Design Issues Related to the Intermodal Marine-Rail Interface

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A major modernization program currently taking place at the Port of San Francisco illustrates the considerations and constraints involved in planning a state-of-the-art intermodal marine facility. Creation of layout alternatives for future expansion possibilities was essential for long-term planning; however, special problems involving railroad and truck access must be resolved before the project design is complete. Impediments to designing modern intermodal marine-rail facilities include problems such as lack of land for expansion of existing facilities and modification of existing facility requirements to accommodate variations in equipment and operations. Larger capacity container ships are necessitating increased container storage capacities in excess of 4,500 TEUs. At the start of deregulation, the railroads carried slightly more than 3.1 million trailers and container units, and in 1982, the year after deregulation, the volume increased further to 3.4 million. These figures were eclipsed when deregulation took hold in 1983, as evidenced by the trailer and container volume reaching almost 4.1 million units (2). The Staggers Rail Act has provided the railroads and other intermodal transportation concerns with significant financial incentives to make long-term capital investment decisions, especially in the areas of new equipment and terminal facilities.
Steamship companies have started to take full advantage of their new-found point-to-point rate-making capability, following passage of the 1984 Shipping Act. Some U.S. steamship lines have been able to assemble substantial marketing and operational advantages made available by this latest deregulation legislation. Implementation of a fully intermodal service concept involving water, rail, and road distribution systems is becoming a key ingredient in steamship line strategic and tactical profit pictures. The Shipping Act of 1984 has encouraged steamship lines to become more flexible and innovative, and with deregulation have composed long-term investment decisions that can substantially cut intermodal operating costs (3).

Thus planners and designers of intermodal facilities must provide flexible layout concepts and designs to accommodate rapidly growing intermodal activity and to match capabilities of present and future facilities with the operating versatility of modern intermodal companies.

Intermodal Service Expansion

Deregulation and the surge in intermodalism are creating new intermodal, full-service competitors with new operating concepts and new equipment. Steamship lines are becoming the competitors of truckers and railroads alike, and inland terminals and ports are competition among themselves to service regional hubs and load centers created by such concerns as Evergreen, U.S. Lines, Sea-Land Service, American President Lines (APL), and Lykes Lines.

In April 1984 APL began its dedicated rail service between Los Angeles and Chicago using three APL-owned container unit trains in a COFC mode. This service introduced a lightweight, articulated, double-stacked railroad car. APL, through its newly formed subsidiary AP Intermodal (API), has been able to secure contracts with railroads that save 25 percent of the usual rail freight rate (3). Recently APL's operations from Los Angeles to Chicago have been upgraded to a 250 40-ft equivalent unit (TEU) capacity, and APL has significantly expanded its involvement in domestic freight transportation by forming AP Domestic (APD), which has acquired three domestic freight brokerage companies.

The new three-way relationship among the domestic shipper, the railroads, and the steamship company is changing. The domestic shipper now may have an agreement with a steamship company subsidiary such as API or APD and may be billed directly by the steamship company (4).

An outgrowth of these new transportation arrangements and an influencing factor in planning is the critical concern of the steamship line about the necessity of transporting empty boxes for return to the West Coast (backhaul). With the insertion of steamship company operations into the domestic transport market, containers loaded with domestic cargo are being backhauled.

Transport Terminal Load Centers

Although hotly debated, the load center concept is gradually being accepted as a standard operational approach for some steamship lines such as Evergreen and U.S. Lines, which are putting into service round-the-world class vessels with very large container capacities that require improved shoreside facilities and specialized service operations. Some of the prime factors that are germane to the selection of load center ports are reportedly to be

1. A large metropolitan population base serving as a market;
2. Geographically well-located suitable harbors and port facilities;
3. Suitable inland transportation infrastructure for trucks and railroads; and
4. Available support systems such as freight forwarders, customhouse brokers, and banks (5).

Currently, major coastal and inland container transfer facilities are being planned for Los Angeles, Chicago, and New York, which will reinforce the transport terminal center concept.

