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Risk Analysis of Incident-Accident Transformation in Air Traffic

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Abstract: International aviation organizations require its member countries to define the level of risk, so-called current level of safety (CLS), and compare it to target level of safety (TLS). It is also necessary to make a forecast of changes in the level of safety in future. This concept is based on the number of accidents with regard to the volume of traffic. In many countries, however, there have been no air accidents in recent years. In this case, a reliable determination of the required CLS value is impossible.
In the paper a method for predicting the number of accidents on the basis of information on air incidents is mentioned. An original approach of solving this problem is proposed. Analysis of serious incidents indicates, that there is sufficient occurrence of only one additional conducive factor, or the termination of only one inhibiting factor, to a serious incident turned into an accident. This observation is the basis for proposing the method, which general algorithm is given in the paper. The method uses colored, stochastic Petri nets for air traffic incidents and accidents modeling. In the paper, example of the serious air traffic incident analysis is given. It shows the opportunities offered by the application of this modeling technique.

Keywords: air traffic safety, accident and incident analysis, Petri nets, risk analysis.

1. INTRODUCTION

Transportation of people and goods takes place within a complex organizational and technical system called the transport system. Such a system can be analyzed in many aspects; one of the most important is the safety of traffic processes [12]. Any change in equipment, organizational principles, interactions with the environment - has to produce a question about the effects of these changes in terms of safety. But there is no possibility of experimentation on the existing system. For this reason, researchers look for new, more efficient and more effective methods of modeling transport processes. This article is an attempt to identify Petri nets, as a very convenient tool for modeling traffic processes, which are the core of the entire transport system.
Transport system includes:
- passive components, namely infrastructure, including its characteristics,
- active elements, namely transport vehicles, performing tasks and creating a traffic flow,
- organization, i.e. the relations between the elements of the transport system, aimed at realization of transport tasks.

In this paper active elements of the transport system are studied, dealt dynamically, during the realization of their task - that is, the traffic processes. Infrastructure and organization are limitations to this process and must be, to some extent considered during its modeling. It is assumed that the purpose of the modeling is the short-term safety analysis.
The traffic process is ordered and designed to reach a specific destination of vehicles using the road (suitably organized in various branches of transport), including the organizational rules, regulations and standards, to ensure the safety of all traffic participants. In this process, there are time periods in which vehicles move in a planned manner, in accordance with standard procedures. These fragments of the traffic process are characterized by its duration. The process is dynamic, because there is a change of position of vehicles in time, but from the point of view of the purpose of analysis, which is posed in this paper, it can be regarded as static. It is possible because in those time periods there are no events influencing the level of safety.
Between these fragments there are traffic events which are extracted whereas the scope of the analysis. In the case of an analysis designed to assess the safety of the traffic process, these events are defined as having an impact on safety of traffic. For such events, one can include:
- occupation of conflicting point of the road (streets junction, runway, waterways crossing) characterized by the fact that there may be only one vehicle on it, or they may be few, but it is necessary to specify the order of passing this point by vehicles, as movement continued by each of them independently can lead to collisions,

- decision by the vehicle operator to continue the movement, or to change its parameters (direction, speed), in particular the decision to stop, or to realize an emergency maneuver to avoid collision,
- decision by the traffic dispatcher (air traffic controller, the railway station dispatcher, coordinator of traffic in seaport) of a similar nature,
- decision by the vehicle operator to take action that is inconsistent with the decisions (recommendations) of traffic dispatcher,
- occurrence of dynamic and intensive meteorological phenomena (storm, heavy fog), or other phenomena of an environmental nature that may affect the traffic process,
- occurrence of events (failures) associated with the vehicle or traffic control system, which cause hazard to vehicles.

The above mentioned events may have the nature of conditions, which logical value can be evaluated. In this case they are represented by a Boolean *true* or *false*. They may also have a nature of a certain process, mostly short-term. In this case, the event will be represented by its type, but also by duration.

Safety is one of the most important criteria for assessing the transport process. Vehicle traffic in available traffic space is partly organized and planned. However these plans are subject to numerous disturbances of probabilistic nature. These disturbances may lead to mistakes of traffic managers and vehicle operators. They lead to traffic incidents, which under certain circumstances can transform into accidents.

