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A WAY OF MODELLING THE PORT OPERATIONS

The main goal of the traffic system modelling is successful running a business and continuously searching the possibilities for its improvement. With the application of the model set in this paper one can get the valuable results for managing the port system. These results should route the port managers to bring appropriate decisions in order to enhance the business efficiency and enlarge the port competitiveness. The model presented is based on the general systems theory. The port system can be presented as a physical system which over time changes its status to a random manner i.e., exceed from one state to another under the influence of random factors that cannot be predicted in advance. Here, the system "serving ship at quay" is defined with the universe of discourse and couplings (UC-structure), dividing it on elements and links between them. Next, the states and the transitions between the states are identified, along with the scheme (ST-diagram). From the ST-diagram the system of differential equations is set and the computer program for solving is recommended.

Key words: *general systems theory, port, serving ship at the quay, computer program CARMS*

1. INTRODUCTION

Our understanding of the traffic phenomenon is based on empirical researches and verbal description of traffic systems. The core concept of a systemic traffic theory is not presently available in a unified and formalized form. The field of traffic science and technology is an extremely broad one, encompassing many different disciplines and activities, thus the unification seems impossible without the application of general systems theory and methodology. The partial use of system theories in the major part of traffic literature has been only a superficial description without precise formulations derived from the concept of a general or generalized system. On the other side, classical analytic approach with bounded discipline-oriented researches, use their own theoretical concepts and methodologies.

The highest-level generalization is axiomatic, mathematical theory of the traffic system. On that level, fundamental traits and relations must be derived from a concise formal definition of the traffic system. The collection of concepts and definitions for fundamental traits of system are given in (Klir, 1972).

The past researches, in scientific and technical literature, have dealt with the port system management, technical and technological processes in the port, theory of stochastic processes in the papers of the mathematicians, and with the modeling systems using analytical and simulation methods. Thanks to the computer technology development, in these papers, simulation is the most frequent way of modeling.

In the book "Stochastic processes and programming models in economy" Tourki (1986) describes certain problems in economic processes and stochastic systems, which can be solved by using Markov processes. Wentzel and Ovcharov (1986) in the book "Applied Problems in Probability Theory" treat Markov stochastic processes and queuing theory giving a lot of solved examples of Markov stochastic processes. In the paper "Analytic modeling of the port system by means of the discrete Markov chains" Radmilović (1989) presents the functioning of port facilities with discrete Markov processes and proposes the application of the model with the system of differential equations, which describes technological processes of direct and indirect trans-shipment of the cargo. On the basis of concrete examples Nelson (1995) in his book "Stochastic Modeling – Analysis and Simulation" explains the continuous, discrete processes and processes of the queuing theory. In the paper "Generalized Traffic Model and Traffic Equations Derived from ST-diagrams" Radić and Bošnjak (1997) give the concept of the generalized traffic model using the general system theory methodology, and derive equations from ST-diagram for stationary behavior of the subsystem. Kia, M., et al. (2002) explore port capacity under a new approach by computer simulation. Asperen, van E., et al. (2003) propose a possible way of modeling ship arrivals in ports. Banks, J., et al. (2000) in the book "Discrete-Event System Simulation" research simulation of discrete-event systems which can be applied on some real-life examples.

There are still few papers dealing with the stochastic models based on the general systems theory with the objective of successful port operations.

Therefore, the reasons stated were the main motive to present the managing of a port system by the synthesis of the two approaches. One is the stochastic approach to the port system in the form of a mathematical model, i.e. the system of differential equations where the state of the system is the function of time. The second approach to the port system is in terms of traffic science. This synthesis results in the proposed stochastic model by which the successful port system management is possible.

The general systems theory is applied in the state system analysis, forecasting and planning development of dynamic systems, in the selection of optimal or at least satisfying managing actions and decisions. Since it is necessary to divide the system observed into the elements and the connections between elements the universe of discourse and couplings will be defined (UC-structure). Next, the state and the transitions between the states will be identified, along with the scheme (ST-diagram) on the basis of which the mathematical model is derived. Through the proposed model one can observe the time varying port system operation.

2. FUNDAMENTAL TRAITS OF THE GENERAL SYSTEMS THEORY

A general system is essentially an abstract model of an already existing (physically or conceptually) system that reflects all the basic or fundamental systemic traits of the original. It is, however, not unique and is directly related to the definition of the system that it is to model.

