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Container Yard Capacity Planning: A Causal Approach

Deepankar Sinha

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Container Yard Capacity Planning: A Causal Approach

Deepankar Sinha*

Abstract

In this paper an attempt has been made to develop a system dynamics model that account for flow of containers, their dwell times, type of equipments and constraints that determine the container yard capacity. The structure of the system is captured with the delays in capacity building and resultant impact on container yard capacity, investments and customer satisfaction. The paper identifies two governing loops. These loops explain the dynamics of yard capacity planning and enable identification of policy variables.

The model shows that the policy decisions relate to enhancement of stacking area through right deployment of equipment; and minimization of dwell time through reduction of average stay at yard and faster shifting rate. The paper concludes that the faster rate of clearance can be achieved through right choice of the equipment. The paper focuses on need for timely information flow for proper planning leading to minimization of dwell time.

Key Words: Container, Container Yard, Planning, Capacity, System Dynamics, Governing Loops, Policy Variables, Hard and Soft Ceiling

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* Indian Institute of Foreign Trade, Kolkata Campus, J1/14, EP & GP Block, Sector-V, Salt Lake, Kolkata-700091. Email: dsinha@iift.ac.in Readers should send their comments on this paper directly to the author.

Container Yard Capacity Planning: A Causal Approach

1. Introduction

Capacity for a particular facility in an organization has a long standing impact in its business. Firstly, it involves capital investments that are irreversible and are sunk cost. Secondly, the period of requirement of such facility is critical as high investments for short term may prove unviable. Thirdly, the operating efficiency of the operations is dependent on the capacity of the facilities. Maintenance cost, ease of scheduling and economies of scale are among the factors affected by the capacity of the facilities. Finally, inadequate capacity may lead to customer dissatisfaction (Gaither et al, 2004).

The major objective with regard to capacity building includes maximum utilization of existing capacity, creation of additional facility to meet future requirements and modernization of the existing facility to meet the changes in technology and / or changes in customer requirements (Schroeder, 2004).

The traditional method of strategic capacity planning usually involves the following activities (Gaither et al 2004):

i) Estimating the capacities of the present facility

ii) Forecasting the long range future capacity needs of all products and services

iii) Identifying and analyzing sources of capacity to meet the future requirements

iv) Selecting among the alternative sources of capacity

Capacity is defined as the maximum or the best operating level. The utilization of capacity is defined (Chase et al, 2004) as:

Capacity Utilization = Capacity Used / Best Operating Level

There are, in a typical business, four levels where capacity planning is required (http://www.smthacker.co.uk/capacity_management.htm, 2007):

i) High level business planning e.g. to justify capital expenditure, or produce profit forecasts

ii) Management of the demand and the gross capacity to meet it (Sales and Operations Planning)

iii) Scheduling of individual cells or process areas

iv) Individual process management e.g. speeds / make ready times

There are also 11 separate degrees of sophistication which can be applied to capacity planning, ranging from the crude approximations of input / output control below, to artificial intelligence / heuristics. Generally, more complex the situation, more is the sophistication needed.

There are two types of capacity constraint:

- **Hard ceiling**, where it is extremely difficult to add or remove capacity e.g. expensive plant or equipment working at full capacity, or a scarce skill.
- **Soft ceiling**, where it is relatively easy to flex capacity by overtime, sub contracting, etc.

It is important to distinguish between the two while capacity planning. Hard ceilings need to be included in high level Master Production Scheduling.

Capacity planning can be simplified by creating representative models of the real world using a capacity model based on critical or bottleneck resource availability and by interpreting the demand on that resource alone to determine the overall likely output. This technique is called "**Rough Cut Capacity Planning**" and provides a rough check whether demand and capacity are in balance. This process was originally envisaged to be the role of an individual called a "Master Production Scheduler" ("Manufacturing Planning & Control Systems" by Volman, Berry and Whybark), who would present the output plan to operations for production. This concept was inherently flawed as in this case only that person owned the plan. If this check (which can usually be done on spreadsheets) is in place, a process can then be built around this to involve the stakeholders in a planning process. This technique "Participative Master Production Scheduling" (PMPS) ensures input from the participants of the plan and thereby commitment by those stakeholders to its achievements.

