basis. On a "maximum" cost basis, however, the service is unprofitable at all rate levels.

Chicago-Houston City Pair

The long distance between Chicago and Houston distinguishes this city pair from the other two. Although both rail and truck service tends to be fairly good, a reliable TOFC shuttle train service is believed to offer some improvement in service over both. Despite its long distance, the traffic between this pair of cities is fairly heavy—roughly the same as between Philadelphia and Cleveland. One might speculate that the economies of rail line-haul operation would make a TOFC shuttle train a profitable undertaking between this pair of cities.

Figure 4 presents the comparison of revenues and costs at various rate levels for the Chicago-Houston TOFC shuttle train service. The almost horizontal revenue curve indicates an elasticity of demand near one, although revenues do drop off at higher rates. Like the previous two city pairs, the service does well on a "minimum" cost basis. Profitability is achieved on a "maximum" cost basis only at fairly high rate levels. At a rate of $915/trailer, the service yields a profit of $430 000/year.

Comment

Perhaps the most striking thing about these results is the differences in estimated demands between city pairs and the different responses of these demands to variations in rates. Clearly, the nature of freight transportation markets varies greatly. It is important to have demand forecasting methodologies for production use that take into consideration the characteristics of individual freight transportation markets.

CONCLUSIONS

This study has illustrated the application of equilibrium analysis to a TOFC shuttle train. This same type of analysis could be applied to the pricing of most any freight transportation service, or to other characteristics of the service as well. In fact, the authors have used essentially the same models presented here to compare shuttle trains using several alternative types of container-on-flatcar technology (4).

The results suggested here are somewhat counterintuitive but reasonable considering the service that was assumed. The results suggest that profitability for this TOFC shuttle train will be achieved, if profitability is possible at all, by operating a low-volume, high-rate service. At profitable rates, the Philadelphia-Cleveland and Chicago-Houston services would carry only 13 and 21 trailers a day, respectively. This differs from the more conventional concept of a TOFC shuttle train service, such as the "Slingshot," which emphasizes low rates and high volume. It would be interesting to repeat this analysis assuming a lower cost, but slower, less reliable service. It is possible that such a service might prove more profitable than the premium service hypothesized here.

These models have allowed us to understand the consequences of the multitude of individual firm decisions that will determine the market for a service. As such, they represent a considerable advance over other methods, such as aggregate econometric models, which require gross assumptions about the relationship of transportation demand to the economy of a region. Better industry data, production-type demand models, and the development of techniques to deal with the entire transportation network are imperative before large-scale implementation can begin.

ACKNOWLEDGMENT

The research described in this paper was sponsored by the U.S. Department of Transportation, Office of University Research.

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Publication of this paper sponsored by Committee on Intermodal Freight Transport.

Economics of Improved TOFC/COFC Systems

Robert H. Leilich, Peat, Marwick, Mitchell and Company, Washington, D.C.

The success of future rail intermodal traffic hinges on satisfying demand, meeting new market needs, and realizing railroad profit objectives. To look at these opportunities, the Federal Railroad Administration has sponsored several major ongoing intermodal studies to

evaluate current, proposed, and needed technologies to achieve those ends. This paper summarizes a portion of a preliminary study conducted by Peat, Marwick, Mitchell and Company to examine the economics and markets of current, proposed, and conceptual systems. It analyzes current and proposed systems and how each ranks with respect to one another, common motor carriers, and owner-operators. Study findings are encouraging and suggest opportunities for more cost-effective systems and more market-responsive service capabilities. Contemporary costing procedures plus specially developed life-cycle costing and terminal models were used. Many unit costs were developed on an engineered basis. The Bimodal Roadrailer emerged as a promising new system. The Santa Fe "Ten Pack" and Paton Low-Profile system proved superior as improvements to current trailer-on-flatcar systems. The Southern Pacific Double-Stacked Container Car offers the greatest promise for container-on-flatcar systems.

