ST MODEL IMPLEMENTATION ON SHORT TERM OPERATIONS' PLANNING AT BULK TERMINALS

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Abstract: *This paper focuses on a bulk terminal short term operations planning problem faced by the port management in tactical decision making. Loading and discharging of ship cargo, cargo stocking, maintenance and service of facility equipment are regular operations of a sea port's bulk terminal. Their organization is subject to difficult-to-predict or unforeseen influences. The challenge that port management faces in day to day operations is in making the best possible plan with scheduled duration of operations/states and transition instants, considering various internal and external factors influencing terminal performance. A states and transitions model is used to derive effective solutions for obtaining states order and states transition time of a bulk terminal, with the objective of minimizing operational costs. Behavior of the terminal is tested with stochastic and deterministic methods.*

Keywords*: operations planning, sea terminal, general systems theory, stochastic modeling*

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 unified and formalized form. The field of traffic science and technology is extremely broad one, encompassing many different disciplines and activities, thus the unification seems impossible without application of general systems theory and methodology. The partial use of system's theories in major part of traffic literature has been only a superficial description without precise formulations derived from concept of general or generalized system. On the other side, classical analytic approach with bounded discipline-oriented researches, use their own theoretical concepts and methodologies.

Radmilović (1989) presents functioning of port facilities with discrete Markov processes and proposes the application of the model with system of differential equations, which describes technological processes of direct and indirect trans-shipment of the cargo. Radić and Bošnjak (1997) give the concept of the generalized traffic model using general system theory methodology, and derive equations from ST-diagram for stationary behavior of the subsystem. Kia et al. (2002) explore port capacity under a new approach by computer simulation. Asperen et al. (2003) propose a possible way of modeling ship arrivals in ports.

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The major objective of port operations planning is to diminish port vacancy, thus minimizing operational costs, while assuring that the service rendered to ships is in line with widely accepted standards.

Even though the wide range of planning problems within the shipping industry received significant attention from researchers so far, as in Cullinane et al. (2009), there are still problems that have to be addressed, i.e. port operations planning under uncertainty. The problem of optimization under uncertainty exists in bulk terminals too, but is of a somewhat different character, see Hess et al. (2007), Hess and Hess (2010). The limited storage capacity and facility output necessitate planning of terminal operations to prevent storage overflow and unoccupied terminal capacities.

This paper focuses on terminal behavior understanding and addresses the question whether terminal operations show deterministic or stochastic behavior. The major contribution of this work is in determination of the states and transitions model (ST model) for bulk terminal behavior observation which is based on comparison of deterministic states and transitions (DST method) and stochastic states and transitions (SST method). Worksheets of bulk terminal of Bakar port in two years period (2013-2014) are analyzed. Contribution is in conclusions on which method better fits real example. Finally, practical extensions are outlined.

2. GENERAL SYSTEMS THEORY APPLIED TO THE PORT

2.1 Fundamental traits

Highest-level generalization is axiomatic, mathematical theory of traffic system. On that level, fundamental traits and relations must be derived from a concise formal definition of traffic system. Collection of concepts and definitions for fundamental traits of system are given in Klir (1972). The general systems theory is applied in the state system analysis, forecasting and planning development of dynamic systems, in selection of optimal or at least satisfying managing actions and decisions. 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 time varying port system operation.

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). Definition 4 and definition 5 of a traffic system (Radić and Bošnjak, 1997) are as follows:

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 set (*B*, *C*), where: $B = \{b_1, b_2, \ldots, b_r\}$ is the set of all permanent behaviors of elements of the universe of discourse and $C = \{c_{ij} \mid c_{ij} = A_i \cap A_j ; i \neq j\}$ is the set of couplings between the set of input quantities A_i and the set of output quantities A_j.

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* such that if $(s_i, s_j) \in R$ then $P(s_j \mid s_i)$ is conditional probability of transition from state s_i to state s_j.

A minimal definition of system would have to be one of the basic definitions.

2.2 The universe of discourse and couplings of the port system

According to the Definition 4, set of all the elements and their links in the system "serving ship at quay" is shown by the UC-structure (Fig. 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 organization 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 invoice.