Polish aviation regulations define three categories of events [1]:

- accident - as an event associated with the operation of the aircraft, which occurred in the presence of people on board, during which any person has suffered at least of serious injuries or aircraft was damaged,
- serious incident - as an incident whose circumstances indicate that there was almost an accident (such as a significant violation of the separation between aircraft, without the control of the situation both by the pilot of the aircraft and the controller),
- incident - as an event associated with the operation of an aircraft other than an accident, which would adversely affect the safety of operation (e.g. a violation of separation, but with the control of the situation).

The European Organization for the Safety of Air Navigation Eurocontrol issued six documents relating to safety standards, called the ESARR requirements. In air transport the last few years resulted in attempts to standardize the methods and tools of risk management, particularly in determining the acceptable (tolerable, target) level of safety [5, 9]. Currently, European aviation authorities use safety minimums set by the ECAC (European Civil Aviation Conference) which were adopted by Eurocontrol in ESARR-4 regulations. Since 2005 they have been obligatory in Poland as well. The ESARR-4 regulations divide the events with the participation of ATM (Air Traffic Management) into 5 categories denoting an acceptable level of safety only for the category of "accidents". TLS (Target Level of Safety) defines the maximum value of probability of an accident, for the commercial aircraft, to be equal $1{,}55 \cdot 10^{-8}$ accident on a flight hour, or $2{,}31 \cdot 10^{-8}$ accident on a flight [4].

All ECAC member states are obliged to designate the so called CLS (Current Level of Safety) and compare it to TLS. It is also necessary to make a forecast of changes in the level of safety in future years and to propose possible remedies (in case of excess of acceptable standards).

This task is substantially difficult because the TLS concept is based on the number of accidents with regard to the volume of traffic. In many countries, however, there have been no air accidents in recent years. That is also a situation in Poland. In this case, a reliable determination of the required CLS value is impossible.

One method of solving this problem is to use data on air incidents, which are obviously more frequent than air accidents. If the value of the CLS determined based on incidents is within the limits specified for the accident, it is assumed that this is a satisfactory result, not requiring further research or action [3]. Such an approach, although it seems to be reasonable, can be subjected to criticism. It may in fact result in conviction of the high level of safety, when in fact situation is different. With not so big number of flights (not so many flight hours), which takes into account, one may find that the existence of only one case of air accident will result in a safety level worse than the required TLS. Such a situation occurs also in Poland. According to statistics from the Civil Aviation Authority, in 2009 there were 165.000 flight hours in whole Polish civil aviation. If only one accident of commercial aircraft had occurred, the CLS could be estimated at $6{,}05 \cdot 10{-}6$, which is much more than recommended by Eurocontrol value of $1{,}55 \cdot 10{-}8$.

In this paper a different approach is proposed. Serious air traffic incidents should be analyzed and used to determine the probability of transforming them into accidents. If there is any regular statistical relationship between incidents and accidents, then on the basis of serious incidents statistics, one can make a forecast of the number of accidents and thus determine the value of the CLS. In this article an attempt to find such a relationship is presented.

2. AIR TRAFFIC INCIDENTS AND ACCIDENTS MODELING

Such an approach to the traffic process allows the use of Petri nets for modeling it [6, 7, 14]. Stable traffic situations correspond to places in the net, traffic events – to transitions. Markers in places can be identified as traffic participants or states of environment. Participants may have different traffic characteristics. For example, we may consider several types of vehicles of varying size and performance. We may also consider objects constituting the disturbances, affecting the traffic process, such as pedestrians on the road, ground service cars on taxiways at the airport. Similar interpretation can be applied to states of environment or external events. Typically, these are logical conditions, and therefore existence of a marker in corresponding place represents the occurrence of the event.

As one can see the markers are of different types, which suggest the need to use colored Petri nets. This is obviously a universal solution, but in simpler cases, the model of traffic incident can use a simpler place-transition net. This is possible if parts of the net using different types of markers are mostly disjoint. In particular, sets of places are disjoint and the only connective points between these fragments are transitions, which firing is dependent on the final markings of these parts of the net. In cases where the same places are used by different types of markers CPN must be used.

