AN INTEGRATED RESOURCE-BASED APPROACH TO PORT AND TERMINAL SIMULATION MODELING

Constantin Semyonov[(a)]

[(a)]Department of Organization of Transportations, Baltic Fishing Fleet State Academy, Kaliningrad, Russia

[(a)]mail3cms@yandex.ru

ABSTRACT
The accuracy of simulation model significantly increases when not only the processes, but also the factors that have on them great influence are taken into account. Many of them is considered as resources necessary for the functioning of the particular process and characterized by power, balance and deficit. Resources are an integral part of most practically useful simulation models, where they largely determine the course of the different processes. This paper describes an integrated method of accounting, analysis and distribution of resources among the active terminal processes implemented in a specialized simulation software BaltInLog PortInvest developed by the author. Resource model presented in the paper may contribute in efficiency and accuracy of terminals and ports simulation as it is based on reduction of the uncertainty of the processes, taking into account the actual conditions of their occurrence. These conditions are largely determined by the resources of the terminal.

Keywords: port and terminal simulation, resources, resource management, simulation software.

1. INTRODUCTION

Simulation is one of the most useful tools in port management which, if implemented properly, can result in significant economic benefits (Law and Kelton 2000). But the development of efficient and accurate simulation model of port or terminal is not an easy task. As each model reflects real activity the latter should be thoroughly studied and decomposed into basic processes such as cargo handling, stowage, warehousing etc.

To take into account all distinctive features of these processes and to get total control over program code the author developed a specialised software in Visual Studio environment using C++ language. Usage of general-purpose software such as ARENA, AnyLogic and others (a good brief review is presented by Park, N.K., Dragović, B., Zrnić, N., Moon, D. S. H. (2012)) is also a good practice as they have sufficient functionality for most basic port models.

The software should simulate port processes in close interrelation with factors which determine their commencement, existence and termination. Some of them are referred to as resources, whose role in simulation models was discussed in several papers. Legato and Trunfio (2007) presented a theoretical framework for holistic simulation model where resources are objects with several states. They also introduced resource managers necessary for complex system model. A similar entity (resource allocation module) is described in another papers (Rizzoli, Gambardella, Zaffalon, and Mastrolilli 1999; Gambardella, Rizzoli, and Zaffalon 1998). Arango, Cortés, Muñuzuri and Onieva (2011), Cortés et al. (2007) described a real port model with several types of resources allocated upon ship's arrival and during cargo handling operations. Authors of another paper (Legato and Mazza, 2001) focused on particular types of resources such as cranes and berth length. Agerchou et al. (2004) provided some general recommendations on resource management.

When resources are insufficient the process is suspended or its productivity decreases. In real systems, such as ports, the purpose of resource management is to distribute the resources in a way that maximizes the entire system efficiency. To achieve this it's necessary to define the key performance indicators (or a single indicator) and estimate them for apparently effective distribution methods and policies.

If the evaluation of these methods is effected by simulation the indicators are estimated according to results of statistical processing of the model outputs. This is a common approach and it is also used in our software.

As most ports are commercial enterprises the efficiency evaluation is based on costs and income. Zaffalon, Rizzoli, Gambardella, and Mastrolini (1998) recommended the same approach. BaltInLog PortInvest also calculates net present value (NPV) which is useful when implementation of resource management system requires significant investments, for example, in case of sophisticated ERP system installation.

There is often a direct connection between resource allocation and port costs. Expenses are often proportional to the quantity of resources used (this is an acceptable assumption for basic models), but in some cases the actual dependence may be far from linear. Moreover, usage of some resources (for example, length of railway segment for cargo handling operations) don't cause any expenses. Nevertheless the connection persists as insufficiency of railway length will prevent cargo handling and result in downtime and, eventually, in economic penalties. To assess this losses we primarily estimate cost of delays per hour and input it to our program.

The revenues depend on the flows of different cargoes going through the port but they are mainly subject to external factors such as port location towards transport routes. But to obtain these revenues port should be able to handle all this cargo. The resource distribution and management system, in its turn, should ensure smooth and efficient running of all handling processes to prevent the loss of revenue. Our model is not intended for estimation of all consequences of inefficient and slow cargo handling as some of them may result in after-effects which can be hardly described by means of simulation. For instance, port congestion prevent some clients from sending cargoes to it that results in overall decrease of cargo flow. Instead the costs of delays in our simulation model is slightly higher than ones stipulated in the agreements.

Thus the resources and resource management are paramount factors of port cost-effectiveness and determinants of its competitiveness.

2. A CLASSIFICATION OF PORT RESOURCES AND THEIR VIRTUAL REPRESENTATION

Researchers consider resource allocation one of the major problems of container terminal (Zaffalon et al. 1998). However this applies also to other types of terminals. Besides, optimising resource management policy on the whole is a much more challenging task.