The "Theory of Constraints" penned by Goldratt & Fox in their book "The Goal" argued that the capacity of the supply chain system was governed by the capacity of its weakest link (the bottleneck) and that overproduction in other areas would simply produce unwanted inventory. Therefore high level control needs to be exercised to avoid **local** optimisation.

Whilst often forgotten in the complications of the budgeting process, capacity has to cope with **peak demand,** not average demand, in order to satisfy individual customer needs. The difficulty is how to control an average costing system with peak demand. This often leads to capacity lagging behind demand in an upturn even if the demand is accurately predicted. Conversely even if a downturn in demand is accurately predicted, the backward looking financial control systems do not create cost reduction tension until too late. This is a problem which management accounting has not yet properly addressed, but fortunately most general managers have a weather eye on the order book and sales pipeline to try to keep costs and income in line.

When capacity is approached by the demand, lead-times start to increase disproportionately.

Stacking area or the container yard which is a subsystem within the port container terminal system, represents one of essential elements affecting the terminal operation efficiency. This is the significance of determining the stacking area capacity and the need for consideration of basic features and technological processes going on between the stacking area and the other terminal elements. In determining the port container terminal stacking area optimum capacity, the stacking area efficiency and its static and dynamic capacities represent the basic prerequisite (Dundović & Hess, 2005).

2. Container Yard Capacity Assessment

As a rule of thumb the area required for a container terminal will be about 10-100 ha/berth depending on the generation of the container ship (Thoresen, 2003). The annual terminal capacity is usually expressed in terms of 20 feet container equivalent units (TEUs). The annual container TEU movement (C_{TEU}/YEAR) is given by the following expression (Thoresen, 2003):

$$C_{TEU}/YEAR = (A_T*365*H*N*L*S) / (A_{TEU}*D*(1+B_J))$$

OR

$$A_T = C_{TEU}/YEAR*(A_{TEU}*D*(1+B_J)) / (365*H*N*L*S)$$

OR

$$= A_N / (N*L*S)$$

Where the following are the important parameters for determining the terminal capacity:

C_{TEU}/YEAR	= container movement per year
A_T	= total yard area needed
A_N	= net stacking area
H	= ratio of average stacking height to maximum stacking height of the containers varying usually between 0.5 – 0.8. This factor will depend on the need for shifting and digging of the containers in the storage area, and the need for containers to be segregated by destination.
A_{TEU}	= area requirement / TEU depending on the container handling system
D	= Dwell Time or average days the container stays in stacking area in transit.
B_J	= buffer storage factor in front of the storage or stacking area between 0.05 and 0.1
S	= segregate on factor due to different container destinations, CMS, procedures etc., varying usually between 0.8 – 1.0
L	=Layout factor due to shape of the terminal area varying usually between 0.7 for triangular area shape to 0.1 for rectangular area shape

The area requirement A_{TEU} in m^2/TEU is dependent on the container handling system and the stacking density, the internal layout arrangement and type of equipment used for stacking the containers, the internal–access road system, and the maximum stacking height. Recommended very approximately, the design estimates for area requirements A_{TEU}, including stacking area, internal road system etc., are shown in table 1 below:

Table 1: Equipment type and stacking area

Sl. No.	Handling Equipment and Method	Stacking Height of Container	A_{TEU} in m^2/TEU with the following breadth or line of containers				
			1	2	5	7	9
1	Chassis	1	65				
2	FLT (Fork Lift Truck)/ RS (Reach stacker)	1	72	72			
		2		36			
		3		24			
		4		18			
3	SC (Straddle carrier)	1 over 1	30				
		1 over 2	16				
		1 over 3	12				
4	RTG (Rubber tyre gantry) / RMG (Rail mounted gantry)	1 over 2			21	18	15
		1 over 3			14	12	10
		1 over 4			11	09	08
		1 over 5			08	07	06

Source: Compiled by author from different literature

The area requirement A_{TEU} in m^2/TEU will also depend on the size of the TEU ground slot. The ground slot will usually vary between approximately 15-20 m^2 per TEU depending on the container handling and stacking equipment.

The container stacking density is dependent on the container stacking layout (width and length), the stack height and the stack position. Therefore the arrangement of the container stacks would directly affect the accessibility and storage of the containers, and would be of central importance to the throughput and efficiency of the container terminal.

