An Optimization Model for Transport-Storage Logistics

"An Applied Study"

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This study is concerned with improving the integrated logistic problem of transport-storage in economic institutions. It provides general proposals to support designers in constructing models and developing computer software to generate optimal logistic decisions. So, closed queueing network and accompanying algorithms were proposed in modeling such problem and developing the computer software which works to perform algorithms in iterative form. It creates plans and studies the impact of them on system's performance indicators. Thereafter, it gradually optimizes plans in each iteration until reaching the acceptable indicators. Accordingly, Port-Said cargo and container handling company (PSCCHC) was selected as an experimental case where facilities' abilities and working limitations were studied for gaining three benefits (a) achieving fair workload distribution among quay cranes, (b) maximizing the demand time on yard cranes and (c) determining the lowest numbers of tractors that can support the previous goals. Results proved the efficiency of the proposed system.

تناولت الدراسة المشكلة اللوجستية المدمجة لنظم النقل-التخزين و قدمت مقترحات عامة لدعم مصممى النظم في بناء نماذج رياضية و برامج كمبيوتر لتوليد قرارات لوجستية مثلى في المؤسسات الاقتصادية. اقترحت طريقة شبكات الطابور المغلقـــــــة و الخوارزميات المصاحبة لها لنمذجة المشكلة المذكورة و تصميم برامج الكمبيوتر التي تعمل على تنفيذ الخوارزميات في شكل تكراري فيقوم البرنامج بافتراض خطط ثم دراسة تأثيرها على مؤشرات أداء النظام ثم تحسينها تدريجيا حتى تحقيق مؤشرات اداء مقبولة. و من هنا تم اختيار شركة بورسعيد لتداول الحاويات و البضائع كحالة تجريبية لدراسة و اختبار كفاءة النموذج المقترح و تم تصميم برنامج كمبيوتر مناسب للحالة و بناءا عليه تم معاينة و اختبار سرعات الروافــع و الجرارات و قيود العمل للحصول على ثلاثة فوائد: (أ) تحقيق توزيع عادل لعبء العمل بين رافعات الرصيف (ب) تعظيم وقت الطلب على روافع الساحات (ج) تحديد أدنى عدد ممكن من الجرارات يستطيع دعم الأهداف السابقة. و اظهرت تنائج إختبارات الاداء كفاءة النظام المقترح.

Introduction

Recently, logistic concepts have become the basic framework which identifies features of the ideal decisions within economic institutions. Indeed, getting the harmonic performance of equipment's routing, collecting raw materials, delivering finished goods and inventory management are considered the main outcome of ideal decisions. Thus, ideal decision making can lead economic institutions to achieve a distinctive work performance.

Institutions seek for compressing cycle time at any stage in their supply chains using operational planning decisions. Moreover, institutions seek for decreasing their costs and tend to give priority to the logistic decisions related to transportation and storage systems.

Operation research is the science which studies the methods of choosing the ideal decisions, policies or designs. It has presented clear visions to decision- makers about the available ideal alternatives which help in raising flow rates in their supply chains. Accordingly, both logistic decisions and operation research have a strong and integrated relation where logistic decisions are commonly picked from a pool of possible decisions using operation research approaches.

Consequently, the proposed general mathematical formulation has been constructed relying upon the stochastic modeling rules in order to create an integrated optimization problem for the transport-storage system in economic institutions. The proposed general transport-storage system was derived from closed network queueing theory and its accompanying algorithms. The proposed transport-storage system consists of some conceptions and general ideas as well as mathematical formulations that are used to help system designers in building private systems and the related computer software.

Port-Said Cargo and Container Handling Company which is known globally as (PSCCHC) was selected as an empirical case in order to be used for testing the efficiency of the proposed general model.

Problem of the Study

The problem of the study can be summarized in the following question:

What are the ideal numbers of sender facilities, receiver facilities and transportation means that are used in transferring some materials inside economic institutions from their entrance points to their storage locations?