Vessel and Crane Geometry Requirements

In an advisory document produced by the Ministry of Transport, Government of Japan (6), the need to respond to future increases in container ship size and equipment advances is addressed. This document forecasts the need for water depth alongside container terminal facilities of from 32 to 49 ft. The Port of Tokyo is reportedly planning a water depth next to wharves of 42 ft, and the Port of Kobe is reportedly projecting the need for a water depth of 49 ft. Some Japanese authorities are predicting a fourth generation container ship, possibly offering capacities of 5,500 TEU, and apparently Japanese equipment manufacturers are already gearing up to meet this challenge.

A ship-loading gantry crane servicing the next generation vessel may have an operating outreach that accommodates 16 rows of containers on a ship's deck stacked four high and twelve rows in the hold stacked nine high. This configuration necessitates a gantry crane outreach of from 137 to 141 ft or greater to service vessels well beyond Panamax class vessel geometry. High-speed computer-indexed multiple trolleys mounted on the outreach boom of the ship-loading gantry crane could handle multiple containers at high throughput rates. The expected lift capacity for the fourth generation container gantry crane may be 40 long tons (6).

Current marine terminal renovation projects that require deeper drafts can cause significant problems in the modification of existing container wharf structural systems, especially for a fixed rail-mounted gantry crane on a pile-supported existing wharf. Widening the wharf deck can be done without affecting the stability of the wharf by adding new piling and wharf deck to the waterside edge of the wharf. However, careful attention must be paid to the slope stability of underwater soil embankments when greater water depths are being evaluated at a marine terminal facility. Wharf widening is frequently accomplished with underwater sheet piling for slope stability, and widenings that are not accomplished by the use of sheet piles may require other retaining devices to stabilize underwater slopes.

Wharf additions can create significant obstructions to vessel maneuvering and berthing constraints for container ships that frequently have large bulbous bow haul geometries and bow thruster capability. Wharf fendering systems are also greatly affected by these operational concerns. Careful engineering and life-cycle cost analyses must be undertaken for proper facilities modification projects. In addition to large initial existing facilities modification costs, significant cost may be incurred in modifying an existing crane boom outreach, height, or other crane geometry.

Double-Stacked Rail Cars

The third revision of double-stacked intermodal rail car is at hand. Lightweight, single-axle, ar-
articulated platforms have been in existence for the last 4 or 5 years and are considerably more efficient than is the standard 89-ft flatcar. These five-mod-
ule articulated platforms have a container capacity of 10 FEU (10.6 FEU if 45-ft containers are placed on top of 40-ft bottom containers) and have con-
siderably fewer couplers and more efficient wheels and brakes. The third generation intermodal car is specifically designed for COFC traffic. Three manu-
facturers that provide depressed platform or "well"-constructed intermodal cars are Thrall Car Manu-
facturing Co., Pullman Standard Manufacturing, and Gunderson Inc. (2).

With the recent announcement of APL's eight double-stacked liner trains between Los Angeles and Chicago, rail liner service has increased to three departures per week, both eastbound and westbound (a 52-hr, one-way schedule, making a round trip every 7 days). APL's agreement with the railroads specifies a fixed cost per mile charge for tow power and com-
mits the railroad to a delivery schedule. Savings realized by using a double-stacked train can be more than 40 percent over conventional TOFC service (1). Perishable commodities could soon be accommodated on the double-stacked trains if generator-mounted units were used on the articulated platforms to supply power to the refrigerated containers.

Modern marine container facilities servicing the fourth generation container vessel can have a throughput capability that allows loading and un-
loading 800 to 1,000 40- to 45-ft containers within a 24-hr period. Although not a valid comparison, the inland APL rail yard in Chicago is reported to take an equal length of time to unload, reload, and turn the double-stacked train with 200 40- to 45-ft con-
tainers. Figures obtained from the Santa Fe Chicago Terminal, a reported model of intermodal efficiency, indicate that, based on yearly averages (1), it can turn 600 containers in a 24-hr period. It should be noted that both the marine facility and the inland rail terminal operate around the clock when a vessel or train is in the terminal. These comparisons point out the need to balance the pressure on the inter-
modal "hose" by planning high-speed, efficient, high-volume facilities designed to minimize handling cost at all points in the intermodal chain. At the same time, the facilities design must allow for flexible efficient use of the terminal for periods of low-volume use.