In such a case simulation is a suitable and effective tool but to apply it we should define what resources should be included in model considering its accuracy and complexity.

Currently our software allows to simulate the following resources:

1. storage capacity;
2. cargo handling equipment;
3. port workers;
4. length of railway segments intended for cargo handling operations;
5. length of berth;
6. maximum number of truck simultaneously loaded and unloaded at terminal.

To deal with more complex tasks the program should contain algorithms for the simulation of additional resources such as:

- finance;
- quay capacity;
- cargo handling equipment service life;
- information used in decision-making etc.

But the way how the model receives and processes resource data is more important. Despite the complexity of modern simulation models the interaction between virtual processes and resources is not the same as between real ones. To reduce the difference with moderate burden on CPU the models should contain and compute convenient data structures that also determined by the nature of processes of port or terminal.

When cargo handling operation is to commence terminal provides a set of equipment and labour determined by modes of transport, type of cargo and other factors. Each set has its own productivity and includes particular quantity of each resource. In fact, this set is an essential element of cargo handling technology. Simulation environment operating with resource sets instead of separate resources would have better performance, but the labour and machinery management policy reduces to choice of the best resource set.

The implementation of labour and equipment sets allows to significantly simplify the problem of optimising management of this kind of resources. We can surely get only a few effective combinations of labour and equipment for each handling process, and the program will be selecting the most suitable set dynamically during runtime.

To guide the program a priority of each set can be specified. Each time it select the set with the highest priority provided all its resources are available. Besides, each set has a rate of cargo handling. But in real conditions the speed of handling is not constant. Many circumstances may affect it. Namely, breach of equipment, rain, wind, defects of cargo etc. To take that into account the rate is multiplied by a random value whose mean is near 1. To find the optimal set the model should be run several times when one of the suitable sets has the highest priority. Then output data on costs and income should be analysed.

Obviously, each set for particular cargo handling process should contain similar types of resources. But to maintain high handling rate, the ratio between quantities of resource types in each set should be approximately equal. This condition limits the quantity of resource sets for each process which differ only in overall amount of resources and, therefore, in cargo handling rate. But the latter is not proportional to the former as high concentration of equipment and workers may create congestions which slow down the speed of loading and discharging. Small equipment number in set don't seem to be reasonable too as it increases the total duration of transport stay in port. Unfortunately, the optimal set cannot be found by direct algebraic solution as it depends on many factors, but simulation is very helpful in this case.

3. SETTING THE SIMULATION ENVIRONMENT

BaltInLog PortInvest provides a simple interface for adjusting sets of labour and equipment for each type of cargo handling operation (fig. 1).

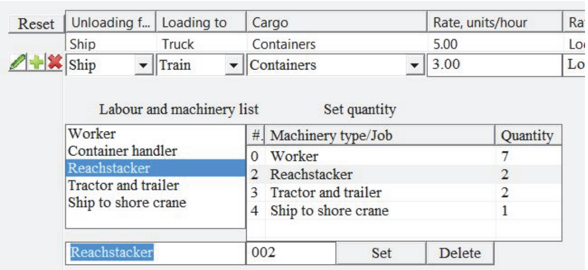


Figure 1: Labour and equipment set adjustment

Total quantity, costs and other parameters of equipment and workers is input through another part of program interface (fig. 2). The costs allow to evaluate economic efficiency of resource management policies. "Running cost/hour" is a value added to expenses for each hour when a resource is involved in cargo handling process. "Maintenance cost/month" are added every time even if a resource is idle.

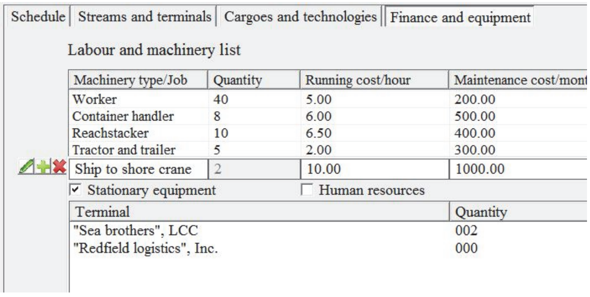


Figure 2: Parameters of workers and equipment

Some resources belong to particular terminal and cannot be used by the others. Namely, length of berth, railways, storage and cargo handling areas capacity which are set as terminal properties (fig. 3). Equipment can be terminal bound as well (for instance, cranes move only within a berth). It is marked by enabling "Stationary equipment" checkbox (fig. 2). The quantity of such equipment is specified for each terminal separately. For workers we should enable "Human resources" checkbox to make the program separate them from equipment in the final report (fig. 4).