Importance of the Study

Given the mentioned above notions about creating ideal logistic decisions in economic institutions, the importance of the current research can be listed in the following points:

1. **Saving time, protecting production tools, increasing profits and achieving production quality in the mentioned institutions especially the ones related to container handling industry in Egypt such as in (PSCCHC).**
2. **Reducing planning defects which lead to the existence of long queues, unfair workload distribution, idle facilities, traffic congestions, and emergence bottleneck device inside the supply chains of economic institutions.**

Purpose of the Study

This study aims at:

1. **Using the notions of closed queueing network as a base in building a general mathematical model for transport-storage system, throughput bounds algorithm to determine the maximum possible throughput. Asymptotic bounds and mean value analysis algorithm in extracting the performance indicators of a system and recognizing upper and lower performance bounds of it. Discovering bottleneck's location in the system by testing the concerned system using bottleneck analysis algorithm.**
2. **Using the notions and mathematical formulas of general proposed system in building the private models and an appropriate computer software to execute the mentioned above algorithms, according to the concerned institution abilities.**
3. **Dividing the expected operating time to successive periods of time besides divide whole jobs into batches, to avoid differences in operating conditions. Thereafter, assigning the lowest number of transportation means that can achieve the main targets.**
4. **Achieving the fair workload distribution between sender facilities in source side and also storage facilities in storage side. Indeed, this strategy aims at reducing the workload pressure on the single facility and thus reduce queues and the incidence of traffic congestion within the storage side.**
5. **Raising utilization of the storage facilities and using the lowest number of transportation means that do not hinder production wheel in the system.**

Hypothesis of the Study

This study intends to solve an optimization problem with deeply complex interwoven variables. A lot of conflicting goals make the following basic assumptions in (PSCCHC):

1. **Closed network queueing system and its accompanying algorithms have effective abilities in generating optimal transport-storage logistic decisions.**
2. **There are significant differences among the discharging service times of containers according to its storing locations on vessels' boards.**
3. **There are no significant differences among yard cranes' service times according to receiving conditions.**
4. **Quay cranes' movements (ex. up empty, up full, down empty, down full and trolley) have speeds that follow the continuous uniform distribution.**
5. **Unscrewing twist locks of a container and putting them on a tractor consuming some seconds follow the exponential distributions.**
6. **According to quay's crane age, the guideline mathematical model can expect its mean service time as a function in age beside containers' locations on vessels' boards.**
7. **Yard's crane service times have an exponential distribution.**
8. **Yard's crane travel times have a continuous uniform distribution.**
9. **The tractor's speeds have continuous uniform distributions.**
10. **There are no significant differences among tractors' speeds which are measured by seconds per meter.**

Queueing Theory

The main objective of analyzing the queueing systems is to understand the behavior of their underlying processes by predicting queue lengths, waiting time and others. So, queueing system is considered a branch of operation research because the results are often used when making business decisions about the resources needed. Queueing systems are frequently used to analyze the logistic service when intelligent decisions are to be made by managers.

In fact, to characterize a queueing system, the probabilistic properties of both incoming flow of requests and facilities speeds have to be identified. These properties such as arrival rate, service times or service disciplines are considered the basic parameters of the queueing models. Furthermore, additional properties such as capacity of the

system, population size and number of servers can be considered in some special systems. Therefore, the basic parameters of most queueing systems can be listed as follows:

1- Arrival Processes

Actually, if a queueing system is considered, it will be supposed that jobs arrive at a serving station at times $(t1, t2, \ldots, tj)$ where the random variables $\tau_j = t_j - t_{j-1}$ are the inter-arrival times between arrival events. Hence, there are many possible assumptions about the distribution of the (τ_j) where the typical assumptions of the (τ_j) have to reflect the properties of (independent and identically distributed). In general, the inter-arrival time in queueing theory can be abbreviated (M, D or G): M refers to Exponential: Memoryless, D is Deterministic where the times are constant and there is no variance and G is General where distribution is not specified and the results are valid for all distributions Source.

2- Service Rate

Service rate can be defined as the average time required to serve one customer in an economic system. Indeed, service times for a facility, as with arrival process, are usually assumed to have an independent and identical distribution and also are independent of the inter-arrival times of customers. So, the service times can be (M, D or G).

3- Service Discipline

Service discipline is the rule that is used for determining the next customer who will be served within a queueing system. Hence, the common kinds of service discipline can be summarized (FIFO: first come first out, LIFO: last come first out and random service).

4- Population Size

Population size represents the number of individuals in a certain community which are qualified to enter a queueing system. Furthermore, population size can be finite or infinite and is considered an important parameter in queueing analysis.

5- Number of Servicing Stations

The number of service stations in a queueing system refers to the number of servers that are operated in parallel and are ready to serve customers simultaneously. It is important to mention that, in a single channel service station, there is only one path that customers can take through the system.

6- Little's Law

Little's law is considered a famous and very useful law in queueing theory where it says that the average number of customers in a queueing system (N) equals the rate of customers arrival to such system (λ), multiplied by the average sojourn time of a customer (r) within a queueing system.