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 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 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,

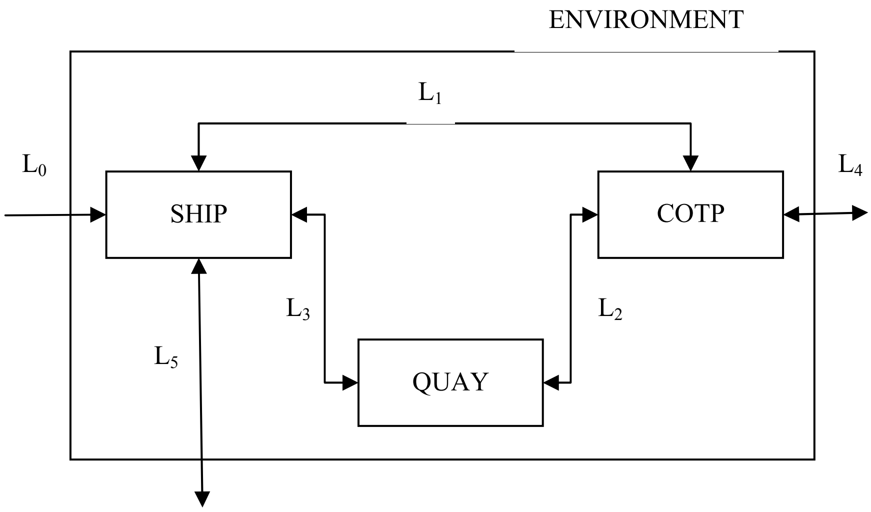


Figure 1. UC-structure of the system serving ship at quay

- 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.

2.3 The states and transitions between states of the port system

The set of states and transitions between these states (Definition 5) for the system "serving ship at quay" is presented by the ST-structure (Fig. 2 and Fig. 3).

3. THE MODEL

The objective of the paper is to identify the particular state in which the bulk terminal will be in a given moment in the future, starting from assumption that in the beginning it was in idle state and that states' switching occurred with designated transition probabilities. The main goal is to answer the question whether the observed bulk terminal behaves as a deterministic system, i.e. according to the logical terminal's operation flow, or as a stochastic system, meaning that the influences causing state transition disorder are not negligible.

Two approaches in quantifying the state transitions are examined. The first consists of setting up a system of differential equations for terminal operations with assumption that the terminal has discrete states expressed with probabilities. The second approach, by defining the bulk terminal operations as Markov processes and setting up matrix of transition probabilities, yield state probabilities and lead quickly to acceptable solution of ST model that is essential for any practical application, Hess and Hess (2010).

The states of the ST model of terminal operations are:

- S_1 – idle state (no operations on the terminal except data processing, i.e. collection and analysis of weather reports, cargo/ships related information)
- S_2 – preparatory state (operations carried on the terminal just before ship arrival, i.e. preparation of facility/cargo/longshoremen for cargo operations)
- S_3 – transshipment state (cargo loading and/or discharging; from economical perspective the most desirable state of the terminal)
- S_4 – closing state (operations immediately after finish of ship loading/discharging, i.e. paper-work, ship departure operation)
- S_5 – repair and maintenance state (regular maintenance of equipment, repair in case of machinery breakdown).

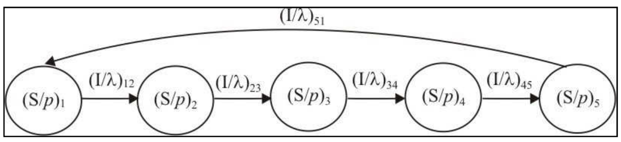


Figure 2. ST-structure of deterministic terminal behavior

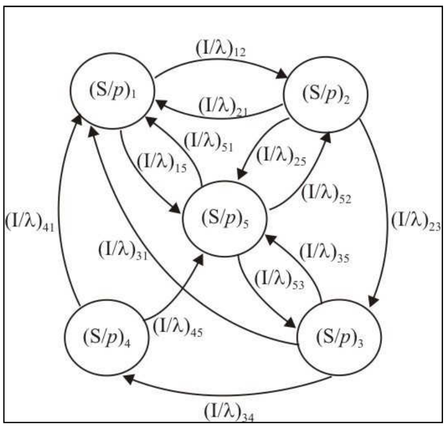
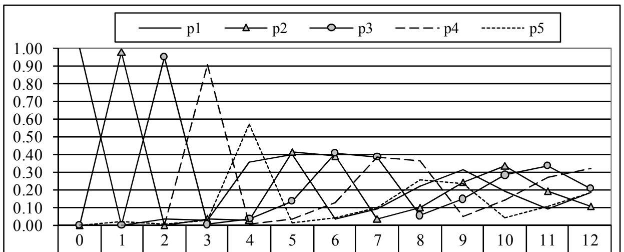