According to general systems theory, the fundamental traits of systems studied in engineering branches of science are: 1) set of quantities and the resolution level, 2) activity, 3) time invariant relations between quantities (the behavior), 4) universe of discourse and couplings (UC – structure) and 5) states and transitions between states (ST – structure).

Five definitions, each based on a separate trait, are defined by Klir (1972). Each verbal definition is followed by a mathematical definition, the two indicated as (a) and (b). Five definitions of a traffic system (Radić, Z., Bošnjak, I., 1997, pp. 237) follow:

Definition 1.

a) A traffic system (TS) can be defined by a set of quantities at a resolution level.

b) A traffic system is 3-member (X, t, L) where:

$X = \{x_1, x_2, ..., x_n\}$ is the set of external quantities, t is time, and $L = \{X_1, X_2, ..., X_n, T\}$ is the resolution level.

Definition 2.

a) After the quantities are chosen and a resolution level is assigned, we can measure the values of the quantities in the time interval T. The variation in time of all quantities is the activity of the system.
b) Activity is formally defined as a 1-member (M), where M is the set of n-members: $M = \{(x_1(t), x_2(t),..., x_n(t) \,|\, t \in T, x_1(t) \in X_i \; \forall i = 1, 2,..., n\}$. In these formal expression the following notation is introduced: $x_i\,(t)$ is the value of the quantity x_i at the time t, X_i is the set of all possible values of x_i, $T = \{t \,|\, t$ is considered time slot and $t \in [0, t_{max}]\}$

Definition 3.

a) The state of the system is defined by the instantaneous values of all quantities of the system. Participating is a certain behavior, i.e. producing certain outputs with given inputs. A traffic system is a given time-invariant relation among instantaneous and/or past and/or future values of external quantities.
b) A system is a 1-member ($R(P_1, P_2, ..., P_m)$), where: R is a relation defined on $X^m_{j=1} P_j$ a $P_j = X_i$ if $j \leftrightarrow (i, \beta)$ for some β or the system is 2-member ($R(P_1, P_2, ..., P_m), P(R)$), where: $P(R)$ is a probability measure, defined on R, such that $P(r)$ is the probability of the occurrence of r, $r \in R$.

Definition 4.

a) A traffic system is a given set of elements, their permanent behaviors, and a set of couplings between the elements and between the elements and the environment.
b) A system is 2-member (B, C), where: $B = \{b_1, n_2, ..., b_r\}$ is the set of all permanent behaviors of the elements of the universe of discourse and $C = \{c_{ij} \mid c_{ij} = A_i \cap A_j; i \neq j\}$ – characteristics.

Definition 5.

a) A traffic system can be defined by its hypothetical (known) ST-structure as a set of states and a set of transitions between the states.
b) A system is a 2-member (S, $R(S, S)$), where: S is the set of states; R a relation defined on (S x S) or a system is 3-member (S, $R(S, S)$, $P(R)$), where: $P(R)$ is a probability measure defined on R so that if $(s_i, s_j) \in R$ then $\mathrm{P}(s_j \mid s_i)$ is conditional probability of transition from state s_i to state s_j.

A minimal definition of a system would have to be one of the basic definitions. One possible basic approach to the generalized modeling will be proposed.

3. THE GENERAL SYSTEMS THEORY APPLIED TO THE PORT

3.1. The set of quantities, the activity and the behavior of the port system

The port system cannot be observed isolated, because in that way the one-sided judgment is achieved and only a part of the problem area is detected. To comprehend the port system as a whole, it is necessary to define it within the framework of the environment that has an impact on it, and determines its feedbacks.

Because of the port system complexity, the system "serving ship at quay" is explored in this paper, as a subsystem of the port system, according to the general systems theory. The set of the quantities with the resolution level, activity, behavior of the system, universe of discourse and couplings and states and transitions are defined.

Input quantities of the element ship:

- demand for transshipment is the only independent quantity (quantity that is independent of the system, is responsible for the events taking place in the system, but is produced by the environment) in the system that causes transition of the system from the idle to the active state,
- acknowledgement of the COTP (centre for the organization of technological process) regarding the ship arrival,
- information to the ship, collected by the COTP, on the state of the system; these are: number of ships in queue, number of ships in service, number of ships leaving the system (port), is the quay free or occupied, and approximate waiting time if occupied.