The growth of trailer-on-flatcar and container-on-flatcar (TOFC/COFC) traffic reflects the ability of railroads to provide highway-competitive service. Next to coal, it is the largest and fastest-growing railroad traffic.

In contrast to coal, most railroads do not regard intermodal traffic as highly profitable. Only western roads, on long hauls of more than 2400-3200 km (1500-2000 miles) claim that intermodal traffic is an important contributor to profits. Although highway competition establishes the upper limit of pricing, it is not always the regulated common carrier that establishes that umbrella.

Under a strongly competitive price umbrella, attributable costs become the principal factor driving profitability. Figure 1 depicts the approximate Rail-Form-A-developed cost structure of TOFC service for each of five major rail cost territories for lengths of haul between 480 and 1600 km (300 and 1000 miles). (Because we will be looking at intermodal alternatives on a comparative basis, Rail Form A is adequate for this purpose even though Rail Form A has some deficiencies.) This exhibit shows the major cost factors, prepared from unit costs developed by the Interstate Commerce Commission. Note, particularly, the major portion of costs that are not distance related.

Costs of rail intermodal service are characterized by high terminal costs—as much as 70 percent of total variable costs at 480 km—and a relatively low-cost unit rate for line haul. The opposite is true for motor carriers. Figure 2 compares rail intermodal costs to the cost structure of common carriers and the owner-operator or private fleet operator. In the latter case, most owner-operators perceive their terminal costs as nearly zero; as a consequence, they tend to price their services accordingly. The wide range of motor carrier costs is influenced by wide variations in labor cost, vehicle use, and operating efficiency. Figure 2 stresses the high crossover point between rail intermodal costs and highway costs. Most alarming is that the efficient owner-operator is competitive with rail intermodal at almost all lengths of haul.

The greatest need in rail intermodal services is to reduce costs, preferably in both terminals and in line haul. Reducing terminal costs reduces the break-even distance compared to highway. Reducing line-haul costs does the same thing but also increases the advantage of railroads with distance. Emphasis on one or the other is influenced by the market in which a carrier competes. Western railroads by virtue of their long line haul should logically concentrate on reducing line-haul costs. Eastern railroads, limited to a shorter-haul market, should investigate better ways to reduce terminal costs. Of course, achieving both is most desirable.

The Federal Railroad Administration (FRA), with the support of the Association of American Railroads and others, has embarked on a series of research efforts to improve the profitability and, hence, marketability of rail intermodal service. One of these research efforts was devoted to examining the economics of current, proposed, and conceptual systems.

The average length of haul for all intermodal traffic in 1976 was estimated at 1798 km/t (1013 miles/ton) from the FRA One Percent Waybill sample. A significant contributor to this high average length of haul is the large volume of traffic moving in the more than 3200-km (2000-mile) block. Excluding the high concentration of intermodal traffic in this category, the average length of haul was 1404 km/t (791 miles/ton).

ECONOMIC ISSUES IN SYSTEMS EVALUATION

The evaluation of alternative systems to reduce intermodal costs should focus on equipment use, equipment value, cost of capital, terminal and origin-destination costs, and line-haul costs.

Equipment Utilization

Freight car trailer/container and other intermodal freight system component use has a major impact on transportation costs in that many of the equipment-related costs are relatively fixed in the short term (though all rolling stock and nonfixed equipment costs are considered to be variable in the long run) and must be distributed over the number of revenue shipments that each equipment component handles. In cost evaluations it is not always appropriate to use historical data in distributing or assigning equipment costs to particular traffic, especially in improved technological, operational, and institutional environments.

Equipment Value

Equipment ownership costs make up a sizable portion of rail transportation costs. Critical to evaluation of intermodal freight systems is the proper recognition of the value (current or replacement) of the equipment being used.

Cost of Capital

Cost of capital is a well-recognized economic cost. In capital-intensive systems with long economic life and slow capital recovery (7 years and more), the cost of capital is a major factor in evaluating system alternatives. This cost should include costs of both debt and equity capital.