The design of inland and on-dock marine-related rail facilities should maximize terminal throughput capability to match current container "pipeline" system demand. Terminal facilities are currently being evaluated for direct vessel-to-rail movements at a marine terminal that may overcome local opera-
tional constraints or "place of rest" concerns at terminals. Compromises in vessel-to-rail efficiencies and other internal operational constraints, as operator preferences for particular equipment, may ultimately cause a premature cap on intermodal con-
tainer transfer facility (ICTF) throughput, and, with the industry in an upward trend, it would be impru-
dent to limit throughput capability without sound rationale. The double-stacked rail car service using articulated equipment has proven that it can provide fast, efficient, low-cost land bridge service between West Coast ports, the Midwest, and the East Coast. Terminals must now meet the challenge and provide efficient, high-throughput, low-cost facili-
ties.

Changes in Container Dimensions

APL's June 1985 exhibition of the 48-ft container has been followed by an order for 1,500 units by International Containers Limited of Hong Kong. The geometry of the 48-ft box is 9 ft 6 in. (height) by 8 ft 6 in. (width). The purchase calls for 1,400 smooth-skinned units for the domestic market and 100 experimental marine containers incorporating corner wells or depressed chassis. It is planned to build these containers in selected prepositioned yard areas. Making changes in aisle widths and hostler pathways of terminal layout dimensions may not be required, depending on the equipment and existing terminal layout dimensions, thus allowing the 45-ft containers to be mixed with conventional containers in the terminal.

Dimensional stability of containers in the future is uncertain. Future directions may include the ever-increasing demand for higher than high-cube containers with heights of 10 to 12 ft, perhaps in wells or depressed chassis. Chassis lengths of 56 ft (to accommodate containers longer than 48 ft) could provide future transport advantages. Clip-on rail bogies to convert conventional chassis to rail-suitable equipment is an interesting concept that is currently being investigated. The industry is faced with continual container dimension change pressures that will significantly affect the geometry of equipment and the layout of marine and rail transfer facilities.

Changes in Terminals and Support Facilities

Intermodal terminal gate geometry is one of the most critical elements in the overall throughput capabil-
ity of a terminal. High-volume marine terminal gate facilities are being enlarged, in terms of both size and the number of gates to minimize throughput bot-
tlenecks. Remote "precheck" stations, with audio-
visual and computer communication links, are trans-
mitting information, including truck scale readouts, to personnel at main entry gate complexes in some facilities. Automated computer-controlled overhead markings bridge structures are being used to control truck traffic on a day-to-day or hour-to-hour basis, thereby allowing ultimate flexibility for inbound truck lanes to match shipper needs. Eventually, com-
puterized transponder identification technology may assist in the identification and processing of in-
bound truck documentation at truck traveling speeds without any need for the truck to stop in the inbound entrance area.

In recent years the high-speed truck lanes that lead directly from the gate to the wharf could increase terminal efficiency particularly for late arrival situations. Changes in planning and design features for container freight stations (CFSs) are also taking place. In some cases there is great demand for direct cargo transfer using transfer docks to handle full container loads (FCL);
in others, less than full container loads (LCL), also requiring across-the-dock direct transfer facilities, are a priority. The desirability of immediate access between marine container terminals and the CFSs can reduce drayage and labor transfer costs, is often constrained by labor union requirements. These concerns sometimes result in construction of off-dock facilities.

Marine terminal planners are also responding to the "just in time" distribution network system whereby cargo is moved to final destinations in a carefully timed, steady flow in order to minimize congestion at intermediate and terminus points. This demand for carefully scheduled cargo distribution will greatly affect planning for future CFSs and direct transfer docks on and off intermodal facilities.