Output quantities of the element ship:

- arrival message to the COTP including the time of arrival, cargo type and quantity for transshipment,
- instructions to the COTP during transshipment.
- Input quantities of the element quay:
- data about the type of equipment and number of workers for the transshipment,
- demand from the COTP for transshipment beginning,
- information regarding cargo position on the ship according to which the transshipment is planned.

Output quantities of the element quay:

- information to the COTP on the performed preparation for the transshipment,
- information to the ship during transshipment,
- information about breakdowns and accidents during transshipment.
- Input quantities of the element COTP:
- information from ship about her arrival, cargo type and quantity for transshipment,
- information from quay on performed preparation for the transshipment,
- information from quay on how the transshipment is utilized,
- information from ship and/or quay about breakdowns and accidents during transshipment.

Output quantities of the element COTP:

- acknowledgement of the ship's arrival,
- data about the size and type of the ship, quantity of cargo for transshipment,
- instructions to the ship and the quay regarding the manner and sequence of the transshipment operations,
- warning on bad weather and transshipment operation termination.

The behavior of the system "serving ship at quay" can be elaborated with the following analysis:

Behavior of the system in idle state. The idle state is the initial state of the system that lasts until the ship arrives, that is until the transition to the preparatory state. While being in the idle state the system takes information on the ship arrival, quantity of cargo for transshipment, type of cargo, ship characteristics, weather reports, etc. In idle state, the element COTP does the statistics and communicates with the environment.

Behavior of the system in preparatory state. On receipt of the information on the ship's arrival and all the necessary data it prepares the following: cargo for loading, area on the wharf for unloaded cargo from the ship, shore facilities for transshipment and necessary longshoremen.

Behavior of the system in the transshipment state. The ship's operation (loading or discharging) is carried out, either by ship's or shore equipment. The cargo is transported from or to the warehoused or open stock place. During the transshipment, there can be a breakdown on the transshipment equipment causing transition of the system to the repair and maintenance state. In the case of bad weather, while the system is in the transshipment state, the system crosses to the idle state.

Behavior of the system in the closing state. After the transshipment is done, the ship and the port does paper work and other necessary customs. Afterwards the ship leaves the port and the system crosses to the idle state.

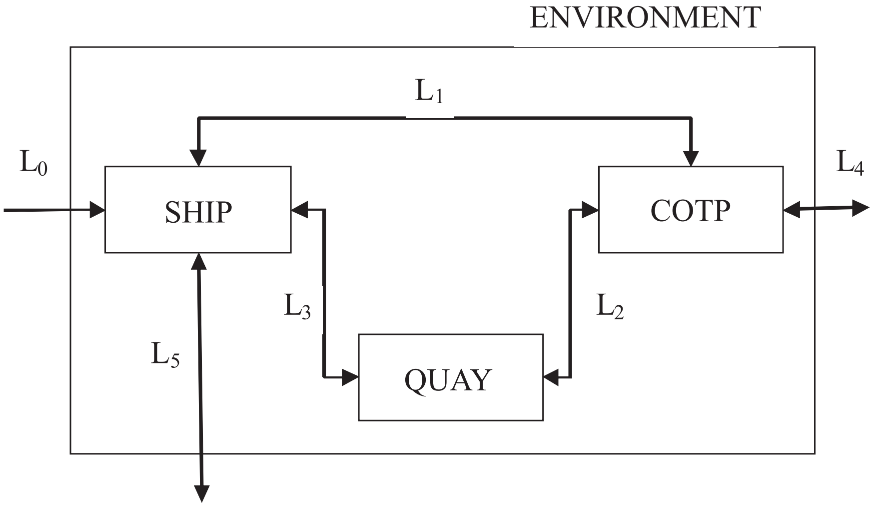
Behavior of the system in the repair and maintenance state. The system is in this state during the regular maintenance of the equipment, repair and in case of breakdown on the transshipment equipment or at the COTP instruction. Repairing is done on the spot or arranged with external services.

3.2. The universe of discourse and couplings of the port system

The set of all the elements and their links in the system “serving ship at quay” is shown by the UC-structure (scheme 1).

