_{s_k} f_r N_{r,s_k} P(s_k) \qquad (2)$$

The frequency of an accident involving the scenario s_k, on the r-th road stretch, can be expressed as:

$$f_{r,s_k} = f_r P(s_k) \quad (3)$$

$$f_r = \gamma_r L_r n_r \text{, where:} \quad (4)$$

$$\gamma_r = \gamma_{0,r} G, \quad (5)$$

where γ_r is the expected frequency on the r-th road stretch [accident·km^{-1}·vehicle^{-1}·year^{-1}], L_r is the road length [km], n_r is the number of vehicles through the road r-th stretch in [vehicle], $\gamma_{0,r}$ is the regional accident frequency [accident·km^{-1}·vehicle^{-1}·year^{-1}], according to [17].

G is probabilistic parameter, characterized as a common evaluation parameter of environment. Various factors influence the accident events: environmental, behavioral, physical, mechanical, Road intrinsic descriptors are described by these parameters.

$$G = \prod_{j=1}^{m} G_j \quad (6)$$

where G is the local enhancing/mitigating parameter. The main types of these parameters we can describe as: G_1 is a parameter depending on temperature, G_2 is a parameter that depends on the inherent factor (such as tunnel, bend radii, slope, height gradient, etc), G_3 is a parameter that depends on the metrological factor (such as snow, sun, rain, ice, etc), G_4 is a parameter that depends on the wind speed and wind direction, and others until such parameter that we can recognize G_m.

N_{r,s_k} is the total number of fatalities according to Eq. (2):

$$N_{r,s_k} = (\Phi^{in}_{s_k} o^{\Delta t} v_r + \Phi^{off}_{s_k} d_r) P(F, s_k) \quad (7)$$

Being the in-road and the off-road number of fatalities calculated, respectively, as:

$$N^{in}{}_{r,s_k} = \Phi^{in}_{s_k} o^{\Delta t} v_r P(F, s_k) \quad (8)$$

$$N^{off}{}_{r,s_k} = \Phi^{off}_{s_k} d_r P(F, s_k) \quad (9)$$

where $\Phi^{in}_{s_k}$ is a consequence of the in-road area associated with scenario s_k [m^2];

$\Phi^{off}_{s_k}$ is a consequence of the off-road area associated with scenario s_k [km^2];

$P(F,s_k)$ is a probability of fatality F for accident scenario s_k;

$o^{\Delta t}$ is the average vehicle occupation factor during specific time period Δt, which can depend on the seasons or day time;

v_r is the vehicle density on the road area [vehicle·m^{-2}];

d_r is the population density of the *r-th* road area environment [inhabitants·km^2].

Also the "Environment" has two incoming channels with the first and the last junction nodes of "Junction-Node" subsystem, through which the "Environment" gets the incoming signal about the complete transportation of the certain goods. The subsystem "Junction-Node" is dedicated to model the certain node of the transportation route, i.e. a port, a city or a border crossing. Each node from such subsystem has out-coming channels with "Chain" subsystem, through which the " Junction-Node" passes the out-coming signal about the finished goods transportation through the " Junction-Node" (goods loading, warehousing, customs).

The results of analysis of attractiveness of the transport system between forwarding agents showed that the most important evaluation criteria are: transport cost, reliability and lead time of transportation. The weight of these three factors is varying among different respondents. It is linked to the nature of cargo being carried and depends on special requirements of senders and so on. Also the basic cargo compatibility characteristics must be taken into account while allocating cargo in a container because the interrelationships between the transport properties of cargos may result in quality degradation and damage. Different cargo may react with one another and possibly with their environment. Most changes of the cargo occurring during transport are unwanted and considered damage. Cargo properties are described by their characteristic features, specific functions, utility value and its quality and etc., where transport properties cover the properties of a cargo which need to be taken into account to ensure value loss-free intermodal container transportation.

The evaluation and selection of route also depends on the type of loads and on the desirable duration of transportation. Information accumulated in the system should help to determine technical state and reliability of routes, transportation duration. In order to select the optimal route of transportation the price of transportation and reliability of the route play an important role as well.

Reliability of the route is a complex evaluation and it is not easily determined. It should reflect assurance of load safety, possibility of assault, assurance of freight delivery in the limits of fixed terms.

3. Representation of Transportation Process Imitational Model using Petri Nets

The computing results of reasoning were obtained by application of logical Petri nets [10]. Classical Petri nets are defined as a structure $N = <S, T, F>$ where S means set of places, T is set of transitions and F is function of transition works.

$F \subseteq (S \times T) \cup (T \times S)$, where $(\forall t \in T)(\exists\ p, q \in S)(p, t), (t, q) \in F$.