Terminal and Origin-Destination Costs

Rail Form A and most other costing methods separately recognize the following: specific major intermodal cost elements origin-destination switching, tie-untie (loading and unloading) costs, pickup and delivery, interchange switching, intermediate switching, station clerical, special services, and highway interchange.

Line-Haul Costs

Similarly, Rail Form A and most other costing methods provide for separate calculation or recognition of these line-haul costs and influencing factors: train tonnage (way and through train), number of locomotive units (way and through train), empty return ratio (flatcars), tare weight (flatcars and trailers), empty trailer dis-

Figure 1. TOFC/COFC variable origin-destination and line-haul expenses for selected territories at January 1978 cost levels (developed from Rail Form A).

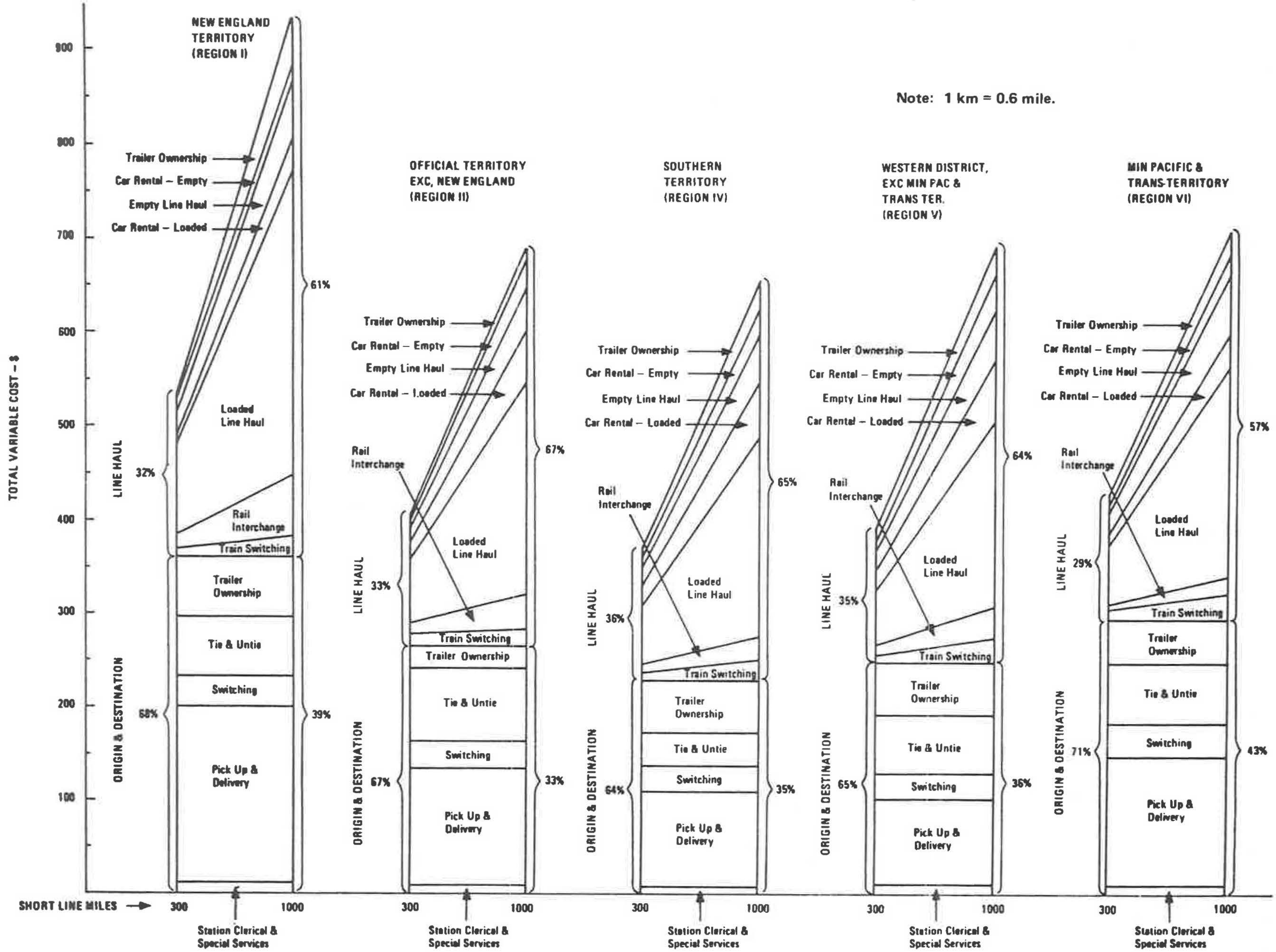
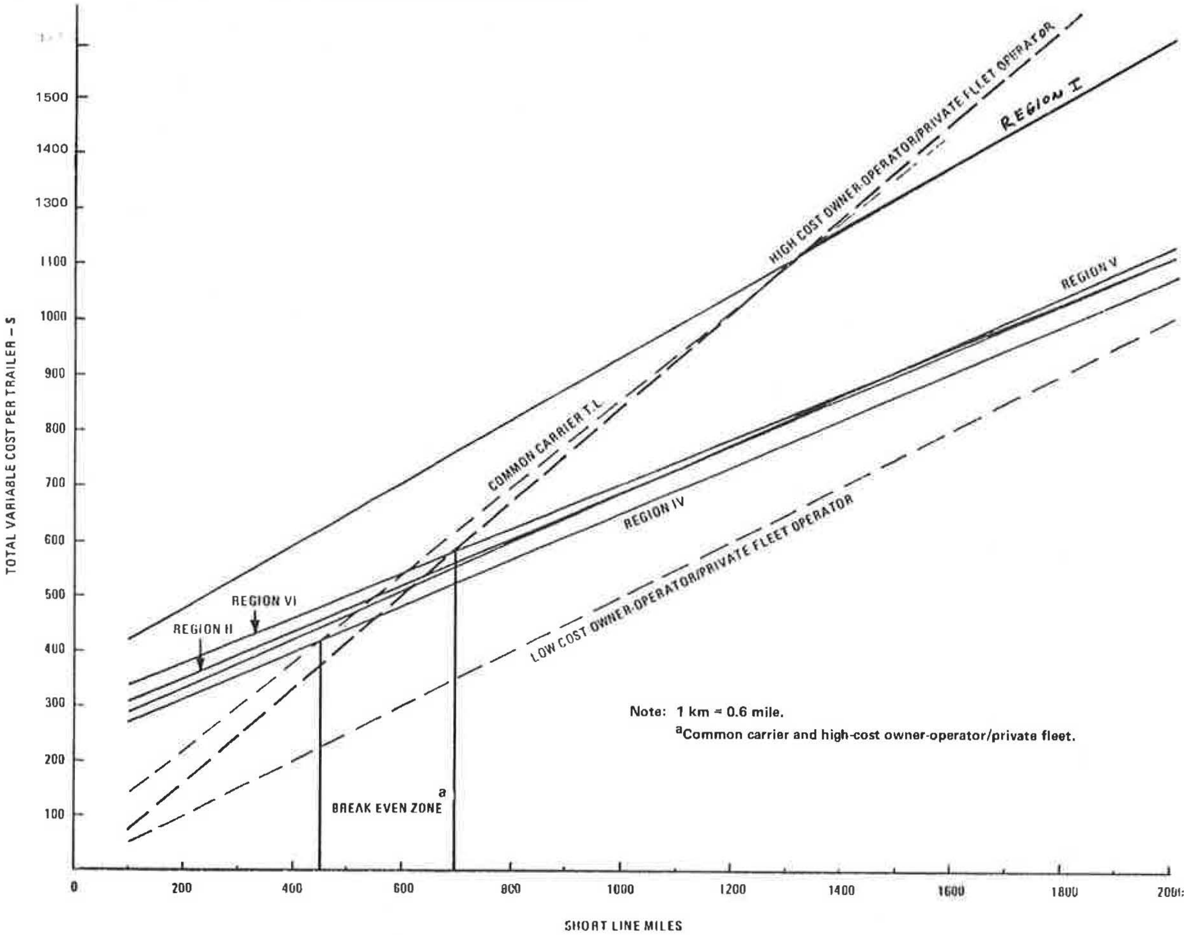