The total number of container slots S_L at the stacking area will be

$S_L = (A_T * N) / A_{TEU}$

Where the following are the parameters for determining the total number of container slots:

S_L = total number of container slots at the stacking yard

A_T = total yard area

N = primary yard area or container stacking area compared to total yard area

A_{TEU} **=** area requirement per TEU depending on the container handling system

To determine the TEU/container crane, per berth meter and per stacking area, one should therefore use the equipment type, dwell time and other factors as indicated above (Thoresen, 2003).

3. System Dynamics

System Dynamics, developed by Forrester (1961, 1968) identifies cause-effect relationships and structures them in a feedback control framework to understand the dynamic behavior of the system. The approach professes causality doctrine associated with determinism. System Dynamics is a methodology that has ability to capture and model dynamic complexity of complex systems. Dynamic complexity refers to state where cause and effect are subtle and where effects over time interventions are not obvious (Senge, 1990). According to Coyle (1977) a System Dynamics study aims at the following objectives:

Explaining the systems behavior in terms of structure and policies, and suggesting changes in structure, policies or both, which will lead to an improvement in behavior .In terms of practical system-dynamics work, and as a conceptual framework, it is useful to look at systems in the light of how much certain knowledge about their workings it is possible to acquire and how far it is possible to exert actual and direct control over what goes on.

Causal loop diagrams: Model boundary charts and subsystem diagrams show the boundary and architecture of the model but don't show how the variables are related. Causal loop diagrams (CLDs) are flexible and useful tools for diagramming the feedback structure of systems in any domain. Causal diagrams are simply maps showing the causal links among variables with arrows from a cause to an effect. Causal loop diagrams emphasize the feedback structure of a system (Sterman, 2000).

Positive feedback loops generate growth, amplify deviations, and reinforce change. Negative loops seek balance, equilibrium, and stasis. Negative feedback loops act to bring the state of the system in line with a goal or desired state. They counteract any disturbances that move the state of the system away from the goal (Sterman, 2000).

4. Container Yard Planning Model

In this paper an attempt has been made to develop a system dynamics model that account for flow of containers, their dwell times, type of equipments and constraints that determine the container yard capacity. The structure of the system is captured with the delays in capacity building and resultant impact on container yard capacity, investments and customer satisfaction. The causal diagram is shown below:

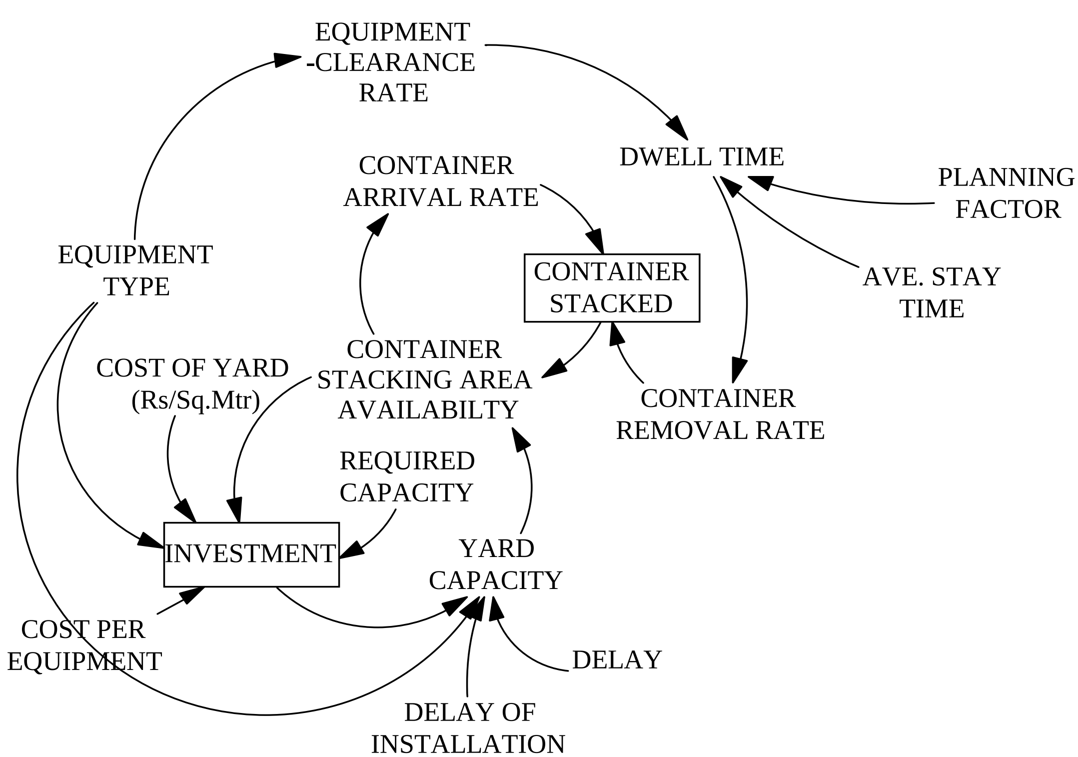

Fig 1: Causal loop diagram of container yard capacity dynamics

5. Loops

There are two loops:

(a) The Container Arrival Rate – Container Stacked – Area Availability Loop

This is a positive loop. The increase in Container-Arrival-Rate results in increase in number of containers stacked which in turn decreases the Area Availability while the removal rate remains constant. Non availability of area in turn reduces the arrival rate of containers.

The "Area Availability" can be enhanced by increasing the Container Removal Rate and/or enhancement of yard capacity.

The causal loop is shown in Figure 2.

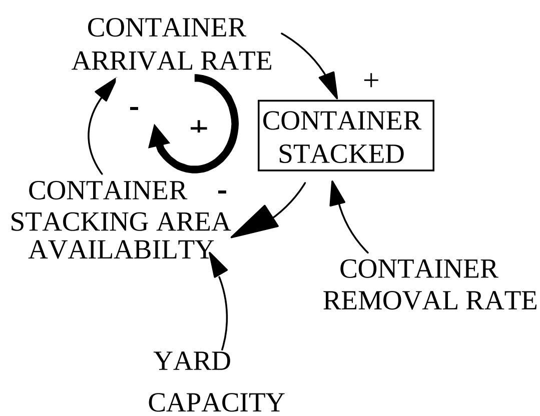

Fig 2: The container arrival rate – container stacked – area availability loop

(b) The Area availability – Yard Capacity – Investment Loop

This is a negative loop. The Area-Availability depends on "Yard Capacity" and "Container Stacked" in the yard at any instant. Decrease in the Area-Availability, due to difference between arrival and removal rate of containers, leads to investments for enhancement of capacity.

Thus, if removal rate can be enhanced through change in processes or increasing efficiency or by any policy decision, the investments can be avoided, deferred or lowered.

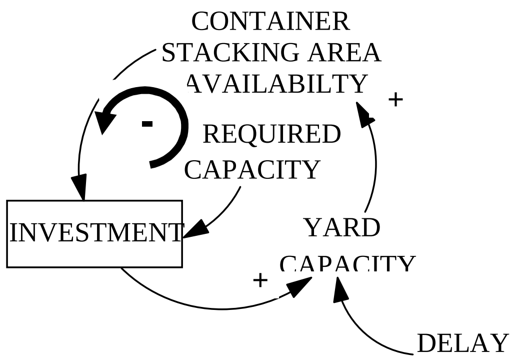

Fig 3: Area availability – yard capacity – investment loop

6. Policy Variables and Decisions:

✦ Equipment Type: Depending on the type of equipment, containers can be stacked at different heights and as a result area per TEU would vary. Equipment such as RTG / RMG can enhance availability of container stacking area. Moreover, the rate of clearance and shifting also depends on the type of equipment.

Ports can decide on optimum equipment mix so as to enhance the capacity of the container yard instead of expending on development of additional area as container parking yard.

✦ Average Stay at Yard: The capacity of the yard increases if the stay time decreases. This can be reduced with proper planning and structuring demurrage charges.

Ports can decide on demurrage charges that discourage unnecessary stay of containers at the yard

✦ Planning Factor: Proper planning can be done if information on container arrival and shifting from the yard is available well before time. Ideally, the Planning Factor should be equal to 1. The "Dwell Time" of containers is a function of the "Planning Factor". It increases if the "Planning Factor" reduces, i.e. tends to be less than 1.

