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SIMULATION METHOD FOR EVALUATION OF LNG RECEIVING TERMINAL CAPACITY

ABSTRACT

Owing to ever increasing share of the natural gas in the world consumption of the power sources, the international maritime traffic with the liquefied gas is recording constant growth with even greater future anticipations. It results in the need for the construction of new LNG receiving terminals. In order to be integrated in those trends and to make provisions for additional quantities of power sources necessary for its future economic development, the Republic of Croatia is making plans for the construction of such a terminal. Successful planning and designing of LNG terminal depends on the application of appropriate methodology for the evaluation of terminal capacity. This paper gives a simulation method for the evaluation of receiving LNG terminal capacity.

KEY WORDS

liquefied natural gas, receiving terminal, evaluation of terminal capacity, model, discrete simulation.

1. INTRODUCTION

A receiving terminal for liquefied natural gas (LNG) is one of the elements in the LNG trade chain between the gas field and the consumer where terminals are most often called by sub-cultural term LNG terminals. Their basic task is accepting, unloading and storing, evaporation and gas distribution into the distribution network.

The ever increasing consumption of natural gas in the world resulted in the increased interest for the construction of new LNG receiving terminals. Today there are 50 LNG receiving terminals in 14 countries, while 10 new ones are in the phase of construction. They are anticipated to be operative in the course of 2-3 years. Furthermore, the construction of some 60 new ones has been announced but it is uncertain whether the location permission for their construction will be obtained because of the increasing public pressure.

Croatia produces about 1.9 billion m^3 of gas every year. In this way the country meets the needs of 60% of total demand while the rest is imported through the pipeline system from the Russian Federation. According to some experts' opinion the needs for natural gas are estimated at 4-5 billion m^3 in 2010, making therefore Croatia more dependent on the imported natural gas [1]. To meet further needs for its economic development, plans have been made for the construction of LNG receiving terminal of maximum capacity of 14 billion m^3 every year, as joint investment between INA & HEP group with their foreign partners.

Successful planning and designing of port terminals, as well as LNG terminals, require appropriate methodology for the evaluation of terminal capacity. For this purpose the most frequently applied one is the *base* and *simulation method*. Since an LNG receiving terminal can be described as an example of discrete, stochastic, dynamic and complex system, the evaluation of its capacity can be explored by the simulation method in order to find its optimum capacity. To make a simulation of LNG terminal it is necessary to set apart its most important features and create a conceptual (structural) model. In the connection with this it is necessary to select targeted annual import and setup of LNG terminal which is supposed to meet the basic tasks of LNG terminal. Then, a computer model should be made in order to simulate the processes at the LNG terminal model. Simulation can be made for the presumed and increased traffic and for the different terminal setups. The obtained results are statistical ones and their analysis makes it possible to select the optimal setup of terminal capacity.

2. TECHNICAL/TECHNOLOGICAL FEATURES OF THE LNG RECEIVING TERMINAL

LNG terminals differ from terminals designed to accept other kinds of cargo regarding safety requirements, reloading facilities, technical/technological reloading procedure, construction of storage space etc. LNG terminals in all the developed countries apply the same or similar safety standards. However, unlike LNG tankers which must respect severe orders of IGC regulations (*Code for the construction and equipment of Ships carrying*), there are no fixed international regulations about design, construction performances and equipment of LNG terminals. Therefore, when making plans and designs for LNG terminals, it is necessary to observe the existing national regulations or use publications, recommendations and experience from different international professional organizations with special analysis of the influence of all the important factors: navigational features of sailing route, properties of anchorage area and approach to the terminal, general and maritime features of LNG tankers, weather conditions, systems for the control of sea navigation, conditions during the stay at the terminal, conditions of unmooring and numerous others [2].

LNG receiving terminals are provided with spare equipment since they are expected to be permanently functional. Exceptionally, they could stop their work because of statutory survey of LNG tanker or necessary maintenance of equipment in the case of problems with condensation of evaporated gas. LNG terminal must be designed in such a way as to meet the following basic functions: discharge and storage, vaporisation, gas delivery into transport system and measurements, control over LNG boiling off and supplying of own utilities. Besides, the terminal is provided with additional equipment and support utilities.

A scheme of an LNG receiving terminal is shown in Figure 1. The conventional berths are being regularly constructed for the purpose of unloading LNG ships because the transhipment operations impose the need for calm, safe, and adaptable berth.