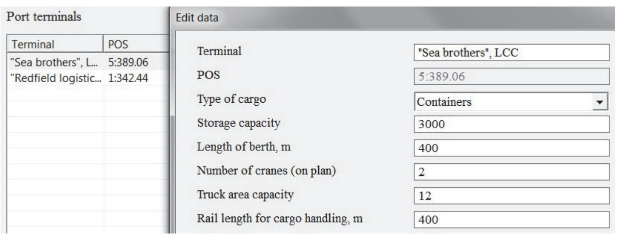
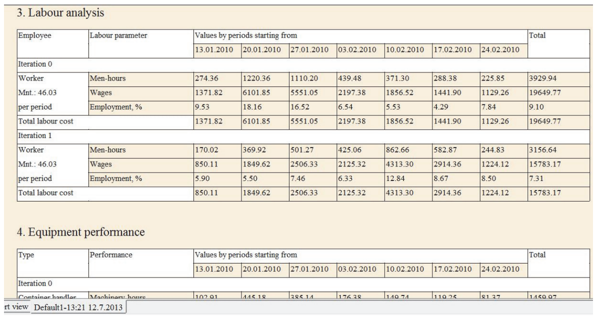


Figure 3: Terminal properties


3. Labour analysis

Employee	Labour parameter	Values by periods starting from							Total
		13.01.2010	20.01.2010	27.01.2010	03.02.2010	10.02.2010	17.02.2010	24.02.2010	
Iteration 0									
Worker	Men-hours	274.36	1220.36	1110.20	439.48	371.30	288.38	225.85	3929.94
Mnt.: 46.03	Wages	1371.82	6101.85	5551.05	2197.38	1856.52	1441.90	1129.26	19649.77
per period	Employment, %	9.53	18.16	16.52	6.54	5.53	4.29	7.84	9.10
Total labour cost		1371.82	6101.85	5551.05	2197.38	1856.52	1441.90	1129.26	19649.77
Iteration 1									
Worker	Men-hours	170.02	369.92	501.27	425.06	862.66	582.87	244.83	3156.64
Mnt.: 46.03	Wages	850.11	1849.62	2506.33	2125.32	4313.30	2914.36	1224.12	15783.17
per period	Employment, %	5.90	5.50	7.46	6.33	12.84	8.67	8.50	7.31
Total labour cost		850.11	1849.62	2506.33	2125.32	4313.30	2914.36	1224.12	15783.17

4. Equipment performance

Type	Performance	Values by periods starting from							Total
		13.01.2010	20.01.2010	27.01.2010	03.02.2010	10.02.2010	17.02.2010	24.02.2010	
Iteration 0									
Container handler	Machinery hours	102.91	445.18	385.14	176.38	149.74	119.25	81.37	1459.97

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Figure 4: Separate report on labour and equipment

Each resource management policy in simulation model must have an algorithm which ensures proper distribution of resources among active processes. If a process lacks resources, it is eventually cancelled, delayed, suspended or slowed down. In the last case, there must be a clear rule for calculating the duration of the slowed process. If the minimum resource set is unavailable cargo handling is suspended. The cancellation of loading and discharging is not typical for ports and terminals as it would break the entire supply chain and result in significant losses for clients.

But insufficiency of other resources prevents cargo handling as well. For instance, while almost all berth is occupied with vessels an incoming ship cannot be loaded of discharged.

To simulate the real circumstances of vessel arrivals BaltInLog PortInvest contains the algorithm:

```
if((vessel length + gaps < free berth length) and
(amount of cargo < free storage space)) then
    check available resource sets
    if(no sets available) then
        add vessel to queue
    else commence cargo handling
else add vessel to queue
```

With minor changes the algorithm is used in similar cases. For truck and train arrivals berth length is replaced with areas for truck loading/discharging and length of railway for cargo handling respectively. If cargo is not unloaded to storage areas (directly to any mode of transport) there is no check for free storage space.

The algorithm places ships in queue, and on release of any resources the checks are made again to find out whether it is possible to commence cargo handling.

The report system of the simulation environment provides all information required for analysis of simulations. This output data also includes indicators of economic feasibility and performance, namely, NPV costs, revenue, berth utilization, labour and equipment employment etc. Testing the resource management policies we don't take into account any investments. Therefore net revenue may be considered as main indicator of policy effectiveness provided the same amount of cargo goes through port in each experiment.

This amount forms cargo stream which must be specified before simulation experiment in respective table (fig. 5). To specify the stream user should input modes of transport, their capacity and its usage (ratio of amount of cargo in each ship/truck/wagon to its capacity). Fields with "f(x)" buttons may be filled with function description, which may include fixed and random numbers, operators and variables (time, length of queue, free storage capacity etc.). The variables provide enhanced control over the model. For instance, season fluctuation may be easily simulated by using time as argument for sine or cosine.

