A Study of Container Terminal Planning

Nam-Kyu Park
Professor
Tongmyong University
Department of Logistics Management

Branislav Dragović
Associate Professor
University of Montenegro
Maritime Faculty

A container port must be planned to satisfy prompt accommodation of ships with minimum waiting time in port, and with maximum use of berth facilities. Somewhere between these opposing objectives each container port must reach a compromise, the number of berths which will achieve the most economical transfer of cargo between ships and shore. Computational experiments were conducted to evaluate the performance of the developed models using real data collected from the Korean container terminals. The effects of various practical considerations on the performance of the suggested planning process are tested numerically and by using a simulation study.

Keywords: *container terminal, computer simulation, optimization models, combination method.*

1. INTRODUCTION

In the development of container transport, container terminals were concerned to be, for some time, a discontinuity, i.e. a bottleneck, as they were not following the development of shipping. The development of new container ships of large capacities, modern technologies, and the introduction of container port automatic appliances at port terminals through their specialization are considered to be the basic features of modern container transport trends.

The crucial terminal management problem is to optimize the balance between the ship owners who request quick service of their ships and economic use of allocated resources. Since both the container ships and the container port facilities are very expensive, it is desirable to utilize them as intensively as possible. Simulation modeling is better than the analytical one in representing random and complex environment of the container terminal.

Container terminals in Korean Port are trying to expand capacity and increase performance at a maximum of investments. Often, the container terminal operations are changing to meet increased customer demands as well as to adapt to new technologies. The reasons for the decrease of the average cost per ship served with the introduction of new container berth, quay cranes (QCs), container yard area and automated stacking cranes include that waiting time of ships and the average time that ships spend in port decrease with the advanced handling systems improving the operations procedures. The objective of this paper is to develop simulation models to analyze the container terminal performance in Korean ports. This analysis includes the integration of container berth and yard simulation planning within container terminal. Combined planning approaches for different decision levels are expressed in this paper. This model will also investigate the most important elements in a port system including ship berthing/unberthing, QCs per ship, yard trucks allocation to a container and crane allocation in stacking area.

Most papers focus their attention on a container port simulation models which have been used extensively in the planning and analysis of the terminal operating scenario. The investigation and determination of container terminal performance has been treated by many different simulation models. These models are coded in different simulation languages. The different types of simulation languages that have been used include *PORTSIM* (Nevins [1]), *Modsim III* (Gambradella et al. [2,3]), *SIMPLE++* (Yun and Choi [4]), *ARENA* and *SLX* (Tahar and Hussain [5]; Merkuryev et al. [6]; Lee et al., [7]; Park et al. [8-10]; Kozan [11]; Dragović et al. [12]), *Visual SLAM* (Legato and Mazza [13]), *AweSim* (Nam et al. [14]; Ng and Wong [15]), *Witness software* (Shabayek and Yeung [16], Martinez et al. [17]), *Taylor II* (Kia et al. [18]), *Visual BASIC* (Yang et al. [19]), *GPSS/H* (Pachakis and Kiremidjian [20]; Dragović et al. [21-23]), *Extend-version 3.2.2* (Sgouridis et al. [24]) and *Java* (Bielli et al. [25]). In addition, the *discrete-event simulation models* for container terminal operations are considered by Dahal et al. [26], Canonaco et al. [27], Petering and Murty [28], Petering [29] and Petering et al. [30]. Mainly, mentioned papers present the simulation models are used to analyze queuing and bottleneck problems, container handling techniques, yard truck and ship scheduling, equipment and container yard utilization, port throughput and operational efficiency regarding container yard, gate and berth. Computer algorithms are described in most of the papers to give examples how the simulation models are built from a sequence of operational procedures which have been conducted to the determination of the port systems performance in different environment within various points of view and in heterogeneous cases.

The rest of the paper is organized as follows. Section 2 presents a brief description of container terminal modeling procedure. Also, this section constructs the model and introduces it in detail. This is followed by the next Section 3 which gives model validation and simulation results for *Sinsundae Container Terminal* (SCT) and *Jasungdae Container Terminal* (JCT). The optimal cost strategy in a container terminal is studied

Received: October 2009, Accepted: November 2009
Correspondence to: Dr Nam-Kyu Park
Tongmyong University, Dept. of Logistics Management,
535, Yongdang-dong, Nam-gu, Busan, 608-711, S. Korea
E-mail: nkpark@tu.ac.kr

in Section 4. In following subsection we give total cost calculation of optimal terminal throughput with case study of *Sinsundae Container Terminal*. Concluding remarks are presented in Section 5.

