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1. INTRODUCTION

EFFORTS TO REVITALIZE the U.S. rail system must consider the quality of rail service in addition to the widely publicized financial problems of the industry. In fact, rail service may be the key to effective solutions of the financial difficulties because service levels determine the competitive position of railroads relative to other modes, influence shippers as they relocate facilities and modify distribution processes, and determine whether railroads utilize their equipment efficiently. Unfortunately, the current level of rail service is rather low. During recent years, railroads have averaged only about 13 loads per freight car per year. Although this figure is depressed somewhat by seasonal use of equipment, Reebie Associates found that the average O-D trip time for loaded cars ranges from 6 to 11 days, depending on car type.[1] Not only is rail transportation slow, but it is also unreliable as documented in the MIT study of reliability sponsored by the Federal Railroad Administration.[2] For trips over the railroads studied, the average reliability was only about 85% as measured by the 3-day-%, the maximum percentage of cars that arrive in a consecutive three day interval of the trip time distribution. Since most trips involve two or more railroads, the typical 3-day-% for an origin-to-destination trip is likely closer to 70%.

The central thesis of this paper is that the U.S. rail system can provide a much higher level of service than that described above. In recent years, railroads, by introducing specialized equipment and operating unit trains, have already improved transportation service for certain commodities such as grain, coal, and automobile parts. Few commodities, however, and in particular few of the high-valued manufactured commodities now moving by truck, are shipped in sufficient volumes to justify such handling. For this reason, railroads should endeavor to create an integrated Interstate Rail Network, a network of high capacity freight yards connected by well-maintained rail lines; railroads could then develop and maintain a competitive route structure consistent with the changing service needs of the U.S. economy.

Discussion of an Interstate Rail Network (IRN) raises a number of transportation issues:

Capacity: How much of total rail traffic volumes should move over the proposed IRN? For maximum impact, the IRN should be able to handle a majority of the traffic that does not move in unit trains.

Coverage: Which metropolitan areas should be included in the IRN? Should coverage be uniform or concentrated in specific regions or along certain corridors?

Circuity: What are the trade-offs between costs associated with upgrading and maintaining a highly connected physical system and the operating costs associated with a circuitous system?

Scheduling: How should traffic be routed through the network so as to balance yard costs, train costs, maintenance costs, and performance considerations? Can a large number of individual railroads cooperate to provide the necessary service in a reliable manner?

Competition: Where should competitive service be offered? Should the competing lines use the same or parallel line and yard facilities? In lieu of competition, should specific routes be assigned to single carriers or should two or more parallel carriers provide coordinated service?

Intermodal Coordination and Competition: What is the role of TOFC/COFC operations in relation to the proposed IRN?

Clearly, these transportation issues are inseparable from many of the institutional and financial issues that will be discussed at the October 1974 session of the Transportation Research Forum. By focusing on service, the author hopes to bring attention to the impressive improvement in rail service that could follow a nation-wide effort to rationalize the U.S. rail system.

Without explicitly describing the physical characteristics of an IRN, the next section hypothesizes typical operating characteristics for a set of O-D moves over the IRN. Using the results of the MIT reliability studies, it is then possible to calculate the expected performance and level of service provided each O-D pair. In order to justify the hypothesized levels of service, the third section of this paper demonstrates that if traffic between major metropolitan areas moved on the most appropriate through trains, it would require relatively few intermediate classifications. However, closer consideration of the current situation identifies serious problems with interchanges, routing, and local distribution and suggests some of the steps necessary to create a true Interstate Rail Network.

2. SERVICE CHARACTERISTICS OF AN INTERSTATE RAIL NETWORK

In existing rail networks, an O-D trip begins when a local train picks up a car from industry and delivers it to a local yard for connection to a through train. If there were an IRN, this first through train would be a shuttle to a nearby IRN classification yard. Depending on the ulti-

Service Characteristics of an Interstate Rail Network

*by Carl D. Martland**†

mate destination of the car, it would move on a number of IRN trains until it reached the final IRN yard where it would be transferred to another shuttle train for movement to a local yard and ultimate placement for unloading. The IRN would provide faster and more reliable O-D service by assuring reliable train operations by concentrating traffic to allow frequent through train service at regular intervals, and by avoiding congested gateways and interchanges.

Given the number of intermediate yards, train frequencies, train speeds, and trip lengths, it is possible to estimate O-D trip times and reliability. Figure 1 hypothesizes what might be typical IRN routing characteristics for traffic moving between O-D pairs 250 to 3000 miles apart. For a 250 mile trip, cars would move from the first yard on a shuttle to the IRN yard, then on another shuttle to the final yard. This, of course, is only intended to be an average trip; some cars would move directly between the origin and destination yards, while others would require more than one intermediate classification. For longer trips, cars will move on IRN trains between as many as four IRN yards. Section 3 of the paper offers evidence that the scheduling assumptions in Figure 1 are reasonable.