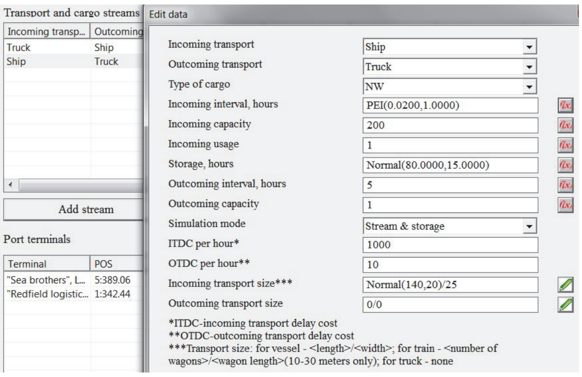

Fig. 5: Transport and cargo streams setting

After setting all necessary properties the user can launch simulation experiment and find out which resource distribution policy is the most effective.

The simulation described below in this paper is effected for a model of typical container terminal, but the method is also suitable for many other types of terminals.

4. TESTING THE RESOURCE MANAGEMENT POLICIES

The resource management policies are tested in a model of container terminal where feeder container ships are discharged. The cargo is transferred to stowage area and stored till the arrival of trucks.

A simple Poisson ship stream is simulated with parameters corresponding to 3 ship calls per day. The average vessel load is 300 containers with deviation of 50.

The labour and equipment sets used in simulation are shown in table 1. There are 3 levels of labour and equipment concentration for each direction, i.e. the amount of resources (proportional to multiplier) with approximately the same ratio between quantity of resource types. Table 2 shows priority of the sets for different resource management policies tested by simulation.

Other resources such as length of berth and railway, storage and truck area capacity are adjusted in a way that they are sufficient during the simulations.

Table 1: Resource sets for different types of cargo handling processes

Process type*	Quantity of resources					Handling speed, containers/ hour
	Worker	Container handler	Reachstacker	Ship-to-shore crane	Tractor and trailer	
S-W x1	9	2	2	1	2	32
S-W x2	18	4	4	2	4	56
S-W x3	27	6	6	3	6	80
W-T x1	2	2	0	0	0	30
W-T x2	4	4	0	0	0	56
W-T x3	6	6	0	0	0	80

*S-W: ship-warehouse; W-T: warehouse-truck; xN - multiplier.

Table 2: Resource set priorities for tested resource management policies

Process type	Resource management policy by labour and equipment concentration		
	High	Medium	Low
S-W x1	1	1	1
S-W x2	2	2	0
S-W x3	3	0	0
W-T x1	1	1	1
W-T x2	2	2	0
W-T x3	3	0	0

This is a simple scenario intended for demonstration but in practice we can use more advanced settings. Two-directional container handling (loading and discharging of the same vessel), non-stationary transport stream with aftereffect and other conditions can be simulated with the same software.

As described above the evaluation of resource management policies is based on output economic data. To get the proper results we should set respective inputs such as average payment for each handled container, cost of resources, penalties for transport downtime and average total fixed expenses of the port.

The results of the simulations are shown in table 3. Economic outputs accounted in custom currency units (1 is approximately equal to one million euro). The experiment lasted 5 months of model time.

Table 3: The results of resource management policies simulation

Indicator		Tested policy		
		High	Medium	Low
Total income		5,95	6,17	5,77
Total expenses		2,21	2,96	2,77
Net revenue		3,74	3,21	3,00
NPV		3,64	3,12	2,92
Average utilisati-on, %	berth	4,70	7,41	11,48
	labour	21,21	19,72	17,50
	equip-ment	21,40	19,64	17,46
	storage	57,71	47,82	44,68

The fists management policy proved to be the most effective. Despite the decrease of cargo handling speed due to overconcentration of labour and equipment the reduction of transport dwell time allowed to cut the costs.

We should also pay attention to the fact that we changed only the priorities of resource sets in the experiment, but it resulted in the significant changes of all parameters in table 3. It demonstrates the sensitivity of a terminal to management decisions related to resource distribution.

5. COCLUSIONS

The result of the above experiment don't lead to any general rule for resource management optimisation. The optimal policy is determined by the properties of port and terminal such as berth length, cost of resources, storage area size etc. If they change need of additional analysis eventually arises.

If the area of port is relatively small high concentration of labour and equipment may result in severe performance losses. In such a case even distribution of resources is recommended. On the other hand, if berth is short individual vessels should be discharged and loaded in short period that makes effective high labour and equipment concentration.

The approach presented in the paper may serve as a basis for further research aimed to solving more complex problems of resource management using advanced simulation models. Thorough analysis of factors that define the optimal resource management policies would lead to development of the practices which may significantly improve port and terminal performance.

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