

ON-OFF TERMINAL SHIP-TO-RAIL TRANSFER

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I. PROBLEMS STATEMENT AND OBJECTIVE

Which Intermodal Configuration is Preferable? All U.S. ports agree that the availability of state of the art intermodal linkage is the key to their survival in the new intermodal era. All of them are currently involved in design and/or construction of intermodal yards, some of them are located "on-dock".

Intermodal Yard is a rail terminal where containers are loaded/unloaded to/from railcars. The Intermodal Terminal consists of a railyard ("ramp") for staging railcars, a marshalling yard for staging containers, and a gate. "On-dock" is a misnomer, since the ramp is not necessarily located on the dock. The more accurate term is on or off marine terminal. While all ports agree on the critical importance of an efficient ship-to-rail linkage, there is much controversy over which is the most effective system for providing this link. In principle, the ship-to-rail transfer can follow two principal *Intermodal Configurations*; it can be performed either within the marine terminal, called *on-terminal*, or outside it, called *off-terminal*. A closer, on-terminal linkage between ship and rail is most desirable. However, the linkage itself, the *intermodal yard*, consumes waterfront land that otherwise could serve as marine terminal (National Science Foundation, 1992).

Scarcity of Waterfront Land. Productivity of waterfront land is the most critical consideration for determining which Intermodal Configuration to adapt. Waterfront lands, especially those facing a deep channel on one side and an unobstructed road and rail access on the other side, are in short supply. Land-side access for the 2.6 Km, double-stack trains is especially difficult, because urban areas cordon most of U.S. ports.

The decision regarding *on vs. off terminal rail linkage* is both critical and complicated. No wonder that a controversy on this issue has been raging for quite some time including dramatic shifts in planning decisions by major ports (Ashar, 1990).

Waterfront Land Productivity. This article presents the result of a comprehensive study on the ship-to-rail linkage. The study applied an innovative, stock & flow modelling approach to assess the productivity of waterfront land

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under conflicting usages. The objective of the article is to explore the decision making situation of port planners facing the complexities of the ship-to-rail linkage, along with providing, hopefully, some general guidelines.

II. DEFINITION OF INTERMODAL SCENARIOS AND INTERMODAL CONFIGURATIONS

Definition of Intermodal (IM) Configurations. The main objective of this article is to measure the effectiveness of a set of *Intermodal Configurations* in terms of their *productivity of using waterfront, land*. The IM Configurations define the relative locations and operation system of the marine and rail (intermodal) terminals involved in the ship-to-rail process. The two principal configurations, the on/off terminal, can be further divided according to the distance between the intermodal and the marine terminals to include altogether six distinct IM Configurations. The IM Configurations can be also characterized according to:

(a) **Service Orientation** -- The type of cargo served there (solely international or combined with domestic), type of trains (public and/or dedicated) and type of users.

(b) **Operational Differences** -- The number of physical and administrative operations required for completing the ship-to-rail process.

Table 1 defines the six IM Configurations and their differences in service orientation.

Figure 1 presents, in a schematic fashion, the ship-to-rail process in the various IM Configurations.

Table 2 presents the series of operations, physical and administrative, that typify each of the six IM Configurations

Operating and Capital Costs. Each configuration involves a different combination of operating and capital costs. The main operating costs include rail switching, truck drayage, gate crossing and lifting in the marine and intermodal terminal. The cost of each of these activities varies according to distance (for the switching and drayage); terminal system (for the lifting); and the degree of inter-terminal integration and automation (for the gate crossing). By assuming typical value for these variables, a rough estimation can be made for the operating costs of each configuration.

The main capital costs associated with the ship-to-rail transfer are related to investments in land and facilities for the rail terminal and for providing the rail access. However, unlike the operating costs, the *capital costs are site specific* to a degree that does not allow any meaningful estimation.

Table 3 provides a general estimate of the operating costs associated with the ship-to-rail transfer.