Unlike other typical applications of Petri nets, in modeling traffic processes in transport, in most cases, it is necessary to use the timed Petri net. This results from the fact that time and the associated dynamic phenomena are often crucial in the analysis in this area. For example, while modeling traffic incidents, it is usually necessary to examine the time sequence of individual traffic situations, resulting in specific sequence of occupation of conflicting points. This sequence may decide about the occurrence of the accident or its avoidance. In specific cases, sometimes it is preferable to use timed characteristics associated with transitions, and sometimes associated with markers.

There is also a class of applications of Petri nets for modeling the traffic processes in transport, where it is sufficient to use non-timed nets. This is possible when considering only the sequence of events leading up to the situation of interest, or sequence of events as a consequence of certain initiating event. This is in fact a study of an event tree analysis, fault tree analysis, or bow-tie analysis. Analytical techniques derived from the theory of Petri nets, applied in this case, can produce very interesting results; in particular, can accelerate obtaining satisfactory results with high accuracy.

In the method presented in this paper the following interpretation was adopted [10]:

- The set of places P corresponds to traffic situations. These situations are referred to both the location of a plane in the airspace, as well as issue of specific permits (clearances). The set P may include, for example, situations such as: aircraft ready for take-off, occupied runway, the plane at the intersection of the runways, taxiing started, etc. Additional elements of this set are situations describing the state of the environment, such as: the occurrence of more than 1000 meters of visibility, ATC controller busy, the pilot of another aircraft watches the situation on the maneuvering area etc.
- The set of transitions T corresponds to the set of events (actions) that change the traffic situation, particularly affecting the safety of maneuvers. These are events such as: ATC controller allows the start, the plane taxiing at a certain taxiway, the plane does not stop the actual maneuver. These events can be characterized by two values: the time of their duration (including the important role played by the zero-time events, the so-called immediate events) and a priority, defined by the probability of realization of events that can occur simultaneously.
- The input function I defines the traffic situations that determine occurrence of certain events, output function O defines what event (action) must occur to change the status of the analyzed system, and the inhibitor function H specifies the traffic situations that must not exist to certain events can occur.
- The initial marking M_0 defines the traffic situation in which we begin the analysis, and the current marking M describes the current state of the system (process).

The analysis, which aims to determine the relationship between serious incident and accident in air traffic, consists in carrying out the simulation of the process modeled by a suitable Petri net, together with recording the time and the probability of staying in each state. General algorithm of the method is as follows [13]:

- Development of a model of a serious air traffic incident as a Petri net. It is necessary to take into account all the events (leading to or inhibiting the incident) and time relations between them.

- Reduction of the network, which consists in elimination of places and transitions that do not affect the transformation of the incident into accident.
- Development of the scenarios of transforming an incident into accident. These scenarios must take into account both the appearance of additional events and absence of inhibiting events.
- Development of a model of an accident, taking into account reduction of the network and all the possible scenarios as defined in previous section.
- Simulation of the process, with registration of system states, time spent in specific states, the average number of markers in each place.
- Isolation of system states representing the transformation of the incident into accident, determination of the joint probability of those states.

The model presented in this paper, was developed based on the Petri net, satisfying a number of conditions, that are necessary for the proper mapping of the essential elements of the system, under which implemented airport traffic processes are analyzed. Such a net must be: colored, timed, stochastic and with priorities. Airport traffic model can therefore be written as