To reduce construction costs in multiple terminal configurations, terminal building facilities that straddle adjacent terminal boundaries are being constructed so that a single building with shared but separate tenancy is designed using a single utility distribution service system for both terminals, thus reducing construction and utility costs. Improvements in computerization of cargo-handling operations are continuing to improve terminal throughput. Systems are being developed that use ultrasonic methods to determine optimum work paths for equipment and machinery. These systems provide faster and more accurate data transmission between control centers and handling units. Some microcomputer systems at marine container terminals are reported to be able to increase container crane handling capability from an average of 22 to 35 or more units per hour. These improvements can be achieved by cutting average duty cycle time from 95 to 60 sec and increasing trolley positioning accuracy (5). Other computer systems will provide complete inventory control with detailed records on the status of both imports and exports from the moment a record is created until the cargo leaves the facility. A computer monitoring system will provide immediate reports on the condition of automatic equipment by giving readings for such key factors as equipment bearing wear, power surges, and fluid levels. Automated ship planning systems may eliminate multiple yard moves. These systems can also provide the ship's master with detailed center of gravity, torsion, and longitudinal and lateral vessel stress variations. Eventually maintenance computerization, permitting equipment to be used for longer periods of time, and planned maintenance periods and maintenance shutdowns will be incorporated into the planning and operation of container terminals. To illustrate some of the factors that influence modern intermodal container terminal planning and design criteria, the planning for the new San Francisco Container Terminal (SFCCT) will be described.

DESCRIPTION OF THE SFCCT PROJECT

As a result of the early conceptual planning studies and the detailed engineering feasibility reports performed by Vickerman-Zachary-Miller from 1981 to 1984, the Port of San Francisco has embarked on a major expansion and modernization program of their southern waterfront container facilities. The SFCCT comprises two terminal areas, referred to as the North Terminal, formerly Pier 80/Kmz Street Terminal, and the South Terminal, comprising Piers 88-96. The purpose of the modernization program is to renovate the existing facilities into state-of-the-art intermodal facilities consisting of

• A modern "on-dock" ICTF rail facility capable of accommodating unit train activity to be located in close proximity to both the North and South marine terminals.
• An intermodal rail and truck bridge spanning a navigable waterway to improve truck and rail access between the North and South terminals.
• Modern container terminals resulting from renovation of existing South Terminal facilities.
• A renovated North Terminal to accommodate current users, to be created by demolishing existing shed facilities and constructing new container terminal improvements.
• A CFS with both rail and truck access and significant expansion potential.
• An internal traffic circulation system permitting on-dock rail-to-ship access among the ICTF, CFS, and both North and South container terminals.
• A centralized gate facility for the South Terminal through which all terminal truck transit is controlled.

Figure 1 shows the location of the SFCCT on the southern waterfront of the Port of San Francisco. Figure 2 is a vicinity map for the major project elements in the SFCCT.

Major Project Elements
North Terminal

The existing SFCCT North Terminal, a 70-acre site, currently handles break-bulk, roll-on/roll-off (RO/RO), combo, and containerized cargoes and is well suited for renovation. The port intends to accommodate current users and steamship lines already calling at the terminal facility by making phased improvements that will not affect current operations. The major container ship company currently using the North Terminal recently made final plans to expand and modernize its present fleet. Several new full cellular C9 container vessels with a capacity of more than 2,500 TEU are expected to begin arriving in 1986; these vessel arrivals were incorporated into the planning and design of the terminal. The significant background information was developed during the early planning studies. Interviews were conducted with all terminal users to incorporate their immediate and future needs into the design criteria. Anticipated needs of new operators were investigated, and terminal expandability and flexibility were included as a primary design objective in order to meet these needs. Alternatives for expansion were carefully evaluated in order to provide guidelines for initial construction. Layouts of wharf and backlands were prepared using various configurations for different modes of container handling. Several alternative layouts were devised to accommodate long-term future expansion schemes.

The near-term needs for this facility include

1. Two efficient container ship berths, along with associated backlands, a reasonable mix of chassis and stacking operations, and a mix of storage spaces for 20-, 40-, and 45-ft containers.
2. A RO/RO berth with adjacent covered storage to suit steamship line requirements.
3. A berth for combination container and break-bulk vessels with adjacent covered storage.
4. Additional site features such as railroad access and two new one-story marine buildings for longshoremen and administration.
5. A railroad and truck bridge link to the ICTF directly across a navigable waterway.