Table 1
Classification of Intermodal Configurations

Configuration Name	Vessel-Train Distance	Type of Cargo Served	Type of Train Service	Type of Yard Users
<i>Off-Terminal:</i>				
Remote	30 km	Domestic	Public	General
Nearby	5	Mar. & Dom.	Pub. & Ded.	Port Tenants
Adjacent	1	Maritime	Pub. & Ded.	Port Tenants
<i>On-Terminal:</i>				
Back-of-Terminal	0.5	Maritime	Dedicated	Term. Tenants
Vessel-Cycle	0.1	Maritime	Dedicated	Term. Tenants
Under-the-Hook	0	Maritime	Dedicated	Term. Tenants

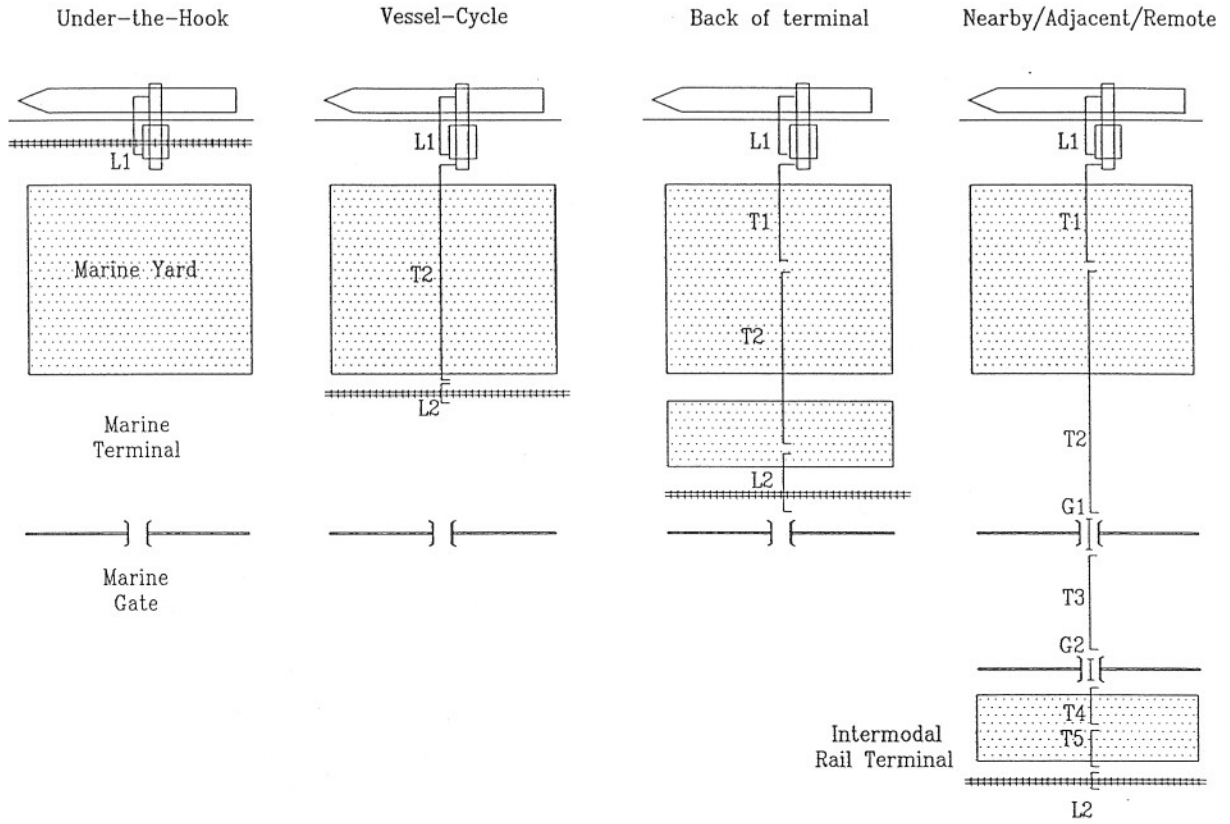
Table 2
Operations in the Ship-to-Rail Transfer

Operation Description	Intermodal Configurations			
	Off-Terminal	On-Terminal		
	Remote, Near & Adjacent	Back of Terminal	Vessel Cycle	Under Hook
Vessel Lift	L1	L1	L1	L1
Vessel-Marine Yard Transport	T1	T1	T1	-
Marine Yard-Gate Transport	T2	T2	-	-
Marine Gate Procedures	G1	-	-	-
Marine Gate-IM Gate Transport	T3	-	-	-
IM Gate Procedures	G2	-	-	-
IM Gate-IM Yard Transport	T4	-	-	-
IM Yard-Train Transport	T5	-	-	-
Train Lift	L2	L2	L2	-
Rail Switch	-	R1	R1	R1
Total Lifts	2	2	2	1
Total Transports	5	2	1	-
Total Gate Procedures	2	-	-	-

Comments:

All-Wheel is assumed.