Hence, a policy decision can be taken to introduce a system of "shifting of container by appointment", so as to ensure complete planning in advance. This is expected to achieve just-in-time (JIT) delivery minimizing the dwell time. The "planning factor" in case of JIT delivery would be equal to 1 (one).

- Investment Decision: Capital costs are sunken cost and are irreversible. In addition capacity expansion projects in ports have long gestation periods. Improper decisions may lead to superfluous expenditure and low returns.

Thus, ports should invest only after effecting change in processes, optimizing the equipment mix, establishing clear channel of communication through implementation of the right ICT (Information Communication Technology) and ensuring that the "Planning Factor" is equal to 1

7. Conclusion

In this paper, use of system dynamics is demonstrated for planning of container yard capacity. System dynamics provides an experimental setup using which the parametric values based on different policy decisions are tuned to ensure available yard capacity, instead of making irreversible and large investments.

The paper identifies two governing loops. These loops explain the dynamics of yard capacity planning and enable identification of policy variables.

The policy decisions relate to enhancement of stacking area through right deployment of equipment and minimization of dwell time through reduction of average stay at yard and faster shifting rate. The faster rate of clearance can be achieved through right choice of the equipment. The paper focuses on need for timely information, flow for proper planning leading to faster clearance of containers and minimization of dwell time.

This work can be extended to include stock and flow diagrams, develop a simulation model, run the model using software such as Stella, VENSIM or similar ones, and observe the results of different policy decisions.

References

Chase R B., Jacobs F R., and Aquilano N J. (2004), "Operations Management for Competitive Advantage", *Tata McGraw-Hill Publishing Co. Ltd*., 10th Edition, 6th Reprint, pp. 386-398

Coyle, R. G.,(1977), "Management System Dynamics", *John Wiley and Sons,* London.

Dundović. C., Hess. S., (2005), Exploitability of the Port Container Terminal Stacking Area Capacity in the Circumstances of Increased Turnover , bib.irb.hr/datoteka/206743.s04p5_ISEPfinal.doc: Assessed 01.04.2011

Forrester, J.W., (1961), "Industrial Dynamics", *M.I.T Press, Cambridge, Massachusetts*.

Forrester.J.W., (1968), "Principals of Systems", *Wright Allen Press, Cambridge, Massachusetts.*

Frankel E G.(1987), "Port Planning and Development", *MIT, A Willey Interscience Publishing*

Gaither N. and Frazier G. (2004), "Operations Management", *Thomson – SouthWestern* , 8th edition, 5th Reprint, pp 163-165

http://www.smthacker.co.uk/capacity_management.htm, 2007

Schroeder Roger G. (2004), "Operations Management: Decision Making in Operations Functions", *McGrawHill International Edition,* 3rd Edition, pp. 267 – 290

Senge, P. M., (1990)," The fifth discipline: The art & Practice of the Learning organisation", *Double Day Currency*, N.Y.

Sterman, John. D, (2000), "Business Dynamics - Systems Thinking and Modeling for a Complex World", Irwin McGraw Hill

Thoresen Carl A.(2003), "Port Designer Handbook: Recommendation and Guideline", *Thomas Telford Publishing*, pp. 304-333

List of working papers of IIFT

Sinha, Deepankar (2010), "Multi-Dimensional Approach to Management of Port Life Cycle: The Case of Major Ports in India" Working Paper No: LD-10-01, Indian Institute of Foreign Trade, New Delhi and Kolkata. This paper can be downloaded from http://cc.iift.ac.in/research/Docs/WP/01.pdf

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Nag, Biswajit (2011), "Comprehensive Economic Partnership Agreement Between India and Sri Lanka: Where Does it Lead?", Working Paper No: EC-11-03, Indian Institute of Foreign Trade, New Delhi and Kolkata. This paper can be downloaded from http://cc.iift.ac.in/research/Docs/WP/03.pdf

Sinha, Deepankar (2011), "Container Yard Capacity Planning: A Causal Approach" Working Paper No: LD-11-04, Indian Institute of Foreign Trade, New Delhi and Kolkata. This paper can be downloaded from http://cc.iift.ac.in/research/Docs/WP/04.pdf