2. SIMULATION MODEL

This study includes the integration of container berth and yard simulation planning. We assume the container terminal has berth and container yard (CY). It also includes quay cranes (QCs), yard trucks (YTs) and transfer cranes (TC). The container terminal is represented as a simulation model and a simplified version is shown as an optimization model. We start by performing several simulation runs in order to get average values of the parameters which are then fed into the optimization model. After solving the optimization model, the result is transformed into decision rules that are used in the simulation model.

Most container terminal systems are sufficiently complex to warrant simulation analysis to determine systems performance. The Arena software (Arena 12.0) has been used in this paper [8-10,12,31].

2.1 Berth simulation model

Instead of the existing method for the calculation of berth performance, this study has built a new model for berth performance analysis based on the real data, as illustrated in the Figures 1 and 2. This simulation model can present a more practical way of calculating berth performance, suggesting more diverse evaluation indicators and making it possible to check up the quality aspect of services at the container terminal.

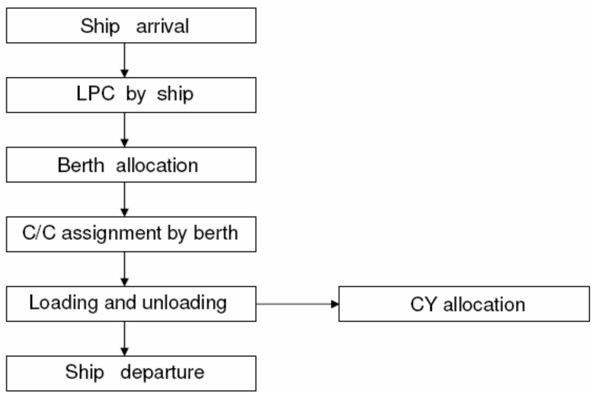

Figure 1. Flow of berth simulation model

2.2 CY simulation model

The capacity of CY is closely related to the size of CY, the mutual relationship among CY cranes, yard truck (YT), external trucks and container turnover. The small size of CY can intensify the traffic congestion, causing reloading, lowering the productivity of CY cranes and eventually delaying the container handling of both external trucks and YT.

2.3 Integration of berth and CY simulation

To develop an integrated simulation model linking berth and CY, the following processes are performed: classification of port type according to the features of each port; select the port type on the initial screen; initial figures can be changed, if necessary; berth simulation performance by port type (initial data production); the throughput derived from berth simulation is linked to the CY simulation; CY simulation is to be performed for one month in order to set up an initial environment; based on the annual distribution of input/output of containers and storage period distribution, both of which are derived from CY simulation, CY occupancy is to be calculated; when the optimal CY occupancy reaches 60 % on the basis of derived CY occupancy, the handling volume is to be calculated; and the sensitivity analysis of major factors is to produce diverse outputs (see Figure 3).