Figure 1
Schematic layout of Major Intermodal Configurations



All Close IM Configurations have Similar Operating Costs. As seen from Table 3, the only significant difference in operating costs is in the drayage cost, especially between the Remote Configuration and the rest of them hereafter, referred as Close. The difference in drayage cost between the Remote and the Close configurations can reach up to \$75 per box.² This is a significant cost item considering that the number of annual moves, for large and intermodal terminal, can reach over \$150,000 per year. Annual savings on the order of \$10 million can justify large investments in rail facilities and access trackage. It can be concluded thus that, in general, Close IM configurations are preferable to Remote configuration for intermodal terminals.

As to the Close IM configurations, their cost structure is affected by two opposing trends: as the rail is getting closer to the ship, the *drayage cost is decreasing*, but the *switch cost is increasing* almost at the same rate. As a result, the differences in total operating costs which are on the order of \$10 per box cannot provide a clear indication as to which of the Close IM configurations is more cost effective. Consequently, it is difficult to make judgement on IM Configurations solely based on their operating cost.

Waterfront Land Productivity. The choice among the four Close IM Configurations should be made thus based their capital costs which, as was observed before, are very site specific. As a proxy for them, this author suggests to take the amount of waterfront land consumed by each of the IM Configuration. Put differently, since the amount of waterfront land for most practical purposes is given, the throughput (capacity) that each of the IM Configurations can handle through this land, or its land productivity, can serve as the ultimate decision criterion.

Land requirement for the remaining 4 IM Close Configurations is affected by two opposing factors: closer rail connection enhances the operational productivity of the marine terminal by enabling a faster rail connection, shorter dwell time and rapid turn-around; but closer rail connection mandates closer IM Configuration which consumes valuable terminal area that otherwise could be used to augment the marine terminal capacity. One IM Configuration, the Nearby, is an exception. Though it is defined as a Close configuration, the intermodal terminal is located outside the area that could reasonably be considered as marine terminal area.³

Intermodal Scenarios. The decision on IM Configuration depends on the "rail content" or the level of intermodal involvement of the marine terminal which varies widely among U.S. (and world) ports. The Pacific Northwest ports are

² E.g., in the case of Los Angeles/Long Beach downtown yards.

³ For example SIG in Seattle or ICTF in Los Angeles.

probably the most heavily involved in the intermodal transfer. Some of Tacoma's terminals move up to 80% of their cargo directly to rail. The Gulf and some North Atlantic ports are on the opposite end of the intermodal involvement scale. New York, for example, moves only 8% of its cargo by rail, and none of it moves on line-controlled train. To simplify the analysis, the rail content situation was defined by five *Intermodal Scenarios*, each with a different percentage range of railbound cargo. It should be emphasized, however, that the *rail percentage only applies to line-controlled unit trains* and not to railbound cargo that uses public trains.

Table 4 describes the five so-called *Intermodal Scenarios* including the percentage of railbound cargo, number of unit-trains per vessel and examples of ports.

III. MATCHING INTERMODAL SCENARIOS WITH INTERMODAL CONFIGURATIONS

Matching Closer IM Configurations with Higher Scenarios? Based on the above definitions, the question of ship-to-rail can be rephrased:

Given an Intermodal Scenario, which Intermodal Configuration is most Land Productive?

Intuitively, it seems that the higher (rail percentage) Intermodal Scenario mandates a closer (distance between ship-to-rail) Intermodal Configuration. The forthcoming analysis suggests that this intuitive observation is only partially true.

Two-Stage Modelling Approach. The analysis of the effect of the Intermodal Scenario on land productivity was structured around two computerized models: (a) an operations simulation based on stock & flow concept (Ashar, 1991) and (b) terminal layout model, calculating the areas required for both marine and rail terminals.

Operational Productivity. The focus of the operations simulation was on tracking the "stock" of containers in the yard, assuming that the yard capacity determines the overall terminal capacity. This stock fluctuates in response to the changes in the flows to/from vessel, rail and truck. The simulation searches, thus, for the *peak stock*, or the maximum number of boxes (slots) that the yard should hold. The terminal *operational capacity* (annual throughput) is measured by the *ratio between vessel-moves and yard-slots, called M/S* (moves per slot).⁴ The higher the M/S ratio, the more productive is the terminal operation.