Graphical representation of Petri nets is set up by the following symbols: *places* - by rings, *transitions* - by rectangles, and *relations* – by pointers between transitions and places or places and transitions. In classical Petri nets, there is a token placed if the expression is true (1) or not if it is false (0).

Let $FLPN=(P,T,F,M_0,D,h,\alpha,\theta,\lambda)$ be a fuzzy logical Petri net. Set of places $P_0 = \{p| M_0(p)>0 \wedge \forall p \in P\}$ is called a set of places of initial true propositions. D_0 corresponding with P_0 is called a set of initial true propositions. Function h_s: $P_s \to D_s$ is an association function, representing a bijective mapping from places to propositions. Propositions, such that $h_s(p)= h_s(p),\ \forall p \in P_s$. Function α_s: $P_s \to [0,1]$ is an association function, representing a mapping from places to real values between 0 and 1, such that $\alpha_s(p)= \alpha_s(p)$, $\forall p \in P_s$; θ_s,λ_s : $T_s \rightarrow [0,1]$ are association functions, representing a mapping from transition to real values between 0 and 1, such that $\theta_s(t) = \theta(t)$, $\lambda_s(t) = \lambda(t)$, $\forall t \in T_s$. The firing rules are the same as in classical Petri nets.

The exceptional feature is the fact that the net transition can represent a sequence of smaller operations with transition parameters connected with the processes. It is possible to consider the net as a relation on (E,M_0,Ξ,Q,Ψ), where E is a connected set of locations over a set of permissible transition schemes, E is denoted by a four-tupple: $E=(L,P,R,A)$, where L is a set of locations, P is the set of peripheral locations, R is a set of resolution locations, A is a finite, non-empty set of transition declarations; M_o is an initial marking of a net by tokens; $\Xi=\{\xi j\}$ is a set of token parameters; Q is a set of transition procedures; Ψ is a set of procedures of resolution locations.

The net transition is denoted as $a_i =(s_i, t(a_i),q_i)$, where s_i is a transition scheme, $t(a_i)$ is a transition time and q_i is a transition procedure. In order to represent the dynamic aspects of complex processes and their control in changing environment it is impossible to restrict ourselves on the using only one temporal parameter $t(a_i)$ which describes the delaying of the activity, i.e. the duration of transition. The input locations L_i' of the transition correspond to the pre-conditions of the activity, and the output locations L_i'' correspond to post-conditions of the activity. The complex rules of transition firing are specified in the procedures of resolution locations Ψ and express the rules of process determination.

Any *IF-THEN* rule is given of the form of:

IF X_1 is A_1 AND ... AND X_n is A_n THEN Y is B, where A_1,.., A_n and B are certain predicates characterizing the variables X_1,...,X_n and Y.

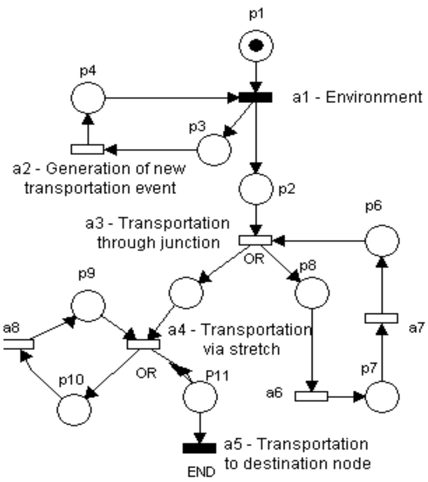

Figure 4. An example of description of transportation chain by means of macro-Petri nets

The set of *IF-THEN* rules forms linguistic description:

$$R_1 := \text{IF } X_1 \text{ is } A_{11} \text{ AND ... AND } X_n \text{ is } A_{1n} \text{ THEN } Y \text{ is } B_1$$
$$\dots\dots\dots\dots\dots\dots \qquad (10)$$
$$R_m := \text{IF } X_1 \text{ is } A_{m1} \text{ AND ... AND } X_n \text{ is } A_{mn} \text{ THEN } Y \text{ is } B_m$$

where each transition of the result of fuzzy Petri net corresponds to one rule of such linguistic description.

4. Integration of Localization and Sensing Information of the Transport Objects in DSS

Moving objects are constrained by a road network and they are capable to obtain their positions from an associated GPS receiver [28]. Moving objects (termed as mobile clients) are recognized by their location information. Location server and the central data warehouse are in the server site. The relationship is possible via a wireless communication network [11, 20]. The disconnection between client and server is realized by other mechanisms in the network than the tracking. The disconnection occurrences activate mechanisms which notify the server which appropriate actions are needed. After each update from a moving object, the position is represented in the data warehouse and the system informs the moving object about the location. The moving object issues an update when the predicted position deviates by some threshold from the real position obtained from the GPS receiver [26, 27, 28, 29].