Queues Performance Metrics

The performance of any system can be defined empirically by estimating the amount of useful work which was done considering to the consumed time and the resources which were used to complete such work. Therefore, the performance metrics of facilities are used to measure performance of queueing systems. On the other hand, queues performance measurements are considered the probabilistic properties of the following random variables,

1- Average Number of Customers in the System

The Average Number of Customers in the System can be defined as the expected number of customers in the queueing system in the steady state. In general, it is evaluated by calculating the difference between the number of arrivals and departures during a period of time $(\boldsymbol{0}, \boldsymbol{t})$. Theoretically, let $\boldsymbol{Q}(\boldsymbol{t})$ be the number of customers in a queueing system at time $(\boldsymbol{t})$ as well $\boldsymbol{A}(\boldsymbol{t})$ and $\boldsymbol{D}(\boldsymbol{t})$ are number of arrivals and departures respectively and simply the average number of customers relationship can be stated as $\boldsymbol{Q}(\boldsymbol{t}) = \boldsymbol{A}(\boldsymbol{t}) - \boldsymbol{D}(\boldsymbol{t})$.

2- Average Number of Waiting Customers

It can be defined as the number of customers waiting for starting their service in lines. It equals the system state minus the number of customers being served.

3- Utilization of the Servers $(\boldsymbol{\rho})$

The utilization of a server is defined as the proportion of time which is consumed during using a server in useful tasks within the observation period. In fact many relations can be used to compute server's utilization such as considering arrival rate $(\boldsymbol{\lambda})$ and service time $(\boldsymbol{S})$ and thus the utilization $(\boldsymbol{\rho})$ can be $\boldsymbol{\rho} = \boldsymbol{\lambda} * \boldsymbol{S}$.

4- Response Time of a Customer

Response time of a customer is the waiting time which must be spend by a customer in the queue waiting for the service plus the time which is consumed in serving itself. Likewise, if there are many servers, in a

network, response time can be defined as the summation of queueing waiting times plus servicing times.

5- Idle Time and Busy Time of a Server

Idle time and busy time of a server are related to each other where idle time plus busy time equals observation period. Actually, the server is classified as an idle server until a service is requested. Thus, the busy time refers to the summation of service times through observation period. The service time means the average of required time to serve one customer. It equals busy time divided by completion number of customers.

Network Queueing System

Queueing network is a system which consists of several service facilities connected by logical or physical links. In this system, customers move from one facility to another where the departure from one queue is often an arrival to another queue. In some cases, customers must choose among alternative paths through the queueing network system. Each path contains only one facility with single queue. Thus, the network queueing system is a collection of $M/M/1$ queueing subsystems. The main types of queueing network can be listed as follow,

1- Open Network Queueing System

Open network queueing system is the system where customers arrive from external resource to take service through several queues of $M/M/1$. Each of these queues is visited by customers one time or re-visited many times and finally customers depart from such system. Furthermore, the customer who has finished its service at any queue, is directed to join another queue in deterministic or probabilistic fashion by a pre-defined probability transition distribution.

2- Closed network queueing system

Closed queueing network is the system which consists of several servers called nodes. Within such queueing system, set of items (N) move to obtain service using its servers. Accordingly, in this structure, the flow of items passes through each node toward the following nodes and thus such model is viewed as a closed network because there are no permissions awarded to any flow for entering or getting out from it.

Generally, each node of the closed queueing network has a single server queue with the service activity processing rate (μ_i). Items are served using a first-come-first-served (FCFS) discipline. They leave server (i) toward server (j) with probability (p_{ij}).

Operational Laws

Operational laws have been described as simple equations derived from direct measurement of the queueing network systems. They are used to describe the average behavior of the facilities in such systems. These laws are very general and don't need any assumptions about the behavior of the parameters which characterize the network queuing systems. These parameters are the probability distributions of either inter-arrival or service times. Exclusively, the following table presents a collection of operational laws relations which will be used later in analyzing the proposed transport-storage system.

Mean value analysis

Mean value analysis is an analytical iteration algorithm which was invented by Reiser and Lavenberg (1980, 1982). It is used to analyze the behavior of closed queuing network systems without using the actual probability of arrival time or processing time distributions. Basically, mean value analysis is based upon the relation between the mean waiting time (response time) and the mean queue size in a closed queueing network system with one customer at least.