Immediate construction recommendations also included filling and leveling pavement that has sustained ma-
ior settlements of approximately 8 ft; evaluating the feasibility of using a concrete paving block surface treatment in fill areas; modernizing facility lighting; improving electrical, mechanical and utility systems; and renovating the existing entrance facility to alleviate inbound traffic congestion. Figure 3 shows existing terminal conditions.

Recommended conceptual plans for the future include the "potential expansion plan" (Figure 4) and the "potential ultimate expansion plan" (Figure 5); the latter requires port acquisition of adjacent non-port-controlled properties. The potential expansion plan provides for the addition of a third renovated berth by the partial demolition of a transit shed and the expansion of the backlands to service this berth. The potential ultimate expansion plan includes the addition of a fourth berth, removal of all remaining transit sheds, addition of a CFS, expansion of existing maintenance buildings, expansion of terminal entrance facilities, and expansion of the intermodal rail and truck bridge.

Figures 6 and 7 show the general equipment and wharf section for the recommended project and the operations plan for the North Terminal.

South Terminal

The Southern Waterfront Master Plan of the Port of San Francisco, for the initial development of the Port of San Francisco's SFCT South Terminal, encompasses the following elements:

- Add one additional container terminal facility (Berth 92) and renovate and modify two existing berths (94 and 96) to provide a modern container terminal facility.
- Provide a state-of-the-art ICTF for rail operations in close proximity to the SFCT facility utilizing planned track realignments.
- Retain the function of Berth 90 as a grain and liquid bulk terminal until implementation of future planned improvements.
- Develop an SFCT centralized check-in/check-out facility for control of terminal operations.
- Implement an internal traffic circulation system permitting on-dock access to the ICTF and CFS from the container terminals.
- Provide a new CFS with future expansion potential in close proximity to the container terminals.

As shown in Figures 8 and 9 the projects planned for the South Terminal include

- Wharf: A new concrete wharf with all-vertical 24-in. prestressed concrete octagonal piles. Pile driving is done into existing subgrade material that is prepared by using a vertical drain or wick system to increase the strength of the existing subgrade material.
FIGURE 2  SFCT project vicinity map.

FIGURE 3  North Terminal, existing conditions.
material. The wharf includes a walkway and mooring dolphin. Complete utility systems including cathodic protection are planned. The wharf includes a modern marine fendering system to accommodate new container vessels.

- Backland area: The container yard backland area comprises approximately 47.6 acres immediately adjacent to the existing backland area of Berth 94. The subgrade is designed to accommodate heavy-duty wheel loads. Initially, a flexible asphalt pavement accommodates a chassis mode of operation with the option of increasing asphalt depth to allow greater wheel loads in the future. The terminal area includes approximately 6.7 acres of bay fill. Complete utility systems, area lighting, and refrigerated container storage outlets are included.

- CFS area: A 52,800 ft² (gross) CFS with transfer dock facilities and future expansion capabilities will be constructed.

- ICTF: Approximately 33.44 acres of ICTF including railroad trackage will accommodate land bridge rail operations.

  - Centralized check-in/check-out circulation road areas: The design includes approximately 16.45 acres of roads and entry and parking areas. The entrance requires relocation of the existing lighter-aboard-ship (LASH) terminal.

  - Modification of existing berths 94-96: Modifications include
    a. Demolition of the existing Berth 96 container freight station building.
    b. New rail trackage to allow high, wide, and heavy loads access to wharf areas.
    c. Modification and conversion of the existing crane electrification system to a 2400-volt system.
    d. Removal or relocation, or both, of existing reefer outlets from the Berth 94 backland area.
FIGURE 5 Potential ultimate expansion plan for North Terminal.

FIGURE 6 North Terminal general equipment and wharf section.
Design Issues

e. New wharf fender system compatible with the new fender system at Berth 92.