Railbound boxes moving on line-controlled unit trains tend to have shorter dwell time than truckbound boxes. The effect of railbound cargo on dwell time is significant, if most of these boxes are removed before the next vessel's arrival, without leaving a *tail*. The *tail clipping effect* results in lowering the peak requirement for terminal slots and, respectively, in an increase in terminal

⁴ The M/S ratio is a flow to stock ratio which measures the stock required to

Table 3
Ship-to-Rail Operating Costs

Operation	Drayage	Rail Switching	Marine Gate Processing	IM Gate Processing	IM Yard Operations
Code	T2+T3+T4	R1	G1	G2	T4+T5+L2
<i>Off-Terminal:</i>					
Remote	\$40 – 75	No Cost	\$25	\$20	\$15
Near	\$10 – 15	\$10 – 15	\$25	\$15	\$20
Adjacent	\$10	\$15 – 20	\$25	\$10	\$20
<i>On-Terminal:</i>					
Back Terminal	\$5	\$20 – 30	No Gate	No Gate	\$20
Vessel Cycle	Included	\$25 – 35	No Gate	No Gate	Included
Under Hook	No Drayage	\$30 – 50	No Gate	No Gate	Included

Table 4
Definition of Intermodal Scenarios

Name of Scenario	Percentage of Railbound Cargo	Number of Unit Trains per Vessel	Examples of Ports
No-Rail	0 – 15%	None	North Atlantic & Gulf Coasts
Minor-Rail	15 – 35	1 – 2	Northern California
Half-Rail	35 – 60	3 – 4	Southern California
Most-Rail	60 – 85	5 – 6	Pacific Northwest
All-Rail	85 – 100	up to 8 Trains	None

capacity. This is reflected in the simulation results especially for the higher IM Scenarios. A Most-Rail Scenario can result in a gain of 43% in M/S ratio over the base-case of No-Rail. The results are much less dramatic for the lower Intermodal Configurations judging by the mere gain of 9% for the Minor-Rail Configuration.

Figure 2 & 3 present the stock & flow profile of a terminal with 50% of the cargo railbound (the so-called Half-Rail Intermodal Scenario).

Table 5 presents the M/S ratios and the M/S index for the various Intermodal Scenarios.

Waterfront Land productivity. The conversion of the slots into actual acreage for the marine terminal was based on standard layout assumptions.⁵ The intermodal terminal area was calculated as a function of the number of unit trains to be staged on-terminal, which, in turn, was a function of the combination of IM Scenario and Configuration. For example, in Most-Rail Scenario and Vessel-Cycle Configuration, the railyard was assumed to hold 7 trains, 6 for the railbound containers, and 1 serving as a "double-cycle" buffer.⁶ For each pair of IM Scenario & Configuration, the total waterfront acreage as well as the land productivity were calculated. The land productivity was defined as the *ratio between the vessel-moves and waterfront acre, called M/A (moves/acre)*.

Full Allocation and Substitution of Terminal Land. The main concern of the decision making process regarding intermodal facilities is whether scarce marine terminal land should be allocated for rail-related activity or kept solely for vessel-related activities. This concern is mute, of course, when the rail handling is performed outside the marine terminal, as practiced in the Remote and Nearby Intermodal Configurations. It can be also ignored in the Under-the-Hook Configuration where the entire terminal is reduced to the apron. As to the three remaining configurations -- Adjacent, Back-of-Terminal and Vessel-Cycle, the land consumption in each of them is affected by a subtle but important difference in their operation system. In Adjacent and Back-of-Terminal the first (last) place of rest of the boxes is in the marine yard, while in the Vessel-Cycle the boxes are placed directly on the railcars. Consequently, *in case of Vessel-Cycle, the railcars themselves serve as a substitution for the marine yard*. The *substitution effect* results in a higher productivity (M/A ratio) for the Vessel-Cycle configuration. Table 6 presents the M/A ratios and M/A indices for a set of IM Scenarios and Configurations.

⁵ Chassis for the yard system and RTG for the railcar handling.

⁶ Assuming vessels with 2000 moves (mostly 40 feet) each way and 250 FEUs per unit-train (2000 x 0.75 : 250 = 6).