The elements of the system “serving ship on quay” are:

- the ship (S) – the object to which the activity is directed,
- the quay (Q) – the element quay *does* the loading/unloading operations of the ship,
- the centre for the organization of the technological process (COTP) – *organizes, coordinates* and *controls* the transshipment process, does the paper-work regarding the cargo, gives possibilities for obtaining the different statistical data, transacts the invoice.



Scheme 1. UC-structure of the system “serving ship at qua”y

The links between the elements of the system are as follows:

L_0 – initiation – puts the system in the active state, and starts with the ship arrival at the quay,

L_1 – two-headed arrow between the elements S and COTP, serves for informing the COTP on the ship arrival and for acknowledgment transmission, and for additional communications between the S and the COTP,

L_2 – two-headed arrow between the COTP and Q, is represented by the communication channels with the purpose to coordinate the loading/unloading operations,

L_3 – two-headed arrow between the elements S and Q, is represented by the communication channels intended for the communications between the S and the Q,

L_4 – two-headed arrow between the COTP and the environment, serves for the COTP to communicate with the meteorological service, the agents, forwarders, land carrier, air and river carriers,

L_5 – two-headed arrow between the ship and the environment, and serves for the communication between the ship and the agents, forwarders, meteorological service, and so on.

3.3. The states and transitions between the states of the port system

The set of states and transitions between these states for the system “serving ship at quay” is presented by the ST-structure (scheme 2).

The states in which the observed system can be are as follows:

S_1 – idle state; S_2 – preparatory state; S_3 – transshipment state; S_4 – closing state; S_5 – maintenance state.

The transitions between the states are:

I_{11} – the system is in the idle state until the ship’s arrival,

I_{12} – in case of the ship’s arrival the system crosses to the preparatory state,

I_{21} – during or after the preparatory works, bad weather conditions can develop (south wind, north-east and similar), or strike of the dockers; because of that the system is coming back in the idle state,

I_{23} – after the ending of the preparation, the system crosses in the state of the ship transshipment,

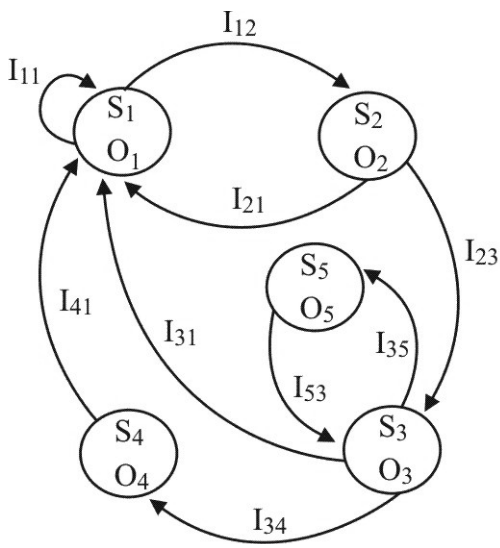
I_{31} – the system crosses in the idle state if bad weather conditions developed, or strike of the dockers, or other unforeseen events set in during the transshipment.

I_{34} – after the transshipment is done, the system passes to the closing state,

I_{35} – in case of a breakdown on the transshipment facility or at the COTP the system passes to the maintenance state,

I_{53} – after the failure is eliminated the system is again coming back in the transshipment state,

I_{41} – when the ship leaves the port the transition to the idle state follows.



Scheme 2. ST-structure of the system serving ship at quay

The outputs from the states are:

O_1 – output from the idle state are procedures depending on the input data,

O_2 – output from the preparatory state is an exchange of information between the ship and COTP, and the quay and the ship are ready for the transshipment to start,

O_3 – output from the transshipment state are the data regarding the course of the transshipment, the coordinates for work and the notification of transshipment ending to all the participants,

O_4 – output from the closing state is the cargo shipment and the paper work for the ship leaving the port,

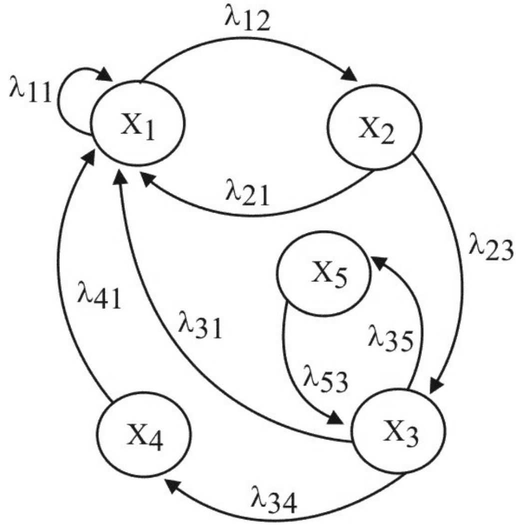
O_5 – output from the maintenance state is the facility or the COTP with the eliminated failure.