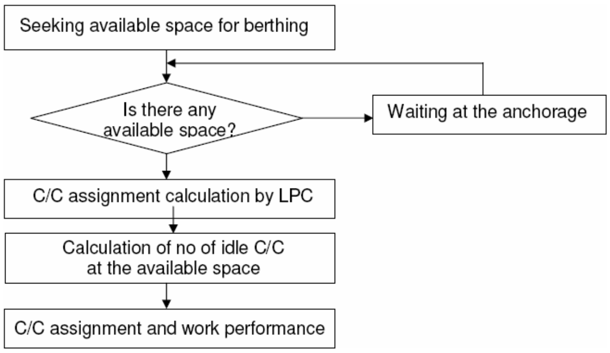

Figure 2. Determination process of berthing location

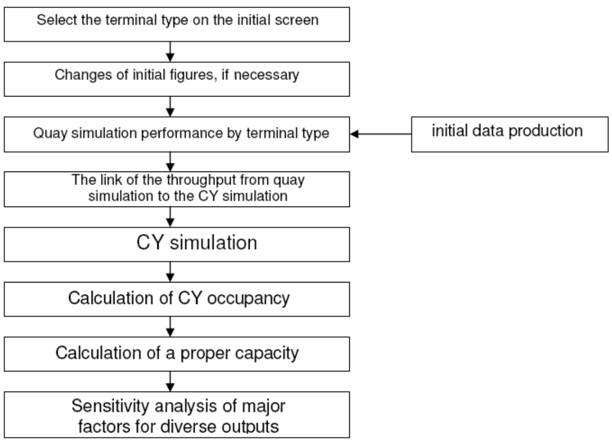

Figure 3. Integration of berth and CY simulation

2.4 Outputs

For purposes of validation of simulation model and verification of simulation computer program, the results of simulation model were compared with the actual measurement. Several statistics were used as a comparison between simulation output and real data: annual throughput of a berth, berth occupancy rate, ship service time and the total time that ship spends in port, handling units per hour per ship, average number of assigned QCs, CY utilization, CY density based on the CY factors, hindrance to stevedoring performance, the number of ship berthing and annual optimal throughput according to the service level.

2.5 Input data analysis for simulation

An important part of the model implementation is the

Table 1. Simulation input values by port type

Type	Ship's arrival time distribution	LPC	No. of container handling	No. of berths	No. of QCs per berth
JCT	-0.001 + 35 * BETA (0.931, 4.75)	• 20 + WEI (797, 1.58)	LOGN (1.07, 0.435) LOGN (0.852, 0.338)	5	3
SCT	-0.001 + 55 * BETA (0.937, 7.67)	• -0.001 + 499 * BETA (2.16, 1.32) • 500 + 498 * BETA (0.991, 1.18) • 1e + 003 + 496 * BETA (0.896, 1.33) • 1.5e + 003 + 1.59e + 003 * BETA (0.946, 2.69)	TRIA (1.8, 2.6, 3.4)	4	3

correct choice of the values of the simulation parameters. The input data for the both simulation models are based on the actual ship arrivals at the *Sinsundae Container Terminal* (SCT) from 28 December 2004 to 31 December 2005 and *Jasungdae Container Terminal* – Hutchison (JCT) from 31 December 2003 to 31 December 2004 [8-10,12].

Furthermore, simulation input values by port type are shown in Table 1.

3. SIMULATION RESULTS

3.1 Berth simulation results

The results obtained using simulation model with corresponding values of real parameters has also been used for validation and verification of container terminal performance calculation by port type. In accordance with it, the correspondence between simulation results and actual data completely shows the validity to the applied simulation model to be used for optimization of processes of servicing ships at *Sinsundae Container Terminal* and *Jasungdae Container Terminal*, respectively, see Tables 2 and 3.

Table 2. Container terminal performance

Type	Current performance		Optimal capacity	
	Average berth occupancy [%]	Throughput per berth (TEU)	Optimal berth occupancy [%]	Optimal throughput (TEU)
JCT	50	430,000	62	530,000
SCT	59	510,000	60	520,000

Table 3. Container terminal performance

Type	Current performance				
	No. of crane per ship	Average service time [hours]	Average time that ship spends in port [hours]	Container handled per hour per ship (TEU)	No. of berthing ship
JCT	3.09	15.1	16.6	84	1,441
SCT	2.94	13.9	15.9	100	1,475

The average berth occupancy of *Sinsundae Container Terminal* closely approximates the proper berth occupancy of 60 % meaning that this container terminal is well in operation. The outputs derived from the simulation models are similar with actual data. On the other hand, the average berth occupancy of *Jasungdae Container Terminal* is 50 %.

3.2 CY simulation results

The existing calculation methods of an optimal throughput of a container terminal have mainly been based on the berth capacity. The high density of CY worsens not only the productivity of a container terminal, but also increases sharply its logistics costs by forcing some cargoes into the ODCY (off dock container yard).

According to the survey based on the opinions of terminal operators, the CY occupancy ratio of 60 % is suitable for smooth workflow of the whole container terminal. Based on this idea, if the logistics volume is generally maintained at the level of CY occupancy of 60 %, then will be reasonable and productive. In addition, Table 4 gives optimal throughput by terminal type.

Table 4. Optimal throughput by terminal type

Type	Berth		CY		N_b	L	TGS
	O	T	O	T			
JCT	57	490,000	60	420,000	4	1,447	10,484
	62	530,000					
	67	580,000					
SCT	55	480,000	70 – 75	450,000 – 550,000	4	1,200	10,950
	60	523,000					
	65	567,000					

Legend: O – occupancy ratio [%]; T – throughput (TEU); N_b – no. of berths; L – length [m]; TGS – total ground slots.