Figure 2

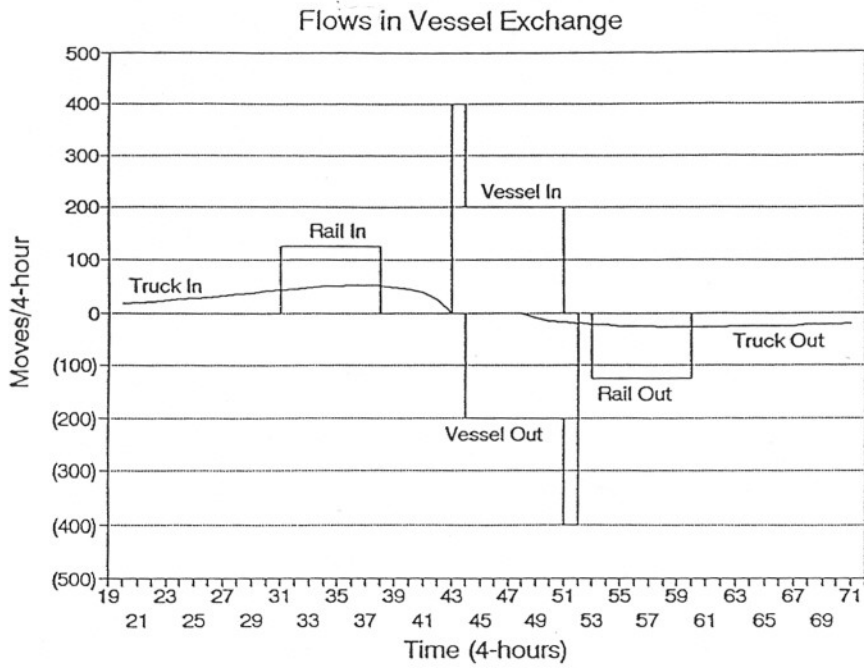


Figure 3

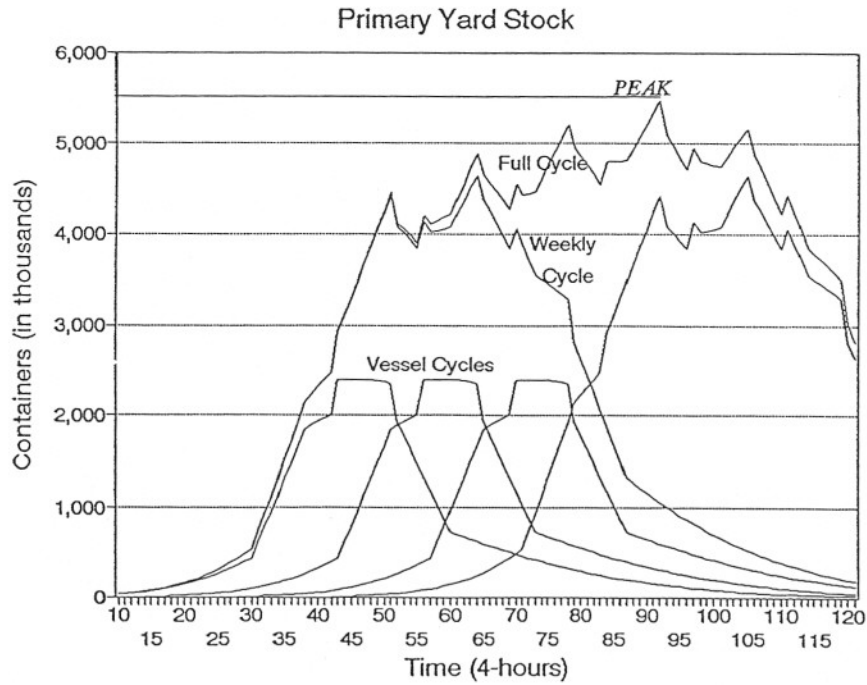


Table 5
Operational Productivity by Intermodal Scenarios

IM Configuration Rail Porportion	Minor 0.25	Half 0.50	Most 0.75	All 1.00	None 0.00
<i>Vessel-Moves per Yard-Slot (M/S):</i>	104	114	137	155	95
<i>M/S Index:</i>	1.09	1.20	1.43	1.63	1.00