The discharging equipment consists of the unloading arms and a pipeline system running from the former elements to the storage tank (1). Modern LNG terminals are designed to accept LNG-tankers of the capacity from 87,000 m^3 to 145,000 m^3. The discharging facility features sizes compatible to standard discharge rate of 10,000-12,000 m^3/h which provides LNG-tankers capacity of 135,000 m^3 to be discharged within 12-14 hours.

The LNG receiving terminals must have appropriate storage spaces (2) which provide storage of total ship cargo without delay. For storage of natural liquefied gas at atmospheric pressure the following types of tanks are used: single containment (with double wall system), double containment, full containment and membrane tanks [3].

The vaporization facilities heat and vaporize LNG, thus obtaining gas which is delivered into the distribution network. LNG is delivered into the vaporization facility by means of a pressurizing system which consists of low pressure pumps in the storage tank (3), high pressure pumps (9) and the pipeline system. By means of low pressure pumps (3) LNG is taken in from the storage tank and pressurized under the pressure of 10-15 bars to the condenser (8). There it mixes with boil-off vapour from storage tanks and then it is delivered to intake of the high pressure pumps (9) by means of which it is being pressurized to 75-80 bars (which is at the same time the pressure of the distribution pipeline) and then it is delivered to the vaporization facility. These facilities consist of several parallel vaporizers including spare ones. The majority of the receiving terminals in their standard work use vaporizers with seawater (11). Water is delivered to the va-

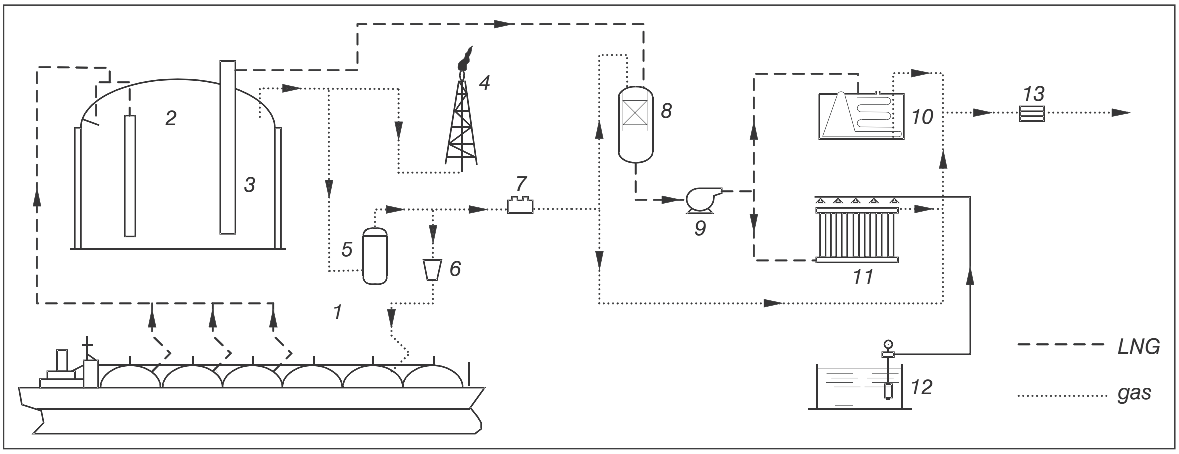

Figure 1 - Scheme of importing LNG – terminal

Source: Bronzan B., LNG Energetika Marketing, Zagreb, 1999, p. 202

porizer by means of a seawater pump (12). In case of problems with the seawater vaporizers (failure or too low temperature of seawater) they use vaporizers with the water heated by the combustion of a part of vapour gas as spare ones (10). The obtained gas is then delivered through a measuring unit (13) into the distribution pipeline.

A part of boil-off vapour from the storage tanks is used during discharging of LNG tankers to regulate pressure in ship tanks so that the gas returns to the ship through compensation vessel (5), blower (6) and feedback line, while the surplus can be pressurised by means of a compressor (7) in the condenser where it becomes liquefied and blends with LNG directed towards the vaporizers. If the remaining part of vapour cannot be absorbed by the repeated action, it will be pressurised directly through the compressor (7) into the distribution pipeline or it can be burned in the torch (4) [4].

The most important features of LNG receiving terminal are the amount of evaporated gas and the size and number of LNG storage tanks.

The amount of evaporated gas depends on the consumers needs and it can vary from the average (nominal) amount, estimated upon annual production of natural gas, to some maximum amount in the case of special consumers needs (industrial facility or electric power plant).

The total capacity of the storage tanks in LNG receiving terminal depends on the capacities of LNG tankers which will deliver LNG to the terminal, the approximate amount of evaporated gas per hour, discharging time and maximum delay time of LNG tankers [4].