The client initially obtains its location information from the GPS receiver and from the physical and virtual sensors [30, 31]. This possibility allows collection of the data from the sensors and processes them on-line. The data of sensor parameters are exchanged, and then the event e_{ti} influence changes in reality. If the data are changed critically, DSS gets a signal or message. The architecture of these components is represented in Figure 5 and 6.

To combine the web service protocol, e.g. simple object access protocol (SOAP), with SIP is very important for securing the communication between server systems and mobile devices [20, 23]. SOAP can be used on top of SIP or in parallel in the same layer. SIP is defined to be used only as a signaling protocol in the application layer. Thus, work is focused on the use of SIP on the control (signaling) plane in parallel of SOAP on the user plane according to [27].

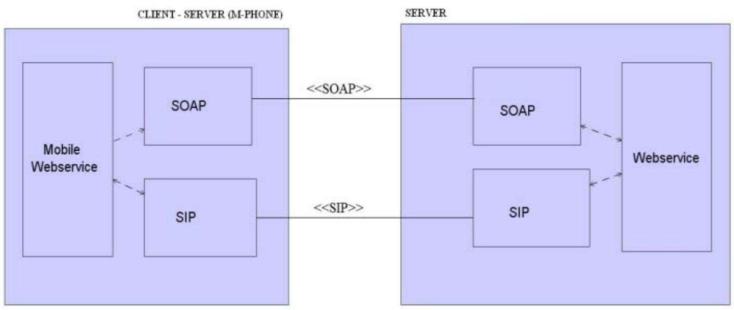

Figure 5. The scheme of integration of mobile Web services and a SIP user agent

Separation the user and signaling plane has advantages with respect to protocol design, communication software design, and performance. SIP is used to transmit "application layer" signaling messages.

In order to communicate between two different mobile devices via Web Service there must be a mobile web service endpoint. The mobile web service endpoint is a SIP URI (URI is based on the IP address). In generally, each terminal is able to provide and use mobile web services (MWS) at the same time and within the same SIP session. The use of MWS in a P2P manner is possible by establishing a SIP session between the devices. The MWS endpoints are SIP URIs, the web services endpoints of both clients are URIs containing the current IP address. First, we need a set of building-block of web services. They are common basic web services required by most mobile-service applications. The MWS and proxies have to register to the SIP agent in order to be notified about URI (IP address) changes (Figure 6).

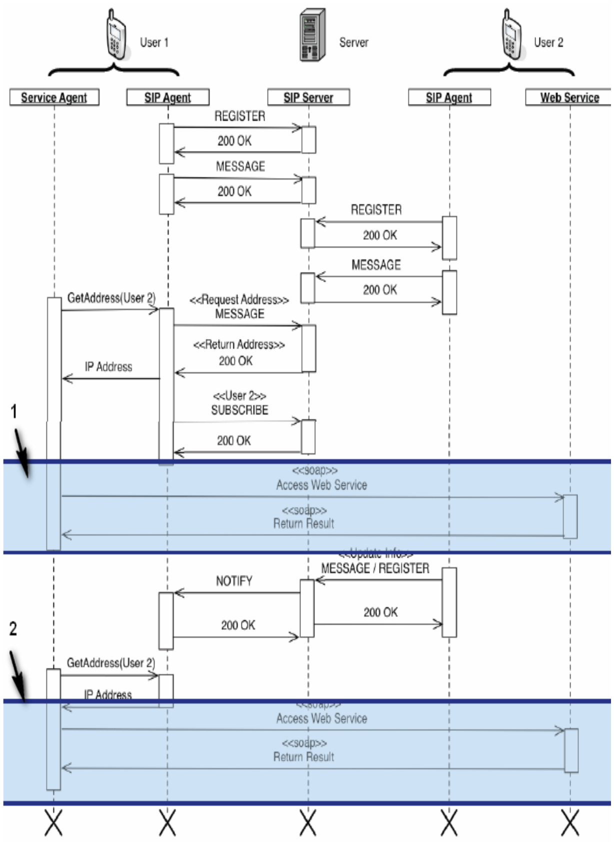

Figure 6. Sequence diagram of messaging of the connection session between SIP agents

The user of mobile device must share its physical address with the registrar in the network. Along with this "registration" is the public identity that is to be bound to the physical address (Figure 7).

The public URI can change physical addresses many times as a subscriber moves about the network, so the binding of addresses may change frequently. The connection of two participators is able to start by sending a SIP *INVITE* message after starting the SIP session between two devices (or conference). This session is initialized by request that enables a virtual connection between two or more entities for exchange of user data. Registration is not required for the agents using a proxy server for outgoing calls. It is necessary, however, for an agent to register the receipt of income calls from proxies.