ICTF

The Engineering Feasibility Study for the South Terminal included a determination of the economic and engineering feasibility of an on-dock ICTF. To meet modern rail operation requirements and the marketing guidelines of the port, the ICTF was planned to meet the following criteria:

1. Operation as an on-dock facility.
2. Utilization of existing land to construct an efficient, operational, and long-term intermodal rail facility.
3. Expansion capability to meet projected market demand for ICTF utilization.
4. Construction of facilities to reduce drayage and transfer costs associated with other rail container movements.
5. Access via existing rail and truck routes.
6. Efficient circulation patterns within the ICTF with emphasis on cargo throughput and safety.

Operation schedules and train frequency will determine actual throughput capability of the ICTF. The most critical operational requirement is to minimize the number of handlings and movements per container unit. This was envisioned as being accomplished with yard hostlers who would bring the containers to the facility and position them at the outbound staging area adjacent to the working track. If this is not possible, the hostler could then position the containers in the storage area. The four basic operating methods evaluated for the ICTF were

- Direct staging, without storage transfer from chassis to rail car, using hostlers and road tractors.
- Prestaging transfer from prestaged chassis (before train arrival) to rail car; no tractor required.
- Remote storage outside immediate ICTF using hostlers or road tractors (longer turnaround time).
- Center storage within ICTF using yard hostlers (short turnaround).

The ICTF was planned to accommodate COFC and TOFC operations. The master plan postulated the use of two rubber-tired, mobile bridge cranes per working track for lifting containers on and off rail cars and the provision of two runaround tracks. Entry and egress for the ICTF is through one of two gates. An internal terminal check-in/check-out area allows containers to be transferred to the ICTF from the container yards by yard hostlers while remaining within the customs secure area. Figure 10 is an artist’s conception of the ICTF project.

ICTF Railroad Access

Investigations were conducted to evaluate the railroad infrastructure leading to the port complex in order to determine impacts on future SPCT development. In-depth feasibility studies were conducted to evaluate tunnel and bridge restrictions and to determine the practicality of modifying or reconstructing tunnel clearances to accommodate new double-stacked container rail cars and other specialized high, wide, and heavy rail car operations. Additional studies were undertaken to evaluate trackage alignment and grade for suitability for connecting marine and intermodal rail facilities with main-line railroad operations.

The tight clearances of Tunnels 3 and 4 on the Southern Pacific main-line approach into San Francisco are well known to Bay Area railroaders. The clearance diagrams for both of these tunnels relative to the double-stacked rail car configuration are shown in Figure 11. Because double-stacked cars and

FIGURE 10 Artist’s conception of ICTF project.
other specialized rail cars will not meet the minimum clearance requirements for the tunnels, several modification schemes were considered. One scheme centers around a gauntlet track arrangement, with a third track constructed between the existing two tracks. Installation of signal systems could allow passage of a single train through the center of the tunnel, with the central crown of the tunnel providing the required clearance. The second scheme involves removing the existing concrete invert and reconstructing a lower invert (Figure 12). A summary of the phased construction approach is shown in Figure 13. The method proposed for lowering the rail elevation was to remove the ballast material down to the concrete invert, and demolish the concrete invert with no further excavation. A new concrete invert, approximately 1-ft thick with reinforcement, could be constructed. The rail could then be attached directly to the concrete with rail clips. This method was used successfully in constructing the Bay Area Rapid Transit (BART), a heavy rail rapid transit system. However, it was concluded that use of the much heavier rail cars loaded with freight would crush the isolation pad on the rail clip and cause structural damage to the concrete.

This view was supported by the Southern Pacific Railroad, who confirmed that the commuter train line uses rail cars that would cause such damage. (Several sections with direct concrete fastening systems were tested by the U.S. Department of Transportation on
the Santa Fe Railway in Kansas during 1972-1973. In all cases, the tested section failed after a period of several days under normal freight traffic.)

It was decided that realignment of the rail line through the Hunter’s Point shipyard with direct access to the ICTF would involve extremely high cost and other inefficiencies. Reconstructing the tunnels with a higher clearance arch was rejected on the basis of economic, operational, safety, and time constraints.