The Pseudocode of Mean Value Analysis

For instance, assuming that there are (M) queueing facilities, (i) as the facility number, and (Z) as the delay time in delay centers are considered, the mean value analysis algorithm can be stated as follow,

1. **Step one initialization**
    - Given $S_i = \ service\ time\ \forall\ i = \{1, 2, \dots\}$
    - Given $v_i = visit\ ratio\ \forall\ i = \{1, 2, \dots\}$
2. **Step two mean value analysis algorithm**

For $N = 1$ to M

1. If $N = 1$ then

   $R_i = S_i$, response time with no queues

   Else

   $R_i = S_i\ (1 + Q_{i(N-1)})$, response time with queues

   End if

2. $R(N) = \sum_i^M R_i v_i$, system response time
3. $X(N) = \frac{N}{R(N)+Z}$, system throughput
4. $x_i(N) = X(N)\ v_i$, the facility (i) throughput
5. $Q_i(N) = \ x_i(N) R_i(N)$, queue length in front of facility (i)
6. Exit when stopping criteria is satisfied

Next (N)

Transport-Storage Model in (PSCCHC)

The working cycle of container terminals consists of discharge, transportation and storage operations. It is viewed as a closed network model. Thus, it can be improved using the proposed general transport-storage model. Therefore, the working system of container terminals satisfies the proposed general model's conditions.

1- Stage One, Quay Cranes Deployment Problem

Stage number (1) addresses the events which happen in quay side. The Standard Deviation of workload among quay cranes is minimized to insure equitable workload distribution. This depends upon the expected total serving time for each quay crane through a batch period. The objective function is given in the following form:

2- Stage Two, Yard Cranes Deployment Problem

Stage number (2) addresses the events that happen in the storage side. The demand times on yard cranes are maximized as much as possible to insure the highest possible utilization of each cranes; provided that the demand time on any yard crane does not exceed the demand time on any quay crane to ensure tractors' accumulation at quay site. This prevents forming queues within yards, and raises operations’ speed as much as possible. The objective function is given in the following form:

3- Stage Three, Tractor Numbers Deployment Problem

Stage number (3) addresses the process of determining the minimum tractor numbers which do not compromise the efficiency of operations. This stage manages the issue of creating balance between increasing production wheel speed and preventing queues formation in front of cranes. The objective function is given in the following form:

Conclusions

Based upon the results obtained from performing hypothesis tests and the developed computer software on the selected experimental case, (PSCCHC), conclusions can be listed in the following points:

1. **According to the three experiments which were conducted in (PSCCHC), the working performance rates can be improved by using the proposed system as shown in the following figure,**

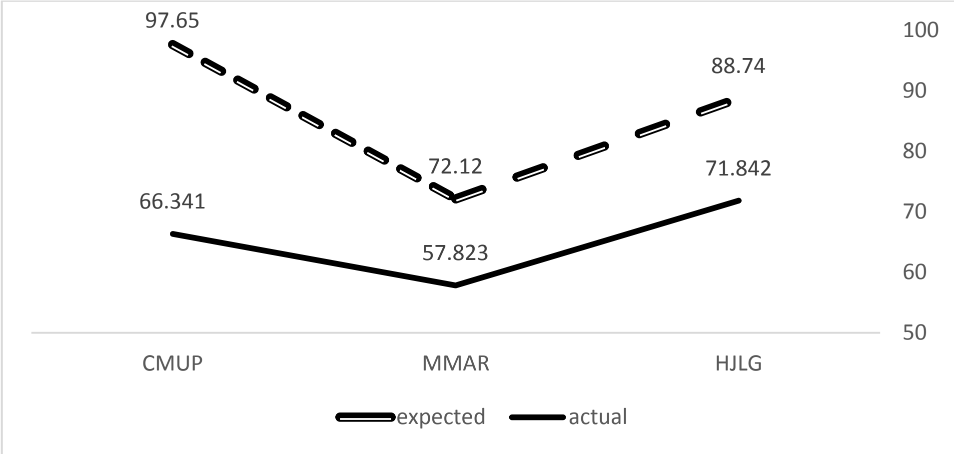

Figure presents a comparison among expected and actual working rates (containers per hour). Accordingly, the improving rates were 23.5%, 24.7% and 47.2% respectively. Thus, it is proved that closed network queueing system and its accompanying algorithms have effective abilities in generating optimal transport-storage logistic decisions in (PSCCHC).