Figure 2. Comparison of rail intermodal costs to the cost structure between common carriers and owner-operators/private fleet operators for a single trailer shipment at January 1978 cost levels.



tance ratio, number of trailers per flatcar, and distance circuity. Each of the costs described here was considered in evaluating improved or potential intermodal systems alternatives.

SELECTED INTERMODAL ALTERNATIVES

Although this study evaluated hundreds of intermodal system concepts and combinations of intermodal system components (such components as lifting cranes, hostlers, and flatcars), the following basic system alternative concepts appeared to be the most promising:

1. Bimodal Corporation Roadrailers—highway trailer equipped with one pair of steel-flanged wheels and couplers for assembly into a "train";
2. Santa Fe "Six Pack"—articulated flatcar that carries one trailer on each articulated section (proposed to be built as a "Ten Pack" when in production);
3. Southern Pacific Lightweight Articulated Equipment—handles containers or trailers [a second concept is an articulated double-stacked container car holding a total of six containers; a third concept is a two-section dual-purpose articulated car that would carry two 12.1- or 13.6-m (40- or 45-ft) trailers or three 12.1-m (40-ft) containers];
4. Trailer Train Prototype TOFC Car—two-unit semipermanently coupled flatcar, four single axles per two-unit car, with each unit holding one trailer up to 13.6 m long;
5. Paton Low-Profile Rail Car—low-profile, lightweight, three-unit articulated rail car to transport conventional trailers and/or containers; and
6. Shannon Side Drive-On—flatcar with swinging "trays" on which to park or remove a trailer.

SYSTEM EVALUATION

Each of the systems was evaluated in 12 basic environments that attempted to characterize short- and long-haul situations under widely different traffic volume levels. The purpose of selecting these environments was to provide a baseline set of conditions against which promising improved and innovative systems would be evaluated.

A life-cycle cost model was constructed to calculate transfer cost (tie/untie) per trailer or container that would result for each combination of environment, terminal concept, and car/trailer/container concept; the rail car "rental" cost per kilometer; and the trailer/container per-diem cost. Calculations are performed on an after-tax basis and account for the following:

1. Cash flows associated with initial capital outlays and the annual servicing of that portion of initial capital outlay financed by borrowing,
2. Investment tax credit,
3. Corporate income tax shield provided by depreci-

ation charges over the accounting life of the investment,

4. Corporate income tax shield provided by interest payments on the portion of the capital investment financed by debt,

5. Cash flow associated with salvage of the capital investment at the end of its economic life, and

6. Operating and maintenance cost per trailer or container (which is added to the equivalent investment cost per trailer or container to determine total transfer cost per trailer or container).

A terminal cost model was constructed that incorporated land, operating, and maintenance costs associated with different systems in each of the proposed environments. Principal categories of TOFC/COFC terminal labor were separately recognized. A separate cost calculator was used to develop line-haul costs.

Noneconomic criteria were included in the systems analysis of each alternative, using a weighting and ranking procedure that converted economic and noneconomic factors into a score. Each factor had a maximum score of 10. Factors were then weighted in proportion to relative importance to each other so that the maximum perfect score was also 10.

EVALUATION RESULTS

Most systems retained their ranking at both long and short hauls with several exceptions.