Table 6
Land Productivity by IM Scenarios & Configurations

IM Configuration Rail Porportion	Minor 0.25	Half 0.50	Most 0.75	All 1.00	None 0.00
<i>Vessel-Moves per Wf-Acre (M/A):</i>					
Nearby	3,507	3,815	4,511	na	3,231
Adjacent	3,158	3,278	3,504	na	
Back of Terminal	3,185	3,321	3,571	na	
Vessel Cycle	na	3,910	5,289	7,687	
<i>M/A Index:</i>					
Nearby	1.09	1.18	1.40	na	1.00
Adjacent	0.98	1.01	1.08	na	
Back of Terminal	0.99	1.03	1.11	na	
Vessel Cycle	na	1.21	1.64	2.38	

Wf = Waterfront

na = Not available or impractical

The "Best" Matches. An examination of the M/A ratios yields that for:

- **Minor-Rail Scenario -- Nearby Configuration** is considerably more productive since it does not require allocation of terminal acreage for the intermodal terminal.
- **Half-Rail Scenario -- Nearby and Vessel-Cycle Configurations** have similar productivity and are preferable over Adjacent and Back-of-Terminal Configurations.
- **Most-Rail Scenario -- Vessel-Cycle Configuration** is clearly the preferable configuration.

A complementary conclusion (not presented in Table 6) is that Vessel-Cycle is the preferable configuration for the All-Rail Scenario. Another complementary conclusion is that Adjacent and Back-of-Terminal Configurations are inferior for all IM Scenarios.

Based on the above, a general decision rule for selecting IM Configurations can be developed: If 50% and over of the terminal cargo is railbound -- the Vessel-Cycle is preferable; if less than 50% is railbound -- Nearby is preferable. This admittedly rough decision rule is somewhat surprising, since none of the U.S. ports, even those with high content of railbound cargo and with on-dock IM yards, is practicing a full Vessel-Cycle system.

Under-the Hook. The Under-the-Hook Configuration, whereby the boxes are loaded/unloaded directly from/onto railcars staged on the apron or "under the hook" of the gantry crane, was intentionally left out of the previous discussion. Such an operation, based on continuous, looping rail system has enormous capacity.⁷ However, the problems related to the stowage match between vessel and trains, along with the technical and layout problems, make this configuration impractical, at least for the time being.⁸

All-Rail Terminal. The combination between an All-Rail Scenario and Vessel-Cycle Configuration is of a special interest. If all (almost) boxes are railbound, and, by employing a Vessel-Cycle Configuration can be staged directly on railcars -- then there is no need (almost) for a marine yard. The terminal becomes, in fact, a *railyard*. The terminal tractors can simply shuttle between the apron and the railcars instead of between the apron and the yard. Consequently, the All-

⁷ Similar to the arrangement of bulk terminal.

⁸ The only terminal known to practice Under-the-Hook operation, Zeebrugge, Belgium, terminated it recently for the same reasons.

Rail ship-to-rail linkage is almost as tight as in the Under-the-Hook, though it is much simpler and does not require any technological breakthrough. Desirably, the rail trackage should be laid in perpendicular to the apron in order to provide an easy access to the railcars and to allow the train blocks remain unbroken for quick switching in/out.⁹ Such an arrangement mandates that the terminal will have a depth equal to at least a quarter of a unit train or about 2500 feet (from berth to gate), which is presently unavailable in most U.S. ports.

Figure 4 presents a schematic layout of an All-Rail/Vessel-Cycle terminal.

IV. SUMMARY

Decision Tree for Port Planners. The intermodal situation of U.S. ports is still evolving, and port planners will be facing difficult decisions regarding IM Configurations. This article was intended to assist "perplexed" port planners in coping with the complexities of the ship-to-rail subject. The article is summarized, thus, by a decision tree, which captures the conceptual structure of the subject, especially the subtle interaction between the tail clipping and substitution effects as illustrated by the M/S and M/A indices.

Figure 5 presents The Port Planner Decision Tree, including a specification of one branch that this author found most interesting -- the Most-Rail Scenario. Note that all figures are relative (indices) whereby No-Rail/Remote serves as a basis (1.00).

⁹ Similar to the arrangement of straddle-carrier.