$$S_{RL} = \{P, T, I, O, H, M_0, \tau, X, \Gamma, C, G, E, R, r_0, B\} \tag{1}$$

where:
P – set of places,
T – set of transitions, $T \cap P = \emptyset$,
I, *O*, *H*, are functions respectively of input, output and inhibitors:
I, O, H: T → *B(P)*, where *B(P)* is the multiset over the set *P*, and functions *I*, *O*, *H* are determined for transition $t \in T$ as:
$t^+ = \{p \in P: I(t,p) > 0\}$ – input set of transition *t*,
$t^- = \{p \in P: O(t,p) > 0\}$ – output set of transition *t*,
$t^o = \{p \in P: H(t,p) > 0\}$ – inhibition set of transition *t*,
$M_0: P \to \mathbb{Z}_+$ – is the initial marking,
$\tau: T \times P \to \mathbb{R}_+$ – delay function, specifying static delay $\tau(t)$ of transition *t* moving markers to place *p*,
$X: T \times P \to \mathbb{R}_+$ – random variable, describing random time of realization of traffic event (transition) *t* leading to traffic situation (place) *p*,
Γ – nonempty, finite set of colors,
C – function determining what color markers can be stored in a given place: $C: P \to \Gamma$,
G – function defining the conditions that must be satisfied for the transition, before it can be fired; these are the expressions containing variables belonging to Γ, for which the evaluation can be made, giving as a result a Boolean value,
E – function describing the so-called weight of arcs, i.e. expressions containing variables of types belonging to Γ, for which the evaluation can be made, giving as a result a multiset over the type of color assigned to a place that is at the beginning or the end of the arc,
R – set of timestamps (also called time points), closed under the operation of addition $R \subseteq \mathbb{R}$,
r_0 – initial time, $r \in R$.
$B: T \to \mathbb{R}_+$ – function determining the priority of transition *t*, this function applies only for transitions that are simultaneously active, in this situation a free choice of transition to be fired is possible.

As mentioned earlier, the basic tool for safety analysis of traffic processes in transport, modeled using Petri nets is the reachability graph *G*:

$$G = \langle M, T, S \rangle \tag{2}$$

where:
M – set of nodes corresponding to Petri nets markings (states of the traffic process), reachable from the initial marking M_0,
T – set of arcs, labeled by names of net's transitions, and illustrating the direct reachability between markings,
S – ternary relation $S \subseteq M \times T \times M$, satisfying the condition

$$\forall (M_1, t, M_2) \in S:\ M_1[t\rangle M_2 \tag{3}$$

where the notation $M_1[t\rangle M_2$ means that M_2 is reachable directly from M_1 by firing transition t.
This graph often contains dozens or even hundreds of states, which makes it difficult to analyze. Then its reduction is necessary. It is a large and difficult task. First, one can apply methods of reduction recommended by the literature (e.g. reduction regarding of the symmetry or regarding of the permanent sets of transitions) [8]. The second reduction step is to remove states (nodes) that occur with probability 1 and do not affect the results of the analysis. It is a reduction specific to the target of analysis. A positive side effect of the reduction process may be to demonstrate the possibility of simplifying the structure of the initial Petri net. This happens when certain sequences of transitions between states are always performed, without possibility to choose a different sequence of firing of transitions. One can then go back to the beginning of the modeling and modify (simplify) the structure of the network.

3. EXAMPLE OF METHOD UTILIZATION – MODELING AIR TRAFFIC INCIDENT WITH TIME DEPENDENCIES

In [11] it was presented an example of modeling, where incident-accident transformation required additional traffic events to occur. In this paper different case is discussed. It is the case, that all conditions of such transformation already happened, and occurrence of an accident depends only on time dependencies.
The presented example illustrates the applicability of the method and deals with the analysis of a serious air traffic incident on January 31st 2007, which took place at Warsaw-Okecie airport (Figure 1). The participants were two aircraft: Learjet 60 (LJ 60) and Embraer ERJ 170-100 LR (ERJ 170). The causes of this incident have been classified as "human factor" and the causal group H3 - "error in communication" and the category of "environmental factor" causal group E2 - "air traffic services (ATS) / radio communication (COM) / misunderstanding in air traffic [2].

3.1. Circumstances of the serious incident

Learjet 60 crew has received clearance to line up the runway RWY 29 ("line up runway 29") without the command for waiting at the runway for permission to start ("line up and wait runway 29"). The LJ 60 crew confirmed command ("lining up") and took the RWY 29, and then started take off, in accordance with the procedure, but without the actual permission from the controller. TWR controller did not observe LJ 60 take off. Detachment from the runway occurred 88 seconds after the beginning of take off procedure. One second later the aircraft was over the runways RWY 11-29 and RWY 15-33 intersection. At the same time the ERJ 170 performed a landing procedure, under the authorization of the controller, and was on the runway RWY 33 in the roll-out phase, at a distance of 300 m from the intersection of the runways.