2. After conducting the Chi square test to prove that there are significant differences among the discharging service times of containers due to their locations on vessels' boards, a great value of the computed Chi square was 1204.042. Therefore, the mentioned allegation was confirmed.
3. It was revealed that there were no significant differences among yard cranes' service times according to the receiving conditions.
4. Each of the quay cranes' movements (ex. up empty, up full, down empty, down full and trolley), yard cranes' travel times and tractors' speeds has a continuous uniform distribution. Indeed, the expected values of quay cranes movements decreased according to their ages as seen in table (6-4). (RTGs) and (RSs) travel times and loaded and empty tractors' speed have expected values which are 1.25, 2.43, 0.23 and 0.15 seconds per meter respectively.
5. Yard's cranes service time as well as the Service time of unscrewing twist locks and putting container on tractor have exponential distributions. The expected values of (RSs) and (RTGs) service times and (unscrewing twist locks and putting container) are 73.6655, 86.4905 and 46.93 seconds per container respectively.
6. After conducting the Kolmogorov-Smirnov test, there are no significant differences among tractors' speeds.
7. An additional guideline model was constructed to evaluate the required time of discharging containers as a function of the

assigned crane's age beside containers' locations. Thereafter, this model was tested using the Chi square test. Results supported the mentioned allegation.

8. **It was planned to operate the first case, CMUP, using three batches of containers. Each batch has completed the assigned mission in 45:39, 25:08 and 14:45 minutes respectively.**
9. **The response time of each planned batch was 13:17, 12:16 and 11:28 respectively. In such batches, each tractor moved in the streets of (PSCCHC) about 4:31, 4:40 and 4:37 minutes per tractor respectively. While they stood about 13:37, 12:16 and 11:82 minutes under cranes in waiting and receiving service respectively.**
10. **The mentioned vessel has used (3) quay cranes to be operated. The quay crane number (8) was exited after 70:47 minutes as it completed all the assigned tasks. Thereafter, the vessel continued using (2) cranes only until all containers were discharged.**
11. **The number of yard cranes varied along the sequentially batches where they were 5, 8 and 5 yard cranes respectively.**
12. **In addition, the number of tractors varied according to the batches as they were 20, 21 and 14 tractors respectively.**
13. **The rates of batches were recorded as 90.68, 109.81 and 73.17 containers per hour.**
14. **The number of loads was 67, 43, 18 per each sequentially batch respectively.**
15. **(RTG18) was presented as a bottleneck device in the first case at batch number (2). The utilization of this crane was 80.3%. The mean queue length under it was 3.04 tractors. Its visit ratio was 32.6%. Its demand time was 28 seconds. It completed 14 containers using 1:26 minute per container.**

Recommendations

Based upon the results of the empirical study and observing the working system in (PSCCHC), the following recommendations can be stated:

(PSCCHC) administrator should:

1. **Take a serious direction in replacing old quay cranes with newer ones to improve the quay cranes' mean service times. As known, newer cranes have special abilities (ex. boom length and handling speeds).**
2. **On the other hand, this direction has to be taken into account to meet the expected future needs of new generations of vessels.**

Therefore, this direction may improve the ability of (PSCCHC) in handling a wider and higher Panamax vessel.

3. **Re-pave roads inside the terminal to decrease containers' transferring time, delay times, and to reduce the cost of maintaining tractors.**
4. **Set clear numbers for the storage slots in yards to ensure storage data quality.**
5. **Rapidly improve the current yard maintenance system. This is by customizing a group of workers for daily cleaning and redrawing the storage cells regularly to improve the data quality.**
6. **Assign specific itineraries to tractors and yards crane to avoid traffic accidents and congestion.**
7. **Abandon the current storage policy. This policy addresses storing containers that have the same final destination in the same storage blocks. Actually, this policy is considered the main reason of traffic congestion in yards and accidents. Consequently, adopting this policy decreases both the safety and the operating rates in (PSCCHC).**
8. **Activate and use the proposed system daily to generate the ideal transport-storage logistic decisions.**
9. **Assign a well-trained group of workers to follow up the implementation of yard plans in real working time to adjust storage quality.**
10. **Activate the role of (RDTs) (radio data transmission) as the operations' supervisor in real time instead of being a data entry device. Therefore, a new effective operation system for (RDTs) is required to support the implementation of loading and unloading processes.**
11. **Improve the inland port in the 10th of Ramadan city as it is a part of (PSCCHC). This can be done by constructing a railway to connect this port to the Egyptian railways network. Of course this would activate the handling process in this inland port which means more profits for (PSCCHC).**
12. **Lastly, container handling in Egypt needs huge efforts in researching to improve this industry. This is because it has already contributed strongly in improving the national economy. Actually, the desired productivity of this industry had not been reached till now; especially if compared to that of other neighboring countries which have no distinguished geographical location like that in Egypt.**

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