The Shannon system suffers a line-haul weight and maintenance cost penalty at long distances. The double-stack container car, the best of all container systems studied, gained in economic ranking over longer hauls due chiefly to lower tare ratios and shorter train lengths for a given number of shipments. (This is a distinct plus on high-density lines where train lengths must be limited.)

Surprisingly, trailer systems are generally less costly than container systems. The extra tare and transportation cost of line haul is not enough to offset the generally higher terminal costs (usually double the costs of handling of container car to storage of the chassis and vice versa) and the cost of equipment support needs (chassis).

Five systems that were recommended for further FRA analysis are discussed here.

Bimodal Roadrailer

The Bimodal Roadrailer ranked at or near the top with respect to almost any evaluation criteria except line-capacity considerations. Although potentially the most attractive of all systems analyzed, there is some uncertainty associated with this concept that only can be resolved through field and in-service testing. Field and in-service road tests for this equipment are currently in progess at the U.S. Department of Transportation's Pueblo (Colorado) Test Track. The results of all tests have met or exceeded expectations. The advantages of the Bimodal Roadrailer are as follows:

1. A cost per shipment saving of up to 20 percent compared to conventional TOFC service is possible.
2. The concept required substantially less investment in motive power and no investment in flatcars, at the price of a reportedly nominal increased investment in trailers.
3. The Roadrailer does not require mechanized lifting techniques, ramps, or even special intermodal terminals.
4. Operation with a two-person crew and with no caboose is feasible.
5. The Roadrailer concept has the best clearance characteristic of any concept reviewed.
6. The Bimodal Corporation claims that the lack of operational compatibility is an asset in that running the Roadrailer in designated trains may result in improved service and help control loss and damage due to reduced switching and train handling.

The Roadrailer has the following disadvantages relative to other concepts:

1. Analysis shows that the cost of ownership is still relatively high compared to other system alternatives.
2. The Roadrailer is limited to shorter train lengths, with higher line-haul costs per trailer kilometer offsetting some of the line-haul savings associated with no flatcars and a 50 percent reduction in the number of axles and wheels per trailer.
3. There are potential operating problems by railroads that have severe line-capacity problems.
4. There is some inherent railroad industry resistance to such a major concept change in operations and practices.

There are a number of minor constraints associated with the implementation of the Roadrailer, but none of them appear to be a major inhibiting factor sufficient to preclude the introduction of this service, should its technical feasibility be proven in an actual operating environment.

Santa Fe Ten Pack

Based primarily on characteristics of economically lower cost per shipment compared to other systems (except Roadrailer), the Santa Fe Ten Pack is the most attractive concept for trailer-only traffic in high-traffic-volume corridors. The primary advantages of the Santa Fe Ten Pack are

1. The saving per shipment for the Ten Pack is second only to the Roadrailer, offering potential cost savings of 15 percent over the baseline case at long line-haul distances;
2. The net-to-tare ratio and aerodynamic drag characteristics of the Ten Pack make it an attractive rail vehicle to use in rail line-haul service;
3. Articulation (as claimed by the Santa Fe) offers improvements in reducing loss and damage (due to the use of fewer cars) and in improved truck riding qualities (the Santa Fe reports no truck "hunting"); and
4. In 216 000 km (135 000 miles) of testing (as of January 1978), the Santa Fe reported that no significant structural or operational problems have occurred, thus suggesting the possibility of greater equipment reliability and lower maintenance and operating costs.

Disadvantages include the following:

1. The requirements for loading 10 trailers per car between origin and destination make it unattractive for use in environments where the volume of traffic is relatively small.
2. The Ten Pack requires lift-on/lift-off terminal capabilities.
3. Failure of one component of the car may cause the entire car, with 10 trailers, to be bad-ordered and set out, or require extra time from special facilities to remove or replace the bad-ordered section.
4. The Ten Pack car does not have the capacity to

carry containers except in a container-on-chassis configuration.

The only constraint noted is the logistics needed to support the use of this technology, at least until the use of such equipment is common (although a number of components are standard railroad hardware).