Figure 3. ST-structure of stochastic terminal behavior

A terminal has deterministic behavior if order of states and their durations are exactly known in advance, Hess et al. (2008). In DST method the set of states and transitions between these states for a bulk terminal is formed around ST-structure shown in Fig. 2. A terminal has stochastic behavior if order of states and transitions doesn't follow logical workflow due to various internal and external unforeseen influences on regular operations. For research of such a system the SST method will be developed. In this case the ST-structure may be defined from Fig 3.

Data that were derived from a terminal work were used to assemble a problem of stochastic terminal operations. To define terminal's various operations for SST method, worksheets of bulk terminal of Bakar port in one year period (2013) have been analyzed. Those operations include transportation of bulk cargo from/to terminal, loading/discharging cargo to/from ships, inspection of ship and cargo, distribution of cargo to shore stock, maintenance and repair of facility equipment, and customs procedures. The data on frequency of machinery failure, bad weather and strike caused stoppages of operations, and congestions on the terminal were also taken into consideration. These data served as a basis for population of stochastic matrix of transition probabilities for bulk terminal behavior.

The solution was obtained with computer-assisted evaluation program WinQSB. WinQSB has an integrated Markov modeling and simulation tool, based on discrete space, continuous-time Markov model. After data entry in the transition table, defined number of periods (n=1,..., 12 steps) and initial state vector of the terminal at time t=0, $P_0 = [1,0,0,0,0]$, probabilities of the five terminal states are obtained and presented in Fig. 4. Starting from idle state, simulation shows in which state the terminal will appear most probably after each transition (step). Probability of the most notable state decreases with number of simulation steps and the terminal approaches steady state probabilities.



	0	1	2	3	4	5	6	7	8	9	10	11	12
p1	1.00	0.00	0.03	0.03	0.36	0.40	0.03	0.09	0.22	0.32	0.19	0.10	0.18
p2	0.00	0.98	0.00	0.03	0.03	0.42	0.39	0.04	0.10	0.25	0.34	0.19	0.11
p3	0.00	0.00	0.95	0.00	0.04	0.14	0.41	0.39	0.05	0.15	0.28	0.34	0.21
p4	0.00	0.00	0.00	0.91	0.00	0.04	0.13	0.39	0.37	0.05	0.14	0.27	0.32
p5	0.00	0.02	0.01	0.03	0.57	0.01	0.04	0.10	0.26	0.24	0.05	0.10	0.18

Figure 4. Probability distribution for terminal states for 12 steps

After obtaining state probabilities for 12 steps in SST method and deducing the state probabilities in DST method follows comparison of results with real-world operations flow for year 2014 and selection of best-fit method for further short term planning. For example, duration of state S_1 depends on actual time of ships' arrival and departure time of previous ship, while duration of state S_3 is influenced with size of ships and quantity of cargo manipulated. Consequently, duration of each state is determined with real situation in terminal operations.

The order of state transitions on weekly basis were evaluated and the final results showed that data obtained by SST method matched the practice in 34 cases (weeks), by DST method in 11 cases and in 7 cases the state transitions followed some other order. It was concluded that the observed terminal had stochastic behavior in 65% cases during 2014.

Comparison of the DST solution to the corresponding SST solution indicates that the later one better emulates the logic of bulk terminal operations flow. Therefore, if the port management, in existing situation and without overtaking specific measures for improvement of operational effectiveness, follows the SST method in terminal operations short term planning, the plan is expected to be more feasible. However, bearing in mind that the SST terminal operations draw longer working procedures and therefore time lost on overcoming effects of unforeseen events and consume more resources, to perform even better the management should strive to adhere to the plan based on DST method.

3. CONCLUSION

In this paper basics of the general systems theory are presented. This theory is applied for the system states analysis, forecasting and planning the development of the dynamic systems, then 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 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 method, presented here, may be used for short term tactical decision making by identifying the particular state in which the terminal will be in a given instant. One of the major shortcomings of the SST compared to DST terminal operations is represented by time lost and consumption of more resources on overcoming effects of unforeseen events, resulting in operational costs inefficiency. The ST model presented can serve as theoretical base for modeling technological operations of other port terminals or traffic systems.

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