Figure 1. Traffic situation – incident 031/07 (source: [2])

3.2. Model of serious incident

This event was classified to serious incident category, as there was almost a collision between these two planes. As the cause of the event Polish State Commission for Investigation of Air Accidents acknowledged the LJ 60 execution of take off procedure without authorization of TWR controller.

Analysis of this event shows the following factors contributing to the creation of this dangerous situation:

- improper formulation of the line up clearance ("line up") instead of the line up and wait for permission to start clearance ("line up and wait"),
- controller did not make sure that the crew well understood the permission; in fact he did not react to confirmation by the crew of the command, which was given verbally by the controller, but was not his intention,
- lack of observation by the TWR controller actions performed by the LJ60 crew.

In this event one can specify an inhibiting factor that prevented to transform it into an accident, namely:

- advantageous time sequence, which resulted in the fact that separation was 300 m and there was no collision.

Both procedures – LJ 60 take off and ERJ 170 landing, took place entirely independently of each other. They did not affect each other either directly or indirectly, for example, by a controller or shared communication media. Therefore, the model of the incident (Figure 2) consists of two independent timed Petri nets, in which the intensities of the transitions are defined deterministically and selected to reflect the actual time and space dependencies between the aircraft. In particular they reflect the fact, that at the time LJ60 passed the runway intersection, ERJ 170 was 300 meters from this place.

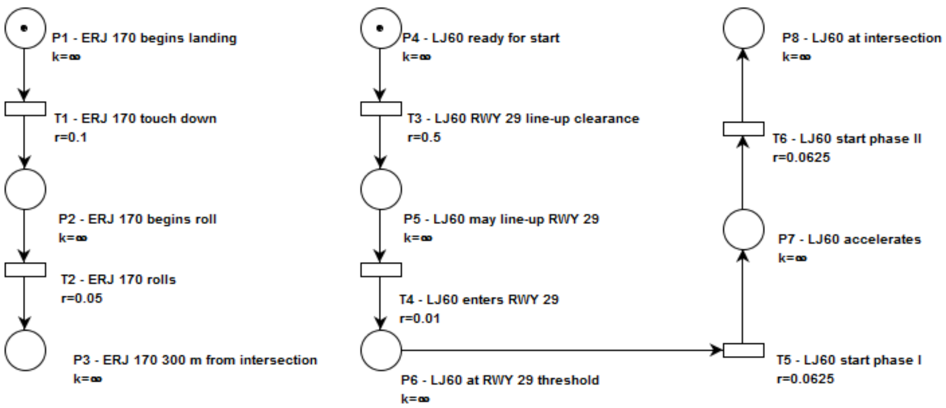

Figure 2. Model of serious air traffic incident 031/07

3.3. Model of air traffic accident

In this example of an air traffic incident, the fundamental role is played by time dependencies. The probability that both aircraft will be at the intersection of the runways is in this case equal 1. Only the time when they reach this point decides whether an accident occurs or not. Denoting by X_1 random variable describing the time after which the aircraft LJ60 reaches runways intersection, and by X_2 random variable indicating the time after which the aircraft ERJ170 reaches the runways intersection, one can analytically determine the expected value and variance of these random variables. It is then possible to determine the probability that the difference between actual realizations of the random variables X_1 and X_2 is smaller than the value defined as the distance at which we are dealing with the collision. It is the sought probability of incident-accident transformation.

Another way to determine the desired probability is to conduct simulation experiments on suitably prepared Petri net.

According to the proposed method, the first stage of modeling incident-accident transformation is the net reduction. In this case, the net reduction is impossible, since the same places and transitions exist both in the model of incident and in the model of accident. Only the intensities of realization of timed transitions should change, so as to introduce an element of randomness, which may affect the formation of accident.

The next step of the algorithm is to add network components that allow tracing the role of individual scenarios leading to air traffic accident. In the current example, such addition is not necessary for the reasons analogous to the reduction of the network. Only one immediate transition, with appropriate activation conditions and additional place were added, to make the simulation experiments easier.