The described ST structure with the scheme 2 is the base for setting up the model in the next part.

4. THE SYSTEM OF DIFFERENTIAL EQUATIONS FOR THE PORT

4.1. Setting up the differential equations

It is convenient to derive equations using a marked graph of the states of the system (Wentzel, E.-Ovcharov, L., 1986).



Scheme 3. Marked graph of the states of the system – serving ship at quay

For the subsystem "serving ship at the quay" (scheme 3), Kolmogorov's equations are:

$$\frac{dp_1}{dt} = (\lambda_{11} - \lambda_{12})p_1 + \lambda_{21}p_2 + \lambda_{31}p_3 + \lambda_{41}p_4$$

$$\frac{dp_2}{dt} = \lambda_{12}p_1 - (\lambda_{23} + \lambda_{21})p_2$$

$$\frac{dp_3}{dt} = \lambda_{23}p_2 + \lambda_{53}p_5 - (\lambda_{35} + \lambda_{31} + \lambda_{34})p_3$$

$$\frac{dp_4}{dt} = \lambda_{34}p_3 - \lambda_{41}p_4$$

$$\frac{dp_5}{dt} = \lambda_{35}p_3 - \lambda_{53}p_5$$

To solve the system of differential equations for the probabilities of states $p_1(t), p_2(t),\ldots, p_n(t)$, the initial probability distribution $p_1(0), p_2(0),\ldots, p_i(0),\ldots, p_n(0)$, whose sum is equal to unity: $\sum_{i=1}^{n} p_i(0) = 1$, has to be specified.

Since condition $\sum_{i=1}^{n} p_i(t) = 1$ is satisfied for any t, any one of the probabilities can be expressed in terms of other probabilities and thus diminish the number of equations by one. If, in a special case, the state of the system S at the initial moment $t = 0$ is exactly known, $S(0) = s_i$, then $p_i(0) = 1$ and the other initial probabilities are zero.

4.2. Solving the system of differential equations

The analysis of the system with the graph description of its functioning through the states and the transitions between these states is called in the literature, and especially those concerning the computer simulations, the Markov model of the system observed. This terminology will be used further on.

Evaluating a Markov model can be time consuming or, at worst, feasible only for the simplest systems – unless one uses proper techniques. In general, most practical applications of the Markov model require computer support for deriving and solving state equations based on the user-specified state diagram.

Obtaining a solution to a Markov model involves three separate steps: setting up the model, deriving equations, and solving state equations (Pukite, J.-Pukite, P., 1998, pp. 119):

1. Setting up the Model. Developing a Markov state diagram for manual evaluation consists of determining the system states, the transitions between these states, and the transition rates. It also includes labeling the states as operational, degraded, or failed.
2. Deriving equations. The Markov state diagram developed in the preceding step must be converted to a set of linear differential equations. The manual derivation of the Markov model equations from the state diagram is time consuming and error prone for Markov models with four or more states.
3. Solving State Equations. The solution of the Markov state equations using this approach involves:
   – Sate equations are transformed to their Laplace counterparts. This step is relatively simple because the state equations are linear and of the first order.

– The resulting Laplace transform domain equations are inverted to obtain their time-domain solutions. This step can be performed either analytically or by using approximate numerical inversion techniques. Some highly stable Laplace transform inversion methods are available. These methods, however, are not well known and thus not widely used.

For details on solving state equations with Laplace transform, see (Bronson, R., 2003; Edwards, H. - David, P., 2004). In the case in point, if the system of differential equations is set on the basis of the ST structure, then the solution of that system presents the probabilities of finding the system in one of the five possible states depending on the independent variable *t*, which can be time.