3. PLANNED LNG RECEIVING TERMINAL AND ITS MODEL

The following features are assigned for the planned LNG receiving terminal:

- one berth with the possibility of accommodating LNG tankers capacity up to 135,000 m^3,
- annual import of about 7.5 milion^3 LNG (about 4.5 billion m^3 of natural gas),
- discharge capacity of LNG up to 12,000 m^3,
- total capacity of LNG storage tanks of 261,000 m^3,
- facility consisting of 6 evaporators, each having a capacity of 250 m^3 LNG/h (4 with seawater and 2 spare ones with the water heated by combustion of a part of evaporated gas
- nominal capacity of natural gas dispatched towards consumers network of 600,000 m^3/h (1000 m^3 LNG/h) to maximum of 900,000 m^3/h (1500 m^3 LNG/h).

Liquefied natural gas will be delivered by LNG tankers of the capacity of 135,000 m^3, which will arrive to the terminal every six days. The scheduled time the ship spends from the moment of arrival at an outer anchorage to the moment of its departure from the terminal is 24 hours, while the scheduled time for its stay at a berth is 20 hours.

Regarding its behaviour the LNG receiving terminal can be observed as discrete, stochastic and dynamic system, suitable for research by the modelling and simulation method. Among previously described parts of LNG terminal, the model will include only those which are important for the simulation study. In this way the observed terminal elements are anchorage, berthing, discharge capacity, storage tanks capacity and gas dispatch into the distribution network. Each of the elements has certain autonomy, but for the harmonious operation of the terminal as a unit, it is necessary to achieve their synchronization in time and space [5].

3.1 Simulation model of LNG receiving terminal in GPSS

The simulation model of the LNG receiving terminal is realized in the form of a computer program written in the discrete simulation GPSS (*General Purpose Simulation System*) programming language and it is simulated by the GPSS World simulator [6]. GPSS has been selected because in order to present the simulation dynamics it applies the processes interaction method appropriate for this case. In this method the process is the movement of the temporary entity through the system, from the moment of its arrival to the moment of its departure [7]. The basic elements of GPSS are the static and dynamic components. The dynamic components are called *transactions* and they are temporary entities which pass through the simulated system. The static components are represented with blocks which simulate certain activities in the system. In GPSS the program defines blocks of simulated system and their interdependence, thus determining the path along which the transactions will pass through the system. For instance, in the model of LNG receiving terminal, transactions will represent the ships while the series of blocks will represent processes in the system such as berthing, delays or discharging.

Here follows a brief description of the used blocks of GPSS. Block ADVANCE describes the time spending (e. g. berthing or unmooring, discharging), block QUEUE describes queuing, block TRANSFER redirects transaction to some other block, and block TEST redirects transaction with regard to some condition. Seizing of resources (FACILITY) in the system (e. g. berth) is realized through the block SEIZE, and releasing with the block RELEASE. Containers of certain capacity (STORAGE) can be seized by means of the block ENTER and released with the block LEAVE. Transactions are introduced into the model (i. e. generated) by means of block GENERATE and they are removed from the model by means of block TERMINATE. Random variable with a certain distribution can define generation time of new transactions as well as the time spent in the block ADVANCE. Time spent in the queue as well as the number of transactions in it depends on the model dynamics. When simulation is run, the program generates transactions, and after the simulation is finished it plots the statistics about the model operation.

The simulation study of the LNG receiving terminal is subordinated to the requirement that the main results of simulation are dependencies of LNG tanker delays on the following factors:

- annual import of natural gas expressed through distribution of LNG tanker arrivals,
- capacity of storage tanks,
- capacity of gas dispatch into the distribution network.

Delays of LNG tankers can be classified as the delays caused by the influence of wind, berth and storage tanks. Delays produced by wind occur due to the impossibility for arrival and departure from berth at the moment of wind stronger than 61km/h. Delays caused by berth are all those delays which occurred because of the incapability of LNG tankers to obtain free berthing. Delay generated by storage tanks occurs at the moment when the tanker stops discharging of LNG since there is not enough free space in the storage tanks at the terminals. Each delay can be measured according to the place where it has originated but cannot always be measured in regard to the real cause.

The simulation model consists of three interconnected submodels which are called wind model, vessels model and distribution model. Each submodel has its dynamic components, i. e. transactions which never interfere but indirectly act upon each other. Basic time unit is an hour but also intervals of 0.1 hour are used (6 minutes).