The proposed solution to modification of the tunnels is one of two alternatives, both of which result in removal of the existing ballast and the 2-ft-thick reinforced concrete invert:

- Alternative A: After removing the concrete invert, excavate approximately 1 ft to 2 1/2 ft of rock or soil. A new reinforced concrete mat with appropriate drainage would provide the base for the new ballast of the rail track.
- Alternative B: Remove approximately 1 to 2 ft of earth (after removal of the invert) and recompact the earth. Place a track stabilization geotextile fabric over the subgrade material. (Southern Pacific is currently using track stabilization fabrics in similar tunnel conditions with satisfactory results.)

To accomplish this work, the double-track main line would be single tracked during the construction period.

When the lowering of the tunnel is completed, the ballast section in Tunnels 3 and 4 would be renewed. Single-tracking could be accomplished by using present crossover switches. All construction work on the tunnels should be undertaken during night hours (7 p.m. to 5 a.m.) and weekends to avoid interference with commuter traffic.

These tunnels were built in 1905-1906, and it is believed that there is no reinforcing in the construction. The tunnel wall footing should be excavated an additional 2 ft by excavating a 10-ft section and leaving an undisturbed 10-ft section. After the exposed sections are cast and set up, the intervening sections would be opened up and cast.

Alternative A involves excavating an additional 12 to 14 in. (to ensure proper clearances) and placing a 12- to 18-in. reinforced concrete invert. Panels would be replaced and the track raised on ballast.

Alternative B involves the use of geotextiles that allow for quicker, less costly construction and afford better drainage. Tunnel 4 and the southern half of Tunnel 3 are laid on a 0.3 percent grade that descends to the south. The northern half of Tunnel 3 is on a 0.10 percent grade that ascends to the south. These grades will provide adequate tunnel drainage through the drain pipes. Figure 13 shows the proposed construction sequence for the tunnel invert lowering.

FIGURE 13 Proposed tunnel construction sequence (invert-lowering scheme).

IMPEDEMENTS TO THE APPLICATION OF CURRENT INTERMODAL CONTAINER TERMINAL PLANNING AND DESIGN TECHNIQUES

The designer of a modern intermodal marine facility must consider a multiplicity of factors that challenge a successful planning effort. Installation of huge paved parking areas; goliath cranes; and a variety of mobile loaders, gantries, and lifts does not automatically ensure efficient container terminal operation. These are often the cause of increases in container terminal throughput costs, and large container terminal areas can be a deterrent to efficient container handling. State-of-the-art design must capitalize on modes of operation that move containers from entry to storage areas to ship or rail loading cranes and vice versa as quickly and efficiently as possible at low capital cost.

The designer must be sensitive to the need for future changes in terminal configurations. Designs must accommodate factors as diverse as changes in terminal boundaries, future terminal operator requirements, and advances in modes of operation. Lack of design flexibility can create significant down-line costs for frequent modification to facilities.

Factors as diverse as pavement durability, union work rules, ease of maintenance and upkeep of reefer outlets, protection of utilities from traffic damage, worker safety, and facility security must all receive
appropriate design treatment. Relationships among building structures are vital to proper operation and future expansion. For instance, the orientation of a roadabillity canopy must be planned so that out-bound trucks can easily maneuver adjacent to the canopy and yet be close enough to the equipment maintenance garage for necessary tire changes and minor repairs.

Existing infrastructure constraints further challenge the marine facility designer. Lack of suitable track curvature and proper clearance in railroad tunnels and bridges such as is currently confronting the Port of San Francisco is a serious impediment to rail service access.

Cost constraints and unanticipated environmental impacts can cripple even the best planning effort. The marine terminal facility owner must ensure sufficient funds for the project, including such things as unforeseen site conditions. The intermodal facilities designer must keep the realities of facility costs in mind and yet plan a facility designed to achieve anticipated throughputs and the flexibility to accommodate the current and future pressures of fully intermodal service.

REFERENCES