Yard performance was estimated using models developed by Reid[3] and Kerr[4]; O-D performance was estimated as a function of the performance at each of the appropriate yards. The mean times for each yard (Table 1) were chosen to reflect typical mean train connection times noted during MIT's recent case study of the Southern Railway[5]. The origin and destination yards are assumed to be flat yards that have slightly better performance than the high volume IRN hump yards. The 2 to 3 hour processing time in Table 1 approximates the minimum time necessary to separate a car from an inbound train, classify it, and have it depart on an outbound train. In addition to this processing time, cars

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TYPICAL MOVEMENTS OVER AN INTERSTATE RAIL NETWORK

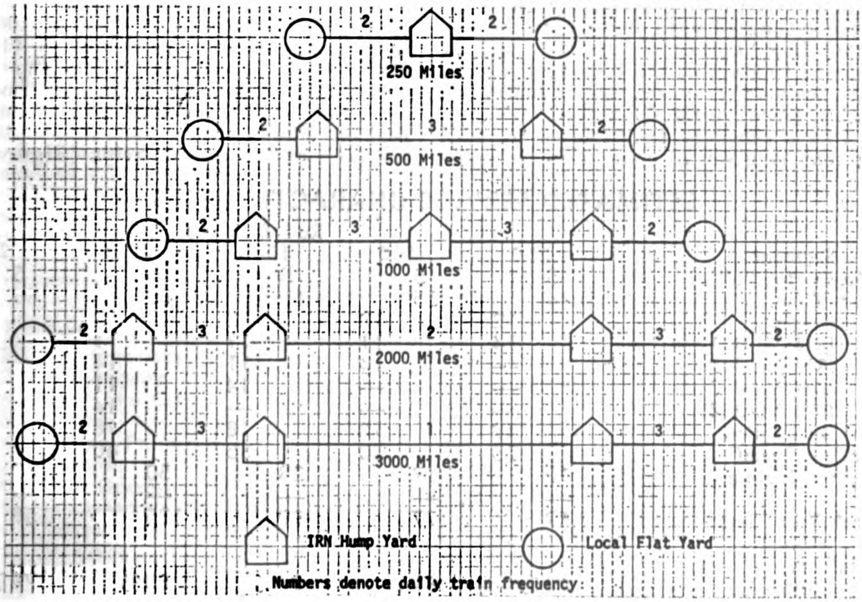

FIGURE 1

ESTIMATING YARD PERFORMANCE

Segment	Frequency	PMISS	Process time	Wait	Delay	Total Yard Time
Release - pull	1	.2	0 hrs	0 hrs	.2(24) hrs	5 hrs
Origin yard	2	.3	2	6	.3(12)	12
Destination yard	1	.2	2	12	.2(24)	18
IRN yard	1	.2	3	12	.2(24)	20
IRN yard	2	.4	3	6	.4(12)	14
IRN yard	3	.45	3	4	(A)	11

(A) .45[.8(8 hrs) + .2(16 hrs)] = 4.3 hrs

TABLE 1

must wait until the next train departs. If trains depart at regular intervals of X hours and if train arrivals are uniformly distributed throughout the day, then the average "scheduled wait" is X/2 hours as shown in Table 1. Finally, there is an additional "delay" because cars miss their most appropriate outbound connections with a probability PMISS, where PMISS is chosen to reflect typical values found in the MIT studies. The average delay equals the probability of delay PMISS multiplied by the interval between trains: as frequency increases, more cars miss connections, but they experience a shorter delay until the next train. When the frequency is three or more trains per day, some cars will even have a reasonable probability of missing a second potential connection as indicated by the calculation in note A of Table 1.

Using these simple yard performance models, it is relatively straightforward to calculate typical levels of O-D service for the trips shown in Figure 1. The mean O-D trip time is merely the sum of the estimated yard times plus the expected line haul time (the O-D trip is assumed to start at the time that a local train ordinarily serves the industry of origin; since locals do not always run on a fixed schedule, the "release to pull" segment is given a mean of 5 hours to reflect a .2 probability that the car will be delayed a day after it is released and before it is pulled.) The average train speeds given in Table 2, although higher than those currently attained by U.S. railroads, are not difficult goals for an Interstate Rail Network.