Let's denote by n – time of reaching place p_3 („ERJ 170 at intersection") and by k – time of reaching place p_8 („LJ 60 at intersection") (Figure 3). Set of additional transitions $T_d = \{t_7\}$, and transition t_7 can be activated when a condition k-n<5 is satisfied, which means that incident transforms into an accident. Modification of the net by adding this transition and corresponding arcs, allows the simulation of many random realizations of this incident, and thus statistical analysis of the process of incident transforming into accident. Petri net for modeling and analysis of this process, taking into account the above mentioned conditions, is given on Figure 3.

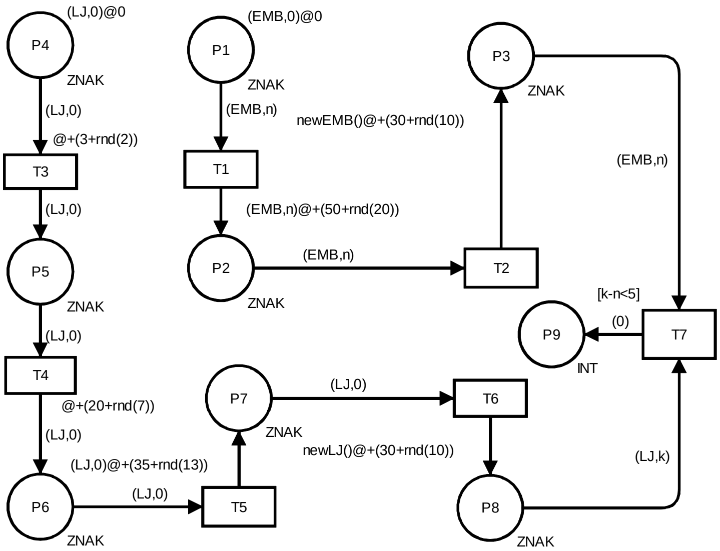

Figure 3. Model of accident transformed from serious incident 031/07

Assume the following places designations: p_1 – „ERJ 170 begins landing", p_2 – „ERJ 170 begins roll", p_3 – „ERJ 170 at intersection", p_4 – „LJ 60 ready for start", p_5 – „LJ 60 may line-up RWY 29", p_6 – „LJ 60 at RWY 29 threshold", p_7 – „LJ 60 accelerates", p_8 – „LJ 60 at intersection" , p_9 – „accident".
Reachability set for the model of air traffic accident transformed from incident 031/07 is presented in Table 1. There are 16 states (markings) possible, one of them is a dead marking (D).

Table 1. Reachability set for the model of accident transformed from incident 031/07

M_0	p_1+p_4		M_1	p_1+p_5		M_2	p_2+p_4	
M_3	p_2+p_5		M_4	p_1+p_6		M_5	p_3+p_4	
M_6	p_3+p_5		M_7	p_2+p_6		M_8	p_1+p_7	
M_9	p_3+p_6		M_{10}	p_2+p_7		M_{11}	p_1+p_8	
M_{12}	p_3+p_7		M_{13}	p_2+p_8		M_{14}	p_3+p_8	*
M_{15}	p_9	D						

The only one marking that can represent an accident is the dead marking M_{15}, which describes the situation when both aircraft are at the runways intersection. As it was mentioned earlier, the probability that the system will be in this state is equal 1, and therefore this is not the basis for conclusion about the probability of incident transforming into accident. Only the time in which markers will appear in places p_3 and p_8 determines that. These times were determined by simulation, using CPN Tools package, as enabling easy analysis of time dependencies.