4.3. Computer-assisted evaluation of the differential equations system

The computer support is needed for the solution of most practical reliability problems. Since many of the reliability, availability and maintainability parameters need to be predicted early in the design stage, the basic requirements of a reliability analysis tool are the following:

– provide a framework and language in which to state reliability problems,
– allow the comparison of alternative designs in a fast, interactive fashion,
– allow an approach flexible enough to model various situations encountered in practice,
– provide insight into assumptions concerning system life characteristics (such as which components are critical).

The computer-assisted evaluation of Markov models requires the same three steps of setup, derivation, and solution, but provides an alternative approach.

Setting up the model. The interactive development of the Markov model is much simpler than that in the manual mode, because several modes of model specification are available. For example, the setup of a Markov model in a symbolic or graphical form is much easier than manually developing the set of Markov state equations. The symbolic representation provides the necessary specification for detailed equation derivation.

As data are entered in the program, they can be checked to determine whether they conform to the required format. Although this checking will not ensure that the correct values have been entered, it will guarantee that the simulation program will run, and possibly aid in the debugging effort. For example, consistency checking can ensure that the graphical state diagram representation matches the database parameter specification and provide diagnostics to the user.

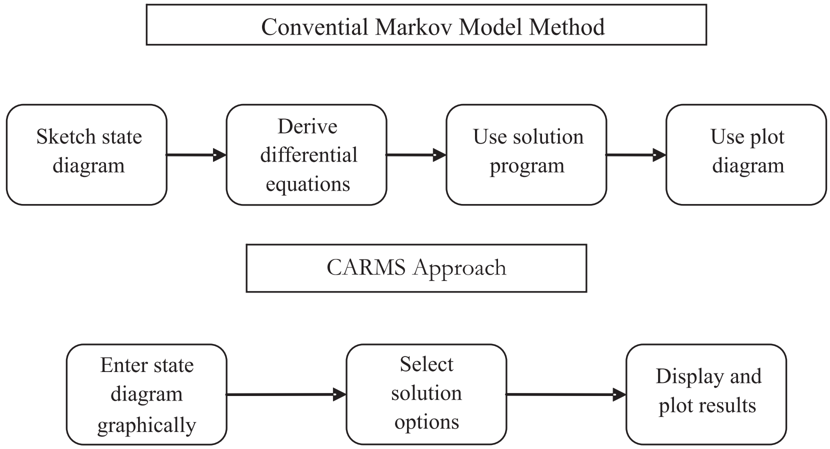
Deriving equations. The Markov model entered in the preceding step must be converted to a set of linear differential equations. The computer can easily perform this task because the state diagram provides all of the required information. Since the system state probability equations are derived from the system state transition diagram in a formal manner, errors due to manual derivation of equations will be reduced.

Solving state equations. Solving the state differential equations by computer is a straightforward process. However, if the equations are stiff (with greatly differing characteristic roots) the solution time will increase. Markov models yield linear differential equations for the state probabilities. These equations must be solved to obtain the final state probabilities. The solution of these equations involves several factors (Pukite, J.-Pukite, P., 1998, pp. 121):

1. Numerical integration methods. Differential equations representing a Markov model are integrated to obtain the state probabilities. Since the solution accuracy is dependent on equation characteristics, a suitable numerical integration method will have to be selected.
2. Integration step. Numerical integration proceeds stepwise, with the integration step corresponding to the time advance. The selected step size will affect solution time and solution accuracy. A smaller time step will normally yield higher accuracy, but will result in longer computation time. Many of the numerical integration methods support the automatic and adaptive integration step selection.
3. Stability of solution method. A stable solution may not always be obtainable. Instability may be due to a large step size, the particular solution method, and the type of problem.
4. Solution accuracy. Solution accuracy will depend on the integration step size and the precision of computation. More accurate results will require the use of double-precision computation.