The reliability calculations are more involved, but still straightforward if it is assumed that delays at one yard do not affect delays at the next. In such cases, the joint probability distribution can be readily computed as a product of the delay distributions for the appropriate yards. For example, the expected delay distribution for the 250 mile O-D trip (Table 2) can be derived from the delay distributions for the release to pull segment, the origin and destination yards, and one intermediate IRN yard with an outbound train frequency of twice a day. The probabilities and lengths of delays for these segments are, respectively, (.2, 24 hours), (.3, 12 hours), (.2, 24 hours), and (.4, 12 hours). The probability of the maximum delay of 72 hours if all connections are missed is therefore .2(.3) (.2) (.4) = .0048; the probability of zero delays is (1-.2) (1-.7) (1-.2) (1-.4) = .2688; and the probability of a delay of any intermediate length can be calculated in a similar fashion. The resulting joint distributions for each of the sample trips (Figure 1)

ESTIMATED SERVICE CHARACTERISTICS

Segment	Rail Distance 250	500	1000	2000	3000
Release to Pull	5	5	5	5	5
Yard Time:	44	55	66	80	86
Origin	12	12	12	12	12
IRN Yard 1	14	11	11	11	11
IRN Yard 2	—	14	11	14	20
IRN Yard 3	—	—	14	11	11
IRN Yard 4	—	—	—	14	14
Destination	18	18	18	18	18
Average Speed	25	30	35	40	45
Line Haul Time	10	17	28	50	67
Total Trip Time (Hours)	59	77	99	135	158
Reliability (2-day-%)	92%	89%	87%	80%	79%

TABLE 2

TOTAL DELAY DISTRIBUTIONS FOR THE SAMPLE O-D TRIPS

	Total Delay in Hours							
Sample Trip	0	12	24	36	48	60	72	84 +
250 miles	**.27	.30	.20	.15**	.06	.015	.005	
500 miles	**.22	.29	.22	.16**	.08	.024	.005	.001
1000 miles	**.18	.28	.24	.17**	.09	.03	.008	.001
2000 miles	.11	**.24	.25	.19	.12**	.06	.016	.004
3000 miles	**.14	.22	.23	.20**	.12	.05	.03	.01

Probabilities may not add to 1.0 because of rounding.
Asterisks define the interval included in the 2-day-%.

TABLE 3

are approximated in Table 3 and were used to develop the expected 2-day-% for each of them as shown in Table 2.

Table 2 demonstrates the potential for improving traditional rail service through development of a coordinated route structure over an Interstate Rail Network. For the 1000 mile sample O-D pair, the estimated mean trip time is just about 4 days and the estimated reliability is about 90%, decidedly better than the current figures of about 9 days and 70% that were mentioned in the introduction. In short, railroads can offer a much higher level of service than they now provide, even without new technology or extensive inter-modal operations.

3. THE FEASIBILITY OF AN INTERSTATE RAIL NETWORK

This section presents an analysis of current rail operations as documented by train schedules listed in the November 1973 edition of **The Official Guide of the Railways.** This analysis shows that, in theory, the current rail service between major metropolitan areas is highly connected in that cars rarely should require more than one intermediate classification. In fact, there is direct rail service between nearly half of the 600 major metropolitan O-D pairs studied. Although this seems to contradict earlier statements concerning the low level of rail service, this actually emphasizes several major rail problems which are discussed in the final section.

Using the **Official Guide**, it was possible to identify through services between major U.S. production areas, where a through service exists if a train picks up cars from a yard in the origin area and delivers them directly to a yard in the destination area (although the train may pick-up or set-off other cars en route). A through service may be a symbol train operated by one railroad or a run-through train operated by two or more cooperating railroads. If the published schedule indicated a change in train symbols or a delay of more than a few hours at a major classification yard, then it was assumed that one train terminates and that another originates, i.e. that there is no through service.

The metropolitan areas utilized are listed in Table 4. Most of these represent the major production areas used by the Census Bureau in the 1967 Census of Transportation[6]; of those areas, only Hartford, Harrisburg, Allentown, and Albany were not included because of their proximity to other production areas. In addition, several of the areas used in the study were defined to include neighboring areas; for instance, service to either Seattle or Portland is considered to be service to area 1. Finally, Salt Lake City, New Orleans, Kansas City, Memphis-Pine Bluff, Richmond and Jacksonville were added to the set of areas under consideration because of their importance as railroad interchanges.