Southern Pacific Double-Stacked Container Car

The Southern Pacific Double-Stacked Container Car was tested for COFC-only traffic. The primary advantages of the double-stacked car are

1. The concept offered the best cost per ton (or shipment) of any container alternative examined;
2. The double-stacked car has the best net-to-tare ratio in line haul of any container concept tested (though the proposed Bimodal concept of container-on-Roadrailer chassis may be superior); and
3. The car has a higher "freight volume capacity rate" (net ton of freight per meter of train length) than any other system, increasing the number of units that can be handled for a given train length (this can greatly increase train capacity where train length is limited by siding length or signal spacing).

The disadvantages of a double-stacked container are

1. Mechanized lift capacity is required at both ends of the movement;
2. Although preliminary testing has proven the concept to be safe, under certain circumstances the car may have a very high center of gravity and reduced safety margins under adverse conditions; and
3. The clearance requirements are a major problem for operation of the double-stacked container in a number of major rail corridors, particularly in the Northeast (up to 9 percent of the track in major intermodal corridors would be unavailable to the double-stacked container concept).

If the ultimate articulated form of the double-stacked container car is built and operated, in addition to the constraints noted here, the car would be limited to relatively high-traffic-volume corridors in order to minimize unused car capacity.

An institutional constraint that may inhibit the use of a double-stacked container car is the persistent imbalance of container traffic in some corridors, which greatly increases the net cost per shipment moved.

Paton Low-Profile Rail Car System

The Paton Low-Profile Rail Car is the most attractive concept evaluated with a capability to carry either trailers or containers (though Bimodal is developing a Roadrailer chassis for containers). The Paton concept has the best clearance characteristic of any TOFC concept tested except Roadrailer, and it has the potential for operating in the Northeast corridor under catenary (though some third-rail clearance problems may exist). A significant technological innovation included in the Paton concept is the car truck that its inventor claims offers significant advantages over contemporary truck systems, including separability. The advantages of the Paton low-profile car include the following:

1. The Paton car has dual (trailer or container) capability.
2. The car is believed to have virtually unrestricted application over the entire railroad network.
3. The Paton truck may offer some improved benefits over conventional trucks, including separability at the articulation points for setouts.

Disadvantages of the Paton car include the following:

1. The concept is not as far advanced as the previous three concepts, and prototype construction and testing are needed.
2. The Paton concept requires mechanized lifts at both ends of the movement and, therefore, does not offer the flexibility to serve shippers at ramp terminals.
3. Insufficient data are available to truly assess the economics, maintainability, and operational performance of the Paton concept.

Other than competition with Trailer Train (see below), there are no other major constraints not applicable to other concepts discussed above that would inhibit the development and use of this concept.

Trailer Train Two-Unit, Prototype TOFC System

The Trailer Train two-unit, semipermanently coupled prototype TOFC car ranks very close to the Paton Low-Profile Car for TOFC service. As with the Paton concept, considerable technological risks exist, particularly those associated with a four-wheel concept.

The advantages of Trailer Train's proposed car are

1. The net-to-tare ratio is significantly improved.
2. The smaller-sized car (less trailers) results in less penalty than other articulated concepts when the equipment is removed from service.

The major disadvantages of the Trailer Train concept include the following:

1. Mechanized lift is required at both origin and destination.
2. The design is too conceptual at this time to adequately assess the economic merits of the system.
3. The potential four-wheel concept with axle centers of 10.9 m (36 ft) or more may create tracking problems on sharp curves (though Trailer Train may be able to solve this problem with an axle steering mechanism).
4. There is significant industry concern relative to the wheel size and track dynamics.
5. The concept offers little in the way of improved aerodynamic streamlining and significant reductions in overhead clearance.

If technically and economically practical, there are no major constraints that would otherwise restrict the use of this concept in specific intermodal system environments.

Publication of this paper sponsored by Committee on Intermodal Freight Transport.