The sensor's subsystems are worked as agents in parallel and the important information is writing on the temporal information registration window (TIRW). The process control subsystem of the DSS must detect such facts: what the maximum value was in concrete time interval in surroundings, the number of times a value exceeded a predefined reference value (i.e., the limitations of concentrations of harmful materials in the surrounding, sewerage water, etc.), the temporal delay between the maximum of a variable, and the maximum effect on another variable (Figure 9).

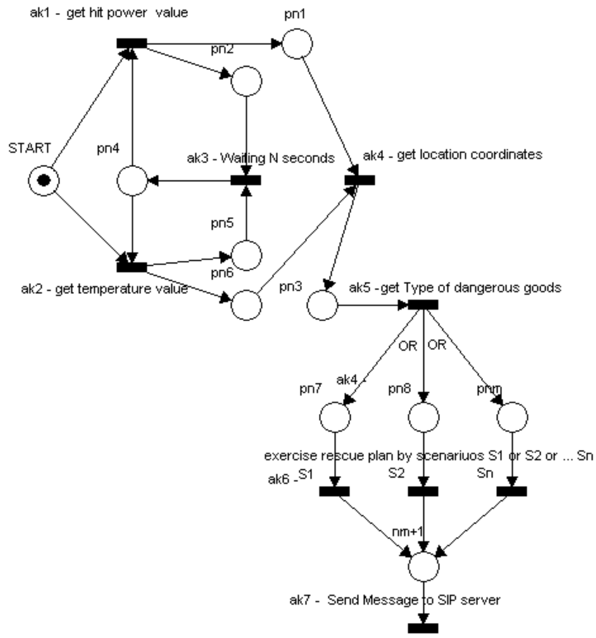

Figure 7. The Petri nets schema of monitoring processes and connection with SIP

Active RFID tags are also constantly powered, whether in range of a reader or not, and are therefore able to continuously monitor and record mobile sensor status, particularly valuable in measuring temperature, humidity and vibration limits, thus they have the flexibility to remain powered for access and search of larger data spaces, as well as the ability to transmit longer data packets for simplified data retrieval. Also, they can power an internal real-time clock and apply an accurate time/date stamp to each recorded mobile sensor value or event.

The detailed data collected from the tags during intermodal container loadings and transportation may uncover inefficiencies in established procedures and among operations strategy elements that could not previously be identified, thus making its transportation processes more agile and safer and improve the overall quality of the general intermodal container transportation management information system, therefore, the efficiency of all transportation operations. Also, automatic tracking of information is valuable in many service operations: for many applications, it is sufficient to know that a tag has passed by a reader in a given location. The automatic wireless reading of multiple RFID tags creates an enormous data flow that is beneficial to the transport operation management of many transportation services, enabling improvements in the accuracy of delivery promise, and in the speed of cargo delivery, but hardens the part of that data analysis. Whereas, in an alert situation the source of the problem can be defined by some basic predefined business process rules within the basic transportation management information system, such that if an object passes into or out of a predefined secure area, or if a problem occurs during a cargo check, then this action can trigger also other events, processes, e-mail or SMS alerts or report notifications to occur automatically. Such safe precaution system would be capable of minimizing the time spent on cargo checks and would let the system automatically decide when to bother employees, thus minimizing the rate of errors in the proposed basic information system in real time manner.

This provides company managers with an up-to-the-minute picture of transportation processes and activities and that, in turn, allows them to respond to developing problem situations in a timely manner. Active RFID tags are also constantly powered, whether in range of a reader or not, and are therefore able to continuously monitor and record mobile sensor status, particularly valuable in measuring temperature, humidity and vibration limits, thus they have the flexibility to remain powered for access and search of larger data spaces, as well as the ability to transmit longer data packets for simplified data retrieval. Also, they can power an internal real-time clock and apply an accurate time/date stamp to each recorded mobile sensor value or event.

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Conclusions

An approach for developing the interaction architecture of mobile devices and remote server systems with additional functionalities for contextual information transmission is proposed. The choosing of Petri nets allows describing the transportation system by imitational model and analyzing dynamic properties of this complex system. Petri nets provide effective formal means for description of decision making processes and scenarios of SIP communication protocol. For the semantic representation of data we are used class diagrams based of semantic object oriented model of UML. For risk representation and possibilities to evaluate the levels of risk we describe the set $S = \{ s_k \}$ of types of scenarios of accident events of transportation which we can to recognize. Scenarios are described using the probability of evolving of such type of scenarios. The proposed context modeling mechanism assures an always up-to-date context model that contains information on the transport device and location. We offer mobile internet services to extend the user interaction with architecture. The main advantage is the extensible architecture so that you can get the data to a mobile devises through web services. In this way, we try to solve the data integration of heterogeneous systems and compatibility issues.

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