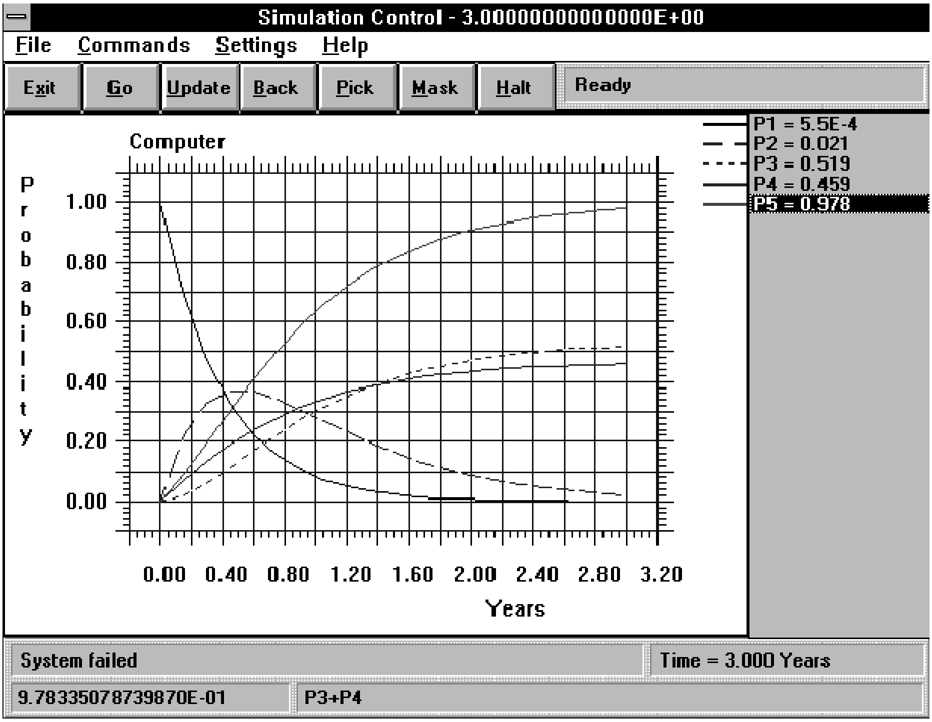
For computer-assisted evaluation as the most appropriate tool the computer program CARMS is selected. CARMS (Computer-Aided Rate Modeling and Simulation)[1] is an integrated Markov modeling and simulation tool. Primary applications are in engineering design, reliability, operations research, scientific and statistical modeling. Its features include a state diagram-based CAD environment for model setup, a spreadsheet-like interface for data entry, an expert system link for automatic model construction, and an interactive graphics interface for displaying simulation results. CARMS is based on the discrete space, continuous-time Markov model.

[1] Website location http://umn.edu/~puk/carms.html



Scheme 4. Convential and CARMS Approach to Markov Model

Source: (Pukite, J.-Pukite, P., 1998, pp. 189)



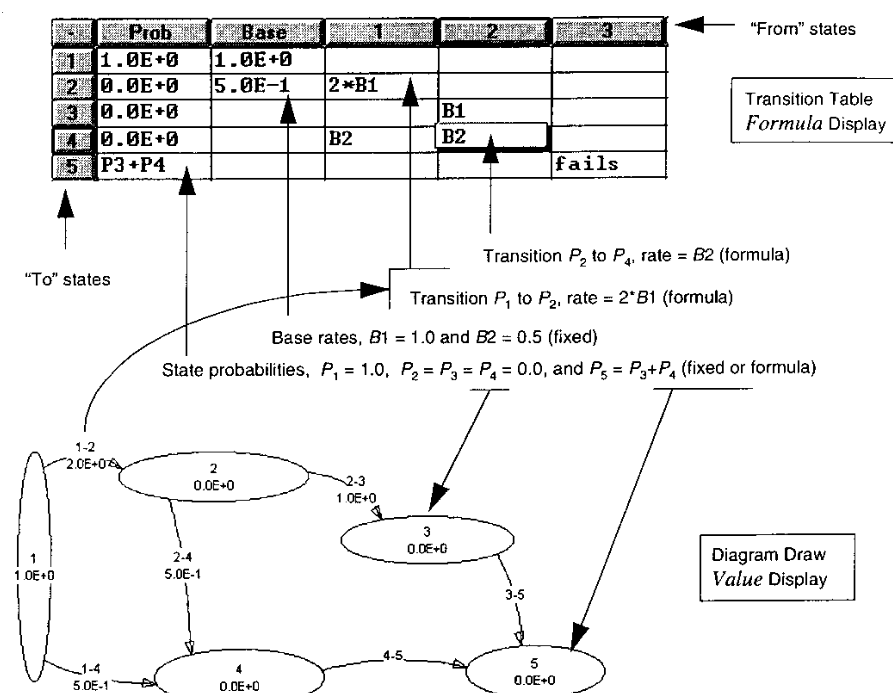
Scheme 5. CARMS Simulation Control View

Source: (Pukite, J.-Pukite, P., 1998, pp. 193)