More accurate results will be revealed after CY-related data have been collected and analyzed, but in case of SCT, the annual throughput per berth amounts to about 450,000 – 550,000 TEU, showing its CY occupancy of 70 – 75 %. Reversely, if it tries to maintain its CY occupancy ratio at the level of 60 %, its annual throughput per berth will be estimated to be 400,000 – 450,000 TEU.

4. COST STRATEGY ANALYSIS

An optimal throughput can be calculated by using a queueing theory based on the distribution of interarrival time of ship and the ship service distribution. The decision-making on the service level depends on how to coordinate between improvement of service facilities and ship's waiting costs.

The optimal service level should be considered by the operating costs of port system and ship's waiting costs, see Figure 4. This leads to optimal throughput calculation. Further to optimal throughput calculation, this study has focused on improving the necessity of port development through an economic analysis based on the direct and indirect costs based on ship and cargo waiting.

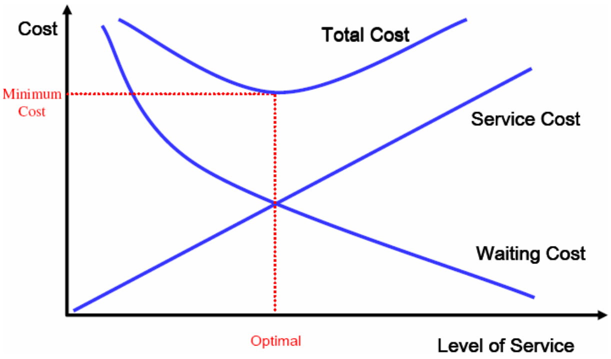

Figure 4. Port queuing system-related costs

Costs of queueing system: In order to apply a queuing theory, we give an approach to minimize the following objective function of operating costs. Hence,

$$Z = C_q + C_w$$

where: Z – total costs (total costs of the system), C_q – service cost and C_w – waiting cost.

Waiting cost: The higher the service level, the less the waiting time and waiting cost, but the waiting costs depend on the interarrival time of ship arrival and ship service time. Consequently, waiting costs include: ship's waiting cost, cargo backlog cost, and hinterland traffic congestion cost. On the other hand, costs at the wharfage are based on: THC (terminal handling charge), container tax, wharfage, Doc-fee, D/O fee, container cleaning fee, tariff, value-added tax, customs clearance charge, carriage, stevedoring fee, forklift fee, ODCY expenses (rehandling fee, shuttling charge). In addition, congestion cost include: charge for cargo handling beyond capacity and cost for extended service hours.

Total system cost (total service cost): Decision-making problem based on a queuing system represents how to balance between the waiting cost and the service level. It can be calculated on the basis of the following formula:

$$\text{Minimize: } TC(S) = I \cdot C_1 + W \cdot C_2$$

where: $TC(S)$ – total system cost based on the service level (S), I – service provider's total hours during a specific period, C_1 – cost per unit hour in the hours, W – total waiting hours during a specific period and C_2 – cost per unit hour in the waiting hours.

4.1 Experimental strategy

If a container terminal exceeds its optimal throughput, ship waiting/backlog-related costs begin to take place. Although the increasing social costs caused by ship waiting and backlogged cargo can be understood by shipping companies, they will bring various kinds of some effects. It causes ship port cost, additional construction of ODCY (off dock container yard), traffic congestion of hinterland roads, increasing contamination, wages increases stemming from additional deployment of workforce, increasing depreciation of various facilities and equipment, and risk handling from overtime or night work.

For this reason, this study has tried to analyze the problems originating from ship's waiting and backlogged cargo by means of a case study of a given container terminal. The object of this case study is *Sinsundae Container Terminal* (SCT) in Busan. In case that there is any difficult item in analyzing this terminal, we have tried to adopt the cases common to many other terminals. The important criteria of this analysis, i.e. the criteria of optimal throughput of a container terminal, are based on the outputs derived from the simulation model developed in the first half of this study.

The fixed costs of SCT for 2005 are composed of labor costs (wages, retirement allowance, and welfare benefits), rental, depreciation, insurance, etc., as shown in Table 5. The variable costs change according to the working volume and working hours. It consists of service charges, energy cost, repairs and maintenance costs, and other expenses as illustrated in Table 6. In, addition, Table 7 shows cost per TEU based on total handling volume (Park et al. [8-10]).