Figure 4
Schematic Layout of an All-Rail /Vessel Cycle Terminal

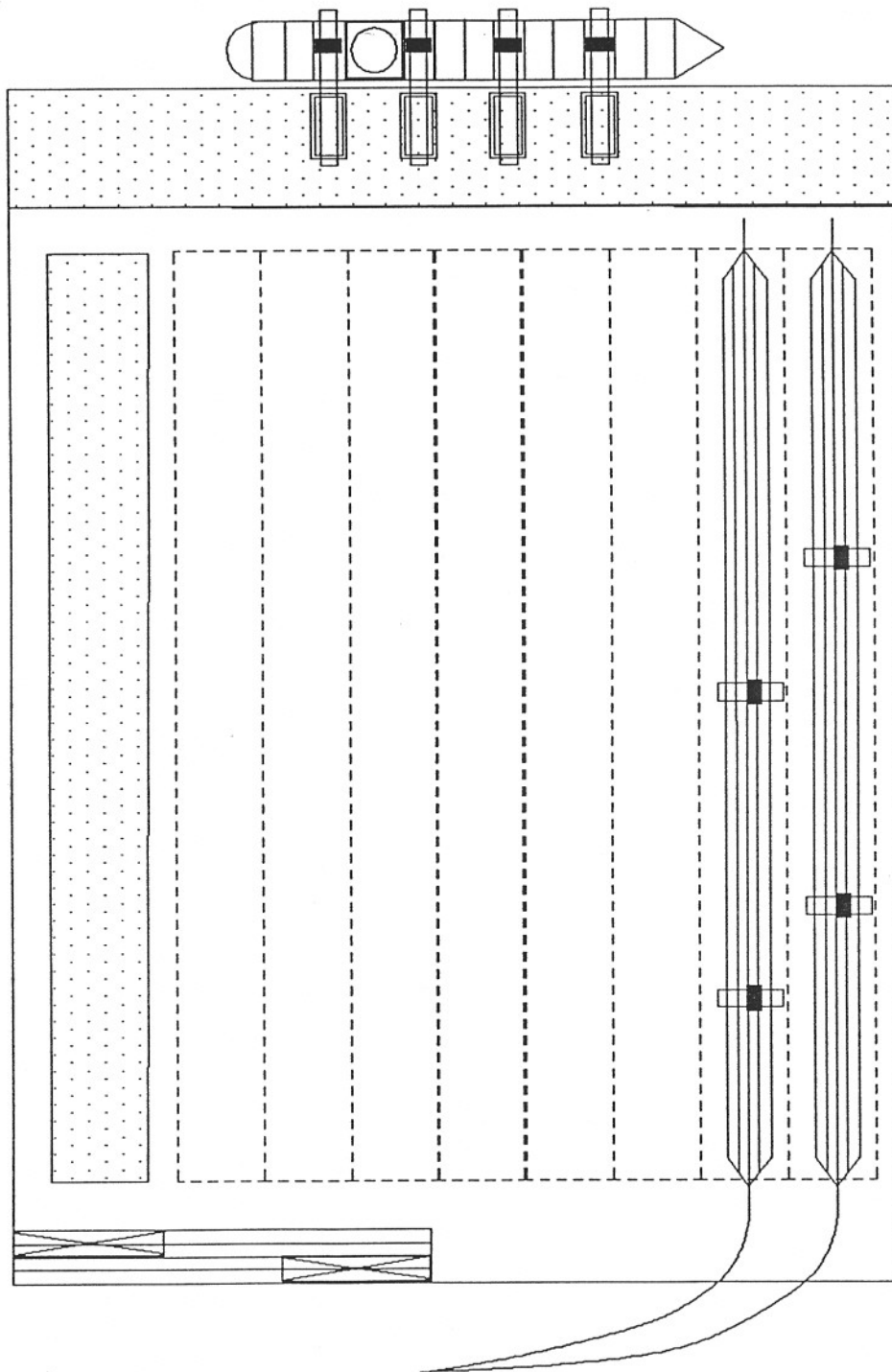
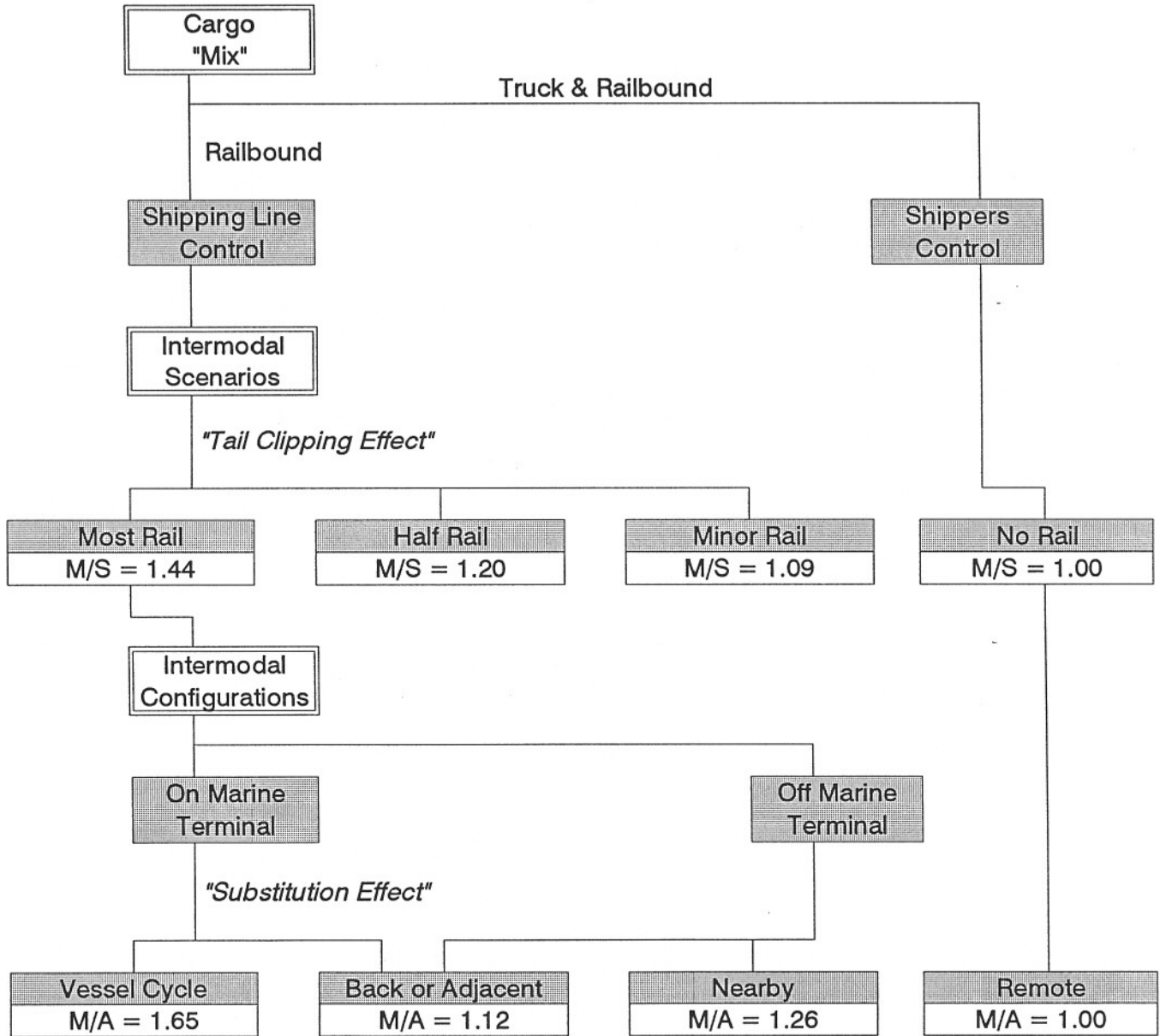


Figure 5

PORT PLANNER'S DECISION TREE



Legend:

Decision Node
 Main Option
 Specific Option

* All figures are in relative values (ratios).

M/S = Vessel-Moves per Primary Yard-Slot

M/A = Vessel-Moves per Waterfront Acre

REFERENCES

1. The conflict in land use is in the center of Impediments to "Land-side Access to U.S. Ports", National Science Foundation, Executive Summary, 1992.
2. The ports of Los Angeles, Long Beach, Oakland, Seattle and New York can serve as examples of the seesaw decision making process. See also A. Ashar, "On-off terminal vessel-to-rail intermodal transfer and the case of Long Beach Port", Maritime Policy & Management, 1990, volume 17.
3. The approach was originally developed by J. Forrester (1961) and was called System Dynamics. The use of this approach for calculating terminal capacity is described in A. Ashar, "Productivity, Capacity and Equity in the Port of San Juan", WWS/Worldwide Shipping, May 1991, pp. 46-52.

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