The analysis reported here concerns

MAJOR METROPOLITAN AREAS USED IN STUDY

1. Seattle - Portland
2. San Francisco - Oakland
3. Los Angeles
4. Salt Lake City
5. Denver
6. Dallas - Ft. Worth
7. Houston
8. New Orleans
9. Minneapolis - St. Paul
10. Kansas City
11. St. Louis
12. Memphis - Pine Bluff
13. Chicago - Milwaukee
14. Cincinnati - Louisville
15. Detroit - Toledo
16. Cleveland
17. Pittsburgh
18. Buffalo
19. Boston
20. New York - Newark
21. Philadelphia
22. Washington - Baltimore
23. Richmond - Norfolk
24. Atlanta
25. Jacksonville

TABLE 4

the connectivity of the U.S. rail system with respect to these 25 major metropolitan areas. Since there are 24 potential destinations associated with each of the 25 areas, there are 24(25) = 600 O-D pairs. If, as is almost always the case, service from A to B is assumed to be equivalent to that from B to A, then there are 300 distinct O-D pairs.

Table 5 classifies the 300 O-D pairs with respect to the number of intermediate classifications and the short line rail distance. For this network as a whole, 123 or roughly 40% of all of the total are serviced by through trains; further analysis showed that 44 of these had competitive through service. In addition, only 7% of the O-D pairs required two or more intermediate switchings. At the shorter distances, through service is even more common; two thirds of the 141 O-D pairs less than 1000 miles apart receive through service. Thus, the operational rail network between major U.S. metropolitan areas is quite highly connected, both at the national and at the regional levels.

The average number of intermediate yards per O-D pair is less than .5 for trips under 1000 miles and less than 1.0 for longer trips. These figures compare favorably with the characteristics of typical O-D movements over the IRN as shown in Figure 1: the 250 and 500 mile trips have no intermediate IRN yards, the 1000 mile trip has 1 intermediate IRN yard, and the longest trips have 2 Intermediate IRN yards. Therefore, the routings shown in Figure 1 certainly seem to be feasible, at least with respect to the problem of routing trains between metropolitan areas. The following section discusses some of the reasons why the current rail system is not an Interstate Rail Network even though it does have a large number of through train services.

4. DISCUSSION OF RESULTS

Analysis presented in the second section of this paper suggests that railroads could substantially improve their service by developing an Interstate Rail Network consisting of a number of high capacity freight yards connected by frequent and reliable freight trains operating over a network of well-maintained rail lines between a number of modern classification yards. The results given in the third section of the paper indicate that the U.S. railroads currently offer quite direct through service between major metropolitan areas. In fact, judging from the results in Table 5, it would appear that there is already a high-quality interstate rail freight system. Unfortunately, as noted at the outset, car utilization figures and studies of O-D performance demonstrate conclusively that rail service is rather poor and that direct, through routing is rare. To determine what must be done to create a true Interstate Rail Network, the rail industry must consider the causes of the discrepancy between the theoretical service levels described by published train schedules and the actual service levels as documented by car utilization records and studies of rail freight service.

Although part of this discrepancy reflects an inability to operate reliably according to the published schedules, there are at least three other important factors:

1. Interchange operations
2. Local distribution in metropolitan areas
3. Routing policies in a Balkanized competitive framework

In the IRN analysis, cars were assumed to transfer from one train to another at an intermediate hump yard with performance characteristics similar to those on railroads studied by MIT. Likewise, the connectivity analysis assumed that each transfer took place at a single yard. In fact, the transfer operation is decidedly more complex; at Chicago, which may be the gateway with the

METROPOLITAN O-D PAIRS CLASSIFIED BY THE MINIMUM NUMBER OF INTERMEDIATE CLASSIFICATIONS AND BY RAIL DISTANCE

Intermediate Yards	0-500	500-1000	1000-2000	2000-3000	Total
0	38	55	20	10	123
	76%	60%	20%	17%	41%
1	10	29	68	48	155
	20%	32%	69%	80%	52%
2	2	7	11	2	22
Total	50	91	99	60	300
	100%	100%	100%	100%	100%
Average Number of Intermediate Classifications	.28	.48	.91	.86	.64

TABLE 5

worst performance, cars require an average of 40 hours to transfer from an inbound through train to an outbound through train.[7] During this process, a car might move through three or more local yards before departing, a situation not unlike that prevailing at St. Louis, Cincinnati, New Orleans, and other major interchanges. Railroads can attack this problem by bypassing congested gateways (as one of many possible examples, Penn Central and Santa Fe bypass Chicago by operating through trains between hump yards in Elkhart, Indiana and Kansas City)[8] or by modernizing and consolidating facilities at the gateway (the FRA, Missouri Pacific, and other roads are now analyzing the alternatives for the St. Louis area).[9]

The second underlying problem reflects the continued existence of redundant and obsolete freight facilities in many metropolitan areas, a situation exacerbated when several railroads all attempt to provide service in the area. Studies of Northern New Jersey,[10] Philadelphia,[11] and other areas have concluded that consolidation of yard facilities, coordination of operations, and improvement of inter-modal operations can significantly reduce operating costs and improve rail service. The redevelopment potential of large tracts of land in or near central cities should help