Table 5. Fixed costs

Item	Amount [US$]	Remarks
Labour costs	42,298,000	Wages, retirement allowance, welfare benefits
Wharfage	32,592,000	Charges for the use of facilities and equipment in the CY and quay (including rental)
Depreciation	6,664,000	Related facilities and equipment
Others	2,682,000	Insurance, etc.
Total	84,236,000	

Table 6. Variable costs

Item	Amount [US$]	Remarks
Service charges	6,736,000	
Energy costs	5,802,000	Electric power, fuel oil, etc.
Repair and maintenance costs	3,846,000	Based on the criteria of variable cost
Others	4,622,000	
Total	21,006,000	

Ship and Cargo Waiting Costs: A terminal's annual costs caused by ship's waiting time are calculated and shown in Table I.1 while ship and cargo congestion costs of SCT are represent in Table I.2 (see Appendix I). The capital cost and fuel cost per day are based on the SCT (Park et al. [5,24]).

Table 7. Cost per TEU: Total costs of each item / (4 berths × 500,000 TEU)

Section	Fixed cost [US$]	Variable cost [US$]	Total costs [US$]
Based on total handling volume	84,236,000	21,006,000	105,242,000,000
Cost per TEU	42.118	10.503	52.621

The relationship between turnover and ship waiting/backlog-related costs is illustrated in Figure 5. This figure shows the part of an optimal throughput in detail.

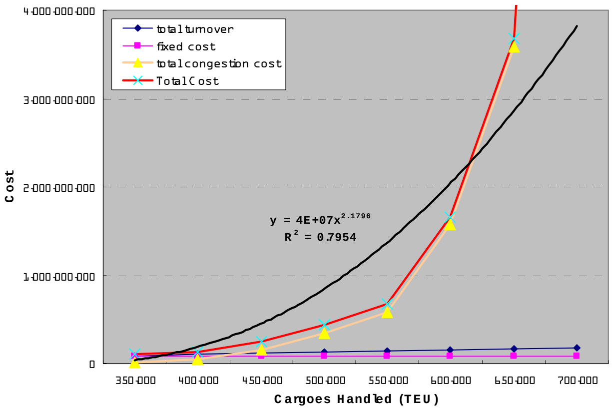

Figure 5. Relationship between turnover and ship waiting/backlog-related costs

Based on the above analysis, we have analyzed the relationship between corporate profit and social costs as shown in Table I.3 (see Appendix I) and Figure 6. When it reaches the optimal throughput of 550,000 TEU, the corporate profit of SCT increases slightly, but the social costs increases sharply to a huge amount.

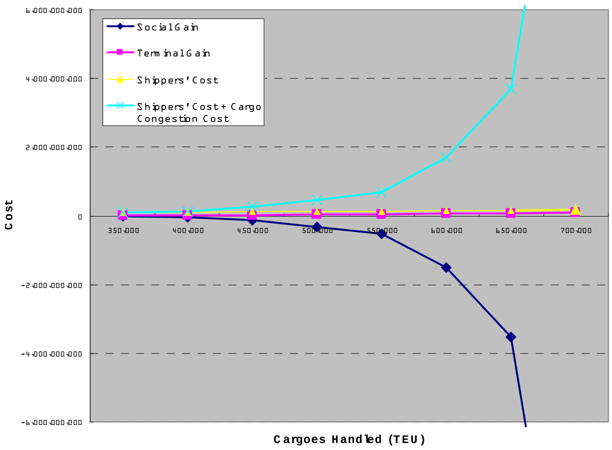

Figure 6. Relationship between corporate profit and social costs of SCT

5. CONCLUSION

A simulation model employing the Arena has been developed for container terminal performance evaluation of Korean container terminals. It is shown to provide good results in predicting the actual terminal operations system of the Korean container port. The attained agreement of the results obtained by using simulation model with real parameters has been also used for validation and verification of applied model. In accordance with that, the correspondence between simulation results and real Korean terminal parameters gives, in full, the validity to the applied simulation model to be used for optimization of processes of servicing ships at existing and new Korean port. Finally, this model also addresses issues such as the performance criteria and the model parameters to propose an operational method that reduces average time that ship spends in port and increases the terminal throughput.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Knowledge and Economy, Republic of Korea, under the ITRC (Information Technology Research Centre) support program supervised by IITA (Institute for Information Technology Advancement) – (IITA-2009-C1090-0901-0004).