3.4. Probability of incident-accident transformation

In current example, critical role is assigned to transition analysis, namely the intensity of their realization. The set of transitions is as follows:
t_1 – „ERJ 170 touchdown", t_2 – „ERJ 170 roll", t_3 – „ LJ 60 RWY 29 line-up clearance", t_4 – „LJ 60 enters RWY 29", t_5 – „LJ 60 start phase I", t_6 – „LJ 60 start phase II", t_7 – „accident?".
Activation of immediate transition t_7 is limited by the conditions mentioned before. Therefore there is no need to assign the priorities, which are typical for the analysis of immediate transitions. However timed

transitions t_1, t_2, t_3, t_4, t_5, t_6 are assigned intensities, respectively μ_1, μ_2, μ_3, μ_4, μ_5, μ_6. In this model of incident, those intensities were defined deterministically in order to achieve the implementation of the model compatible with real situation. But in model of accident, those intensities have been modified in such a way that the duration of realization of each transition is the sum of a fixed value and a random variable with Poisson distribution. The resulting random variable has the same expected value as in model of incident, but variances are different. Intensities of transition realization for selected simulation experiment are given in Table 2. The term *Poisson*(x) means a computer implementation of a random variable with Poisson distribution with parameter x, obtained by inverting the distribution function.

Table 2. Intensities of transition realization in models of incident and accident

Transition	**Model of incident**	**Model of accident**
μ_1	70	50 + *Poisson*(20)
μ_2	40	30 + *Poisson*(10)
μ_3	5	3 + *Poisson*(2)
μ_4	27	20 + *Poisson*(7)
μ_5	48	35 + *Poisson*(13)
μ_6	40	30 + *Poisson*(10)

For this specific data, as a result of 1000 simulation runs, in 198 cases the result was transformation of incident into an accident. Therefore the searched probability is equal 0,198. A similar result is obtained with the analytical method. For a Poisson distribution with parameter λ a general formula for the probability distribution function is as follows.

$$P(X = m) = e^{-\lambda}\frac{\lambda^m}{m!} \tag{4}$$

Let k denote the realization of random variable X_1 , and n realization of random variable X_2 (Figure 3), and λ_1 and λ_2 respectively parameters of the Poisson distribution of random variables X_1 and X_2. Then the probability of transforming incident into accident under condition X_1=k equals

$$P_{I\to W}(k) = P(X_1 = k)\cdot\sum_{n=k-4}^{n=k+4} P(X_2 = n) = e^{-\lambda_1}\frac{{\lambda_1}^k}{k!}\cdot\sum_{n=k-4}^{n=k+4} e^{-\lambda_2}\frac{{\lambda_2}^n}{n!} \tag{5}$$

The sought probability of incident-accident transformation is the sum of $P_{I\to W}(k)$ for all values of k

$$P_{I\to W} = \sum_k\left(e^{-\lambda_1}\frac{{\lambda_1}^k}{k!}\cdot\sum_{n=k-4}^{n=k+4} e^{-\lambda_2}\frac{{\lambda_2}^n}{n!}\right) \tag{6}$$

In this example we use the theorem that the sum of two random variables with a Poisson distribution is a random variable with Poisson distribution with parameter equal to the sum of the component parameters. We then obtain that $\lambda_1 = 32, \lambda_2 = 30, k \in \langle 88,163\rangle, n \in \langle 84,167\rangle$ (Table 2). For these data analytically determined from the formula (6) probability of incident-accident transformation is 0,2.

4. CONCLUSIONS

In the paper the method for analysis of relationship between serious incident and accident in air traffic is presented. The starting point for this analysis was the assumption that a serious incident describes a situation in air traffic, which needs only one additional occurrence of adverse event to cause an air traffic accident. In analyzed, real air traffic events, one can usually distinguish several scenarios, which lead to an accident. Analysis using generalized, stochastic, colored Petri net allows determining the probability of incident-accident transformation. The method is efficient both for logical dependencies [11] and time dependencies (as in example presented in this paper) and also for the mixed case.

The analysis provided gives the basis for the conclusion that the proposed method is of general nature and allows to predict the number of accidents based on the number of incidents (serious incidents) in air traffic.

The creation of such method is an important step to use the idea of TLS in air traffic management practice. In cases, where the sought probability is likely to depend only on the events characterized by the time – it is better to determine it analytically, although it is also possible to designate it by simulation.
Colored, timed Petri nets are an important and convenient tool for the analysis of traffic processes in air transport. Research has indicated its usefulness in the analysis of traffic safety problems. However one can also specify other applications, also in other modes of transport.

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