CARMS computes the likelihood of events based on a probabilistic model that the analyst using the tool defines. The representation of a state transition diagram allows the user to specify the transitions from one operating state to another operating (or failed) state. From this state diagram, Markov equations can be formulated for each state. These equations express state probabilities for each state as functions of time and can be transformed into a matrix for solution. Further, it makes sense to view the model from a different perspective. Typically, associating the probabilities, initial conditions, and transition rates in a tabular form or transition matrix form does this.

The flexibility of CARMS allows either a table or a diagram to be used for problem formulation. Therefore, the standard method of setting up the matrix and differential equations can be replaced with the CARMS method of graphically inputting the state diagram with a mouse or keyboard (scheme 4). CARMS provides a graphical Simulation Control interface (scheme 5) that not only will control the simulation time and model updating, but will also show intermediate results. The user can further specify which curves it can display, print or plot.

The table entries correspond to the diagram attributes as shown in scheme 6.



Scheme 6. Correspondence between Table and Diagram

Source: (Pukite, J.-Pukite, P., 1998, pp. 195)

A combination of text-and graphics-based data input makes the program ideal for problems in which an engineering design is at the conceptual phase. In this phase, flexibility, ease of use, and speed are prime requirements in determining the ideal course of action and probing tradeoff scenarios. CARMS features an interactive environment that allows the user to quickly change data values and graphical views of a given system.

5. CONCLUSION

The basics of the general systems theory are presented in this paper. This theory is applied for the system states analysis, forecasting and planning the development of the dynamic systems, the choice of the optimal or at least adequately controls actions and decisions. Lack on uniformity in the case of cargo arrival at the port and impossibility to predict exactly the time and the quantity of the cargo arriving to the port, are the main reasons of the stochastic property in the port operating. The port can be presented as physical systems with random changes during time which draw necessity of using probabilities in its modeling.

The system "serving ship at quay" is explored and presented with the ST-structure, as set of states and transitions, from which structure the system of differential equations is set. If the solution obtained does not satisfy (the probabilities of certain states are too few or too large in the moment t) the transition probabilities are changing until the solution is sufficiently well. In that case the analytic method is supplemented with the simulation method. Every change of the initial state implicates on the final result that does not have to be optimal, but at least tolerably.

The proposed way of modelling the port ST-structure can contribute to a successful managing of the port operations. The model presented can serve as a theoretical base for modeling any operating processes of some traffic system. Further research will be based on testing the proposed model on a real-life example.

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Sažetak

JEDAN OD NAČINA MODELIRANJA LUČKIH OPERACIJA

Glavni cilj modeliranja prometnog sustava je uspješno poslovanje i kontinuirano istraživanje mogućnosti za njegovo poboljšanje. Primjenom modela predloženog u ovom radu mogu se dobiti korisni rezultati potrebni za uspješno upravljanje lučkim sustavom. Ovi bi rezultati trebali usmjeriti menadžere u luci na donošenje odgovarajućih odluka u cilju poboljšanja poslovne efikasnosti i povećanja konkurentnosti luke. Model se temelji na teoriji općih sustava. Lučki sustav može se predstaviti kao fizički sustav koji tijekom vremena mijenja stanja na slučajan način, tj. prelazi iz jednog stanja u drugo pod utjecajem slučajnih čimbenika koji se ne mogu unaprijed predvidjeti. Ovdje je sustav "usluživanje broda na pristanu" definiran sa skupom elemenata i veza između njih, odnosno UC-strukturom. Nadalje, identificirana su stanja i prijelazi između stanja, zajedno sa shemom ST-dijagrama. Na temelju ST-dijagrama, postavljen je sustav diferencijalnih jednadžbi i preporučen računalni program za njihovo rješavanje.

Ključne riječi: *teorija općih sustava, luka, usluživanje broda na pristanu, računalni program CARMS*

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