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ЈЕДНА СТУДИЈА О ПЛАНИРАЊУ КОНТЕЈНЕРСКИХ ТЕРМИНАЛА

Нам-Кју Парк, Бранислав Драговић

Контејнерске луке морају бити планиране тако да обезбеде опслуживање контејнерских бродова са минималним временом чекања и са максималним нивоом искоришћења веза. У циљу постизања компромиса између ових супротстављених критеријума, потребно је да број везова у луци омогући највећи ниво економичности оперативних процеса на лучкој спони брод – оперативна обала. Реализовани компјутерски експерименти обезбедили су процену перформанси система развијених модела користећи реалне оперативне показатеље са кореанских контејнерских терминала. Утицај различитих практичних разматрања на перформансе моделираног система планирања су тестирани нумерички користећи симулацију.

APPENDIX I

Table I.1. Ship and cargo's waiting cost (a case of 550,000 TEU), (Waiting ratio: 0.35, LPC ratio: 0.165, product cost: US$ 17.81)

TEU	Capital cost + fuel [$]	No of ship per day	Weight	Waiting ratio	Days	No. of containers	Total product cost [$]	Cargo congestion cost [$]	Ship congestion cost [$]
1,000	20,482	4.0	0.13	0.35	365	10,961	195,215	12,968,101	1,360,617
2,700	28,487	4.0	0.23	0.35	365	52,360	932,525	109,599,633	3,348,119
4,024	35,614	4.0	0.21	0.35	365	71,250	1,268,954	136,171,501	3,821,788
5,300	46,851	4.0	0.17	0.35	365	75,968	1,352,987	117,533,962	4,069,944
6,400	55,637	4.0	0.17	0.35	365	91,735	1,633,795	141,927,803	4,833,149
8,400	71,263	4.0	0.08	0.35	365	56,660	1,009,109	41,252,372	2,913,242
9,000	70,856	4.0	0.0029390	0.35	365	2,230	39,720	59,653	106,413
10,000	73,446	4.0	0.0007348	0.35	365	620	11,034	4,143	27,578
Sum						361,782	6,443,339	559,517,168	20,480,849

Table I.2. Ship and cargo congestion costs of SCT

Cargoes handled (TEU)	Turnover per berth	Total turnover	Variable cost	Fixed cost	Ship congestion cost	Cargo congestion cost	Total congestion cost	Total cost
350,000	22,020,250	88,081,000	3,676,050	84,236,000	2,925,836	11,418,718	14,344,553	102,256,603
400,000	25,166,000	100,664,000	4,201,200	84,236,000	5,266,504	36,996,645	42,263,150	130,700,350
450,000	28,311,750	113,247,000	4,726,350	84,236,000	10,533,008	147,986,582	158,519,590	247,481,940
500,000	31,457,500	125,830,000	5,251,500	84,236,000	15,799,512	332,969,809	348,769,321	438,256,821
550,000	34,603,250	138,413,000	5,776,650	84,236,000	20,480,849	559,517,168	579,998,017	670,010,667
600,000	37,749,000	150,996,000	6,301,800	84,236,000	33,939,693	1,536,502,655	1,570,442,349	1,660,980,149
650,000	40,894,750	163,579,000	6,826,950	84,236,000	51,494,707	3,537,061,999	3,588,556,706	3,679,619,656
700,000	44,040,500	176,162,000	7,352,100	84,236,000	105,330,082	14,798,658,156	14,903,988,238	14,995,576,338

Table I.3. Corporate profit and social costs of SCT

TEU	Total turnover	Total congestion cost	Total cost	Social gain	Terminal gain	Shippers' cost	Shippers' cost + cargo congestion cost
350,000	88,081,000	14,344,553	102,256,603	-14,175,603	168,950	88,081,000	99,499,718
400,000	100,664,000	42,263,150	130,700,350	-30,036,350	12,226,800	100,664,000	137,660,645
450,000	113,247,000	158,519,590	247,481,940	-134,234,940	24,284,650	113,247,000	261,233,582
500,000	125,830,000	348,769,321	438,256,821	-312,426,821	36,342,500	125,830,000	458,799,809
550,000	138,413,000	579,998,017	670,010,667	-531,597,667	48,400,350	138,413,000	697,930,168
600,000	150,996,000	1,570,442,349	1,660,980,149	-1,509,984,149	60,458,200	150,996,000	1,687,498,655
650,000	163,579,000	3,588,556,706	3,679,619,656	-3,516,040,656	72,516,050	163,579,000	3,700,640,999
700,000	176,162,000	14,903,988,238	14,995,576,338	-14,819,414,338	84,573,900	176,162,000	14,974,820,156