In the case of wind model, the transaction is wind which appears as random event in time intervals determined by random variable with exponential distribution. Such winds are supposed to generate 30 times a year and last for 10 ± 4 hours. During such a strong wind, because of safety measures, the operations of mooring and unmooring are not performed, and the ships wait in queue at an outer anchorage or at berth. Vessels receive meteorological reports about possible strong wind and this is represented in the wind model by means of logical switch for the event which occurs in a certain time period (2 hours) in advance, before the wind really starts blowing.

In the vessels model, the transactions are vessels and the static components are anchorage, berth, tugs and storage tanks at the terminal. The vessels model consists of 4 parts which correspond to the vessel arrival at the anchorage, landing to berth, discharge and departure.

In the first part of the vessels model called "*generation of LNG tankers*" vessels are being generated, certain characteristics are assigned to them (the delivered quantity of LNG, discharge capacity, serial number) and finally they approach the anchorage. The time interval among vessels arrivals is 144 hours (6 days) increased by the random delay with triangular distribution, which is selected because the modelled system is in the design phase and the data about ship arrivals are not yet known [7]. For the triangular distribution the intervals of possible delaying have been estimated in the interval from 0 to 24 hours and the most probable time of delay is 4 hours. The distribution of arrival significantly influences the results which will be obtained from the model [8]. Exponential distribution is very often applied in such cases but this would be wrong since here the arrivals are planned.

The second part of the vessels model is called "*arrival of LNG tankers at terminal*". It presents the distance the vessel covers from the outer anchorage to the berth. In that part the vessel arrives at the terminal when it is its turn, that is, after the vessels that had been waiting for a longer period of time, and under the condition that there is no wind, that the weather forecast is favourable, and that the berth is free (which means that there are no other vessels at the berth or in the process of arriving to or departing from the berth). If these three conditions are met, the vessels will be tugged to the terminal; otherwise, the vessel queues at the outer anchorage which is recorded by the program as a delay.

In the third part of the vessels model, called "*discharging of LNG tankers*", the vessels are discharged and storage tanks loaded. During discharging it is constantly checked whether there is enough room in the tank. The condition is checked by comparing free space in the storage tank with the discharge capacity during a period of 0.1 hour. If there is not enough room in the storage tank, the discharging will be stopped for a certain time (1 hour) which the program records as a delay.

In the fourth part of the vessels model, called "*departure from the terminal*", LNG tanker leaves the terminal by means of tugs and under the condition that the wind is not strong. Until this condition is met, the vessel waits at berth and the program records it as a delay.

In the distribution model there is one transaction which controls the distribution (with the duration of 0.1 hour) and the static element is the storage tank.

The necessary condition for the gas distribution is that the amount of gas in the storage tank is equal or higher than the distribution capacity. If this condition is not met, the distribution will be stopped, and it is recorded as a delay.

The simulation experiment is designed to check the influence of different factor levels (input) on the model behaviour and its response. The model of LNG receiving terminal contains random variables and their outputs are random values. Therefore, the treatments (i. e. experiments for each combination of factors) must be performed several times and with different series of random numbers. In this way for each treatment obtained from the experiments repeated *n* times, we obtain *n* independent random output values from which it is possible to calculate the mean values and variances of the results by applying standard statistical methods. The simulation experiment in GPSS is controlled by instructions RESET, CLEAR and START and the combination thereof makes it possible to repeat the desired experiment but with the new series of pseudorandom numbers.

The following is a partly simplified and shortened listing of the developed model in GPSS:

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**********************************************************************************************
*  MODEL  OF  LNG  RECEIVING TERMINAL
**********************************************************************************************
* Definition of storages and variables
BAY              STORAGE 1        ;gulf capacity: 1 ship
TUG              STORAGE 4        ;tugs: 4 tugs
OUT_ANCH         STORAGE 2        ;capacity of outer anchorage: 2 vessels
TANKS            STORAGE 261000   ;capacity of tank in m3

INITIAL X$DELIVERED,0      ;counter of delivered LNG (from tanker to storage tanks)
INITIAL X$DISTRIBUTED,0      ;counter of distributed gas (from storage tanks into pipeline)
INITIAL X$DELAY_DISTR,0      ;meter of total time delay in gas distribution

*Definition of tables for data collection
TOT_TM_VE  TABLE M1,0,1,7              ;time vessel spends from arrival to departure
DELAY_WD   TABLE P$DELAY_WIND,0,1,60   ;time of delay because of wind
DELAY_BT   TABLE P$DELAY_BERTH,0,1,60  ;time of delay because of berthing
DELAY_TN   TABLE P$DELAY_TANK,0,1,60   ;time of delay due to storage tank
DELAY_TOT  TABLE P$DELAY,0,1,60        ;total time of delay

********************************************************************************************
* 1.WIND MODEL
*********************************************************************************************
           GENERATE ,,24,1                ;wind is generated not before 1 day
NEXT       ADVANCE (EXPONENTIAL(5,0,292)) ;period between two winds
           LOGIC S   POSSIBLE_WIND        ;wind has not yet begun but is expected
           ADVANCE   2                    ;known 2 hours in advance
           LOGIC R   POSSIBLE_WIND

           LOGIC S   WIND                 ;windy weather
           ADVANCE   10,4                 ;duration of windy weather
           LOGIC R   WIND                 ;wind stopped
           TRANSFER ,NEXT                 ;next windy day

**********************************************************************************************
* 2.VESSELS MODEL
**********************************************************************************************
*******  2.1. Generation of LNG-tankers  ****************************************************
         GENERATE 144,,0                      ;first vessel is arriving immediately
         ADVANCE (TRIANGULAR(2,0,24,4))       ;possible delay of 0 - 24 hours
         MARK
         SAVEVALUE ORD_NUMB,(X$ORD_NUMB+1)    ;ordinal number of vessel
         ASSIGN CAPACITY,(135000)             ;vessel capacity
         ASSIGN QUANTITY,(P$CAPACITY#0.95)    ;discharge quantity is less for 5%
         ASSIGN TRANSFER_NUM(P$QUANTITY/120)  ;vessel discharging capacity at 0.1 hour

         ASSIGN DELAY_WIND,0                  ;initial delay of vessel due to wind
         ASSIGN DELAY_BERTH,0                 ;initial delay of ship due to berth
         ASSIGN DELAY_TANK,0                  ;initial delay of ship due to storage tank
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*******  2.2 ARRIVAL of LNG-tanker to terminal  ********************************************
         QUEUE OUT_ANCH                      ;queue at anchor
         ENTER OUT_ANCH                      ;vessel arrival at outer anchorage
         DEPART OUT_ANCH                     ;leaving queue

* Checking three conditions of arrival: favourable weather forecast, no wind, empty gulf

OUTER_ANCH  TEST E LS$POSSIBLE_WIND,1,CHCK_WIND  ;forecast checking
            ADVANCE 1                            ;delay arrival for 1 hour
            ASSIGN DELAY_WIND+,1                 ;adding delay due to wind
            TRANSFER ,OUTER_ANCH                 ;remain at OUTER_ANCH and queue

CHCK_WIND   TEST E LS$WIND,1,CHCK_BAY            ;wind checking
            ADVANCE 1                            ;waiting 1 hour due to wind
            ASSIGN DELAY_WIND+,1                 ;adding delay due to wind
            TRANSFER ,OUTER_ANCH                 ;remain at OUTER_ANCH and wait

CHCK_BAY    TEST E S$BAY,1,ENTRANCE              ;checking gulf(berth)
            ADVANCE 1                            ;wait 1 hour due to busy gulf
            ASSIGN DELAY_BERTH+,1                ;adding delay due to berth
            TRANSFER ,OUTER_ANCH                 ;remain at OUT_ANCH and wait

ENTRANCE    ENTER BAY                            ;entrance into gulf
            LEAVE OUT_ANCH                       ;departure from outer anchorage
            ENTER TUG,4                          ;demand for  4 tugs
            ADVANCE 2                            ;tugging time 2 h
            SEIZE BERTH                          ;arrival to berth
            LEAVE TUG,4                          ;end of tugging

*******  2.3 Discharging of LNG-tankers  *****************************************************
DISCHARGE   ADVANCE 4                            ;preparation for discharging 4 h

* Checking of discharge conditions: space available in the tank

CH_TANK     TEST L R$TANKS,P$TRANSFER_NUM,PUMP   ;check tank
            ADVANCE 1                            ;if no space, delay discharge for 1 hour
            ASSIGN DELAY_TANK+,1                 ;adding delay due to tank
            TRANSFER ,CH_TANK                    ;remain at CH_TANK and wait

* Discharge into containers a quantity equal to discharge capacity of 0.1 h
PUMP        ADVANCE 0.1                          ;duration of discharge
            ENTER TANKS,P$TRANSFER_NUM           ;increase quantity in container
            ASSIGN QUANTITY-,P$TRANSFER_NUM      ;reduce quantity in tanker
            SAVEVALUE DELIVERED+,P$TRANSFER_NUM  ;increase total quantity of delivered gas
            TEST NE P$QUANTITY,0,PREPARATION     ;if tanker empty, go to depart.preparation
            TEST L P$QUANTITY,P$TRANSFER_NUM,CH_TANK ;if there is more gas in tanker than
*                                                     discharge capacity then continue with
*                                                     discharge (CH_TANK)

;Otherwise there is less gas than it is discharge capacity
REST       ADVANCE 0.1                           ;discharge the rest during 0,1 hour
           ENTER TANKS,P$QUANTITY                ;increase quantity in container
           SAVEVALUE DELIVERED+,P$QUANTITY       ;increase total quantity of delivery gas
           ASSIGN QUANTITY,0                     ;tanker is now empty

******* 2.4 Departure from terminal*********************************************************
PREPARATION  ADVANCE 4                           ;preparation for depart. 4 h

* Checking 2 conditions for leaving gulf: favourable forecast, no wind

C_FORECAST TEST E LS$POSSIBLE_WIND,1,C_WIND2     ;forecast checking
           ADVANCE 1                             ;delay departure for 1  hour
           ASSIGN DELAY_WIND+,1                  ;adding delays due to wind
           TRANSFER, C_FORECAST                  ;remain at C_FORECAST and wait
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C_WIND2    TEST E LS$WIND,1,DEPARTURE           ;wind checking
           ADVANCE 1                            ;waiting 1 hour due to wind
           ASSIGN DELAY_WIND+,1                 ;adding delay due to wind
           TRANSFER, C_FORECAST                 ;remain at C_FORECAST and wait
DEPARTURE  ENTER TUG,3                          ;demand for 3 tugs
           RELEASE BERTH                        ;leaving berth
           ADVANCE 2                            ;tugging time 2 hours
           LEAVE TUG,3                          ;ending of tugging
           LEAVE BAY                            ;departure from bay
* Collecting statistics on delays and time of ship passage
           ASSIGN DELAY (P$DELAY_WIND+P$DELAY_BERTH+P$DELAY_TANK) ;summing up total delays
           TABULATE DELAY_WD                    ;delay time due to wind
           TABULATE DELAY_BT                    ;delay time due to occupancy of berth
           TABULATE DELAY_TN                    ;ship delay time due to occupancy of tank
           TABULATE DELAY_TOT                   ;total delay time for all vessels

           TABULATE TOT_TM_VE                   ;total time of a vessel from arrival to depart
           TERMINATE                            ;vessels abandons model

*********************************************************************************************
*  3.MODEL OF DISTRIBUTION
*********************************************************************************************
           GENERATE ,,24,1           ;after the first day generate one equipment transaction
P_CONT2    TEST L S$TANKS,100,SEND              ;wait if less than 100 m3 in tank
           ADVANCE 0.1                          ;duration of queuing
           SAVEVALUE DELAY_DISTR+,0.1           ;summing up distribution delays
           TRANSFER ,P_CONT2                    ;remain at P_CONT2 and wait
SEND       ADVANCE 0.1                          ;distrib. 100 m3 during 0.1 h
           LEAVE TANKS,100                      ;reduce quantity in tank
           SAVEVALUE DISTRIBUTED+,(100#600#0.98) ;increase total quantity of distributed gas
*                                             reduced for consumption of replinification (2%)
           TRANSFER ,P_CONT2                    ;continuation of distribution
*********************************************************************************************
* Definition of simulation duration and definition of simulation experiment
*********************************************************************************************
           GENERATE 8760                  ;duration of simulation 8760 hours = 1 year
           SAVEVALUE UNDISPATCHED,S$TANKS ;amount of undistributed LNG at the end of year
           TERMINATE 1                    ;termination of simulation after 1 year

           START 1                        ;simulate 1 year - for the first time
           RESET                          ;repeat for the second time
           CLEAR
           START 1
```

3.2 Planning of simulation experiments

In order to check the LNG terminal model behaviour dynamics, it has been planned to perform simulation experiments for treatments with the following values of each factor:

- annual import of 7.5, 9.5, 11.5 and 13.5 million m^3 LNG expressed in the number of arrivals of LNG tankers with capacity of 135,000 m^3; total of 4 levels,
- storage space of 261,000 and 300,000 m^3; total of 2 levels,
- distribution capacity of 1000, 1250 and 1500 m^3 LNG/h; total of 3 levels.

It is evident that 24 different treatments should be simulated. Further on, various statistic indicators will be investigated for each simulation experiment. The most important are the following ones:

- total transition time that the LNG tanker spends from the moment of arrival to the moment of departure,
- delays of LNG tanker due to wind, tanks, berth and total delays,
- maximum number of vessels queuing at the anchorage and utilization of the anchorage,
- number of vessels at the berth, average queuing at the berth and utilization of the berth,
- delays of distribution, delivered and dispatched amount of gas and utilization of the storage tanks.

3.3 Analysis of results obtained from simulation experiments

Due to the large number of treatments and limited space for their presentation, here only the results (*Ta-*

Table 1 - Results of simulation experiments

	Annual import of LNG-a in millions m^3			
	7.5		9.5	
	Distribution capacity 1000 m^3/h			
	Storage tanks capacity in m^3			
	261,000	300,000	261,000	300,000
LNG-TANKERS				
Total number of ships	60	60	74	74
Approximate total transition time of vessel (hours)	24.8	24.8	242.9	216.8
Approximate total vessel delays (hours)	0.38	0.38	189.3	96.4
Approximate delays due to wind (hours)	0.38	0,.8	5.5	5.1
Approximate delays due to container (hours)	0	0	73.4	68.5
Approximate delays due to berth (hours)	0	0	110.4	100.3
Maximum number of vessels queuing at anchorage	1	1	2	2
Utilization of anchorage	0.001	0.001	0.449	0.445
Number of ship arrived to berth	60	60	70	70
Approximate time vessel spends at berth (hours)	20.4	20.4	93.2	88.7
Approximate utilization of berth	0.140	0.140	0.745	0.709
Delivered quantity	60	60	74	74
STORAGE TANKS				
Max. amount LNG in tanks (m^3)	116,500	116,500	261,000	300,000
Remained quantity of LNG in tanks (m^3)	16,200	16,200	260,596	298,980
Approximate utilization of tanks	0.196	0.171	0.872	0.850
GAS DISTRIBUTION				
Delays in distribution (hours)	1057.2	1057.2	110.9	110.9
Distributed amount of natural gas (1000 m^3)	4,515,134	4,515,134	5,071,500	5,071,558

ble 1) for the treatments which comprised the following factor levels are given:

- annual import of 7.5 and 9.5 million m^3 of LNG expressed as 60 and 74 arrivals of LNG tankers every year, respectively,
- storage capacity of 261,000 and 300,000 m^3,
- distribution capacity of 1000m^3 LNG/h.

The results given in *Table 1* show that for annual import of 7.5 million m^3 of LNG, the average distribution capacity of 1000m^3 LNG/h and storage capacities of 261,000 and 300,000m^3, there are minimal delays due to strong wind (only 0.38 hours) and more significant delays in distribution (1057.2 hours). Delays in distribution result from excessive average distribution capacity which, for this level of annual import, should be 880m^3 LNG/h. At this optimal level of distribution capacity, namely, the delays in distribution are the shortest, only 137 hours without parallel delays of storage tanks.

With the increase of annual import to 9.5 million m^3 of LNG, such terminal setup is not satisfactory, which follows from the majority of statistic indicators given in *Table 1*. In this particular case, namely, until the end of the simulation period, out of the number of totally generated 74 LNG tankers, only 70 of them arrived to berth. Two LNG tankers are at the outer anchorage and two more are queuing in front of the anchorage. The approximate time an LNG tanker spends at berth with storage capacity of 261,000m^3 is 93.2 hours and for the storage capacity of 300,000m^3 it is 88.7 hours. *Figure 2* gives the frequency distribution of berth delay durations for 74 generated tankers and for the storage tanks capacity of 261,000m^3. The Figure shows that among 70 LNG tankers which arrived to berth, delay was not recorded for only 24 tankers.

With approximate capacity of the dispatched gas of 1000m^3 LNG/h, the main reason for all delays was inadequate capacity of storage containers at the terminal. In order to avoid delays and raise the annual import to 9.5 million m^3 LNG the average capacity of

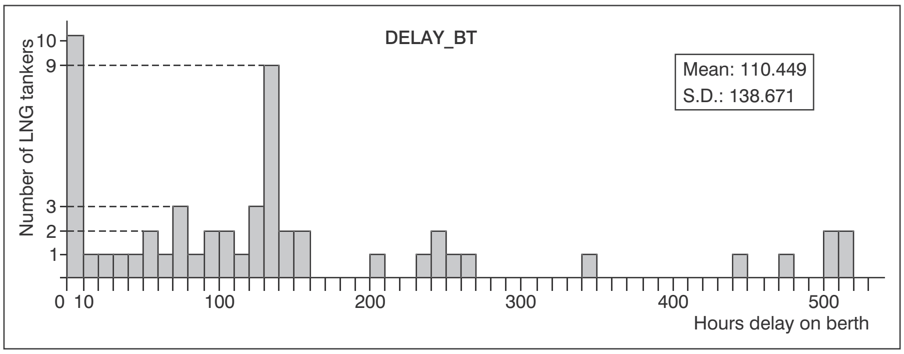

Figure 2 - Distribution of delay frequencies at berth

equipment should be increased as well. The optimum number of arrivals is 68 LNG tankers per year, which is equivalent to annual import of 8.72 million m^3 of LNG.

Analyzing all the conducted simulation experiments it is possible to determine optimal parameters of LNG terminal for different levels of annual LNG import:

- annual import of 13.08 million m^3 of LNG and distribution of 7.63 billion m^3 natural gas per year at maximum dispatching capacity of 1500m^3 LNG/h and at 102 arrivals of LNG tankers with capacity of 135,000m^3 (approximately every 3.5 days),
- annual import of 10.9 million m^3 of LNG and dispatch of 6.34 billion m^3 natural gas per year at dispatching capacity of 1250m^3 LNG/h and at 85 arrivals of LNG tankers with capacity of 135,000m^3 (approximately every 4.5 days),
- annual import of 8.72 million m^3 of LNG and distribution of 5.06 billion m^3 natural gas per year at nominal dispatching capacity of 1000m^3 LNG/h and 68 arrivals of LNG tankers with capacity of 135,000m^3 (approximately every 5.3 days).

Based on the performed simulation of LNG terminal for various configurations and on the analysis of performed simulation experiments, it is possible to make the following conclusions:

- the planned LNG receiving terminal, which was investigated by method of modelling and simulation, completely meets all the requirements of an LNG receiving terminal according to the planned annual import of LNG,
- the characteristics of LNG receiving terminal are determined in such a way that they provide future development of the terminal, since they enable increased amounts of imported LNG.

4. CONCLUSION

Growing demands for LNG worldwide impose the need to developed countries to ensure new additional supply directions, which has resulted in an interest in the construction of new LNG receiving terminals. In order to get integrated into the international LNG trade and provide additional energy power sources for its future economic development, the Republic of Croatia is making plans for the construction of such a terminal. The design of port terminals is a particularly complex and responsible task because it is based on the anticipations which are almost always difficult to estimate. Therefore, it is necessary to apply an appropriate designing method. This paper deals with the application of simulation modelling for evaluation and planning of port terminals capacity. GPSS simulation language proves to be simple and natural for modelling and simulation of an LNG receiving terminal. By using it, we have determined optimal setup of the terminal at different levels of annual import of LNG.

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SAŽETAK

SIMULACIJSKA METODA PROCJENE KAPACITETA PRIHVATNOG LNG-TERMINALA

Zbog sve većeg udjela prirodnog plina u svjetskoj potrošnji energeneta, međunarodni pomorski promet ukapljenim prirodnim plinom bilježi stalan rast s još većim očekivanjem u budućnosti. Posljedica toga je potreba za gradnjom novih prihvatnih LNG-terminala. Kako bi se uključila u ta kretanja i time osigurala dodatne količine energenata za budući gospodarski razvoj, Republika Hrvatska planira gradnju takvog terminal. Za uspješnost planiranja i projektiranja LNG-terminala važna je primjena odgovarajuće metodologije procjene kapaciteta terminala. U ovom radu prikazana je simulacijska metoda procjene kapaciteta prihvatnog LNG- terminala s ciljem pronalaženja njegovog optimalnog kapaciteta.

KLJUČNE RIJEČI

ukapljeni prirodni plin, prihvatni terminal, procjena kapaciteta terminala, model, diskretna simulacija.

LITERATURE

[1] **I. Dekanić**, **S. Kolundžić**, **G. Slipac**: "*Energetska budućnost Hrvatske i opskrba plinom*", Energija, god. 55, br. 4, 2006

[2] **Č. Dundović** : "*Lučki terminali*", Pomorski fakultet u Rijeci, Rijeka 2002

[3] **A. Vaudolon**: "*Liquefied Gases: Marine Transportation and Storage*", Witherby & Co. Ltd., London, 2000

[4] **B. Bronzan**: "*LNG*", Energetika marketing, Zagreb, 1999

[5] **V. Žiljak**: "*Simulacija računalom*", Školska knjiga, Zagreb, 1982

[6] http: //www.minutemansoftware.com/

[7] **V. Čerić**: "*Simulacijsko modeliranje*", Školska knjiga Zagreb, 1993

[8] **E. Van Asperen**, **R. Dekker, R.**, **M. Pollman**, **H. De Swaan Arons**: "*Modelling Ship Arrivals in Ports*", Proceedings of the 2003 Winter Simulation Conference, 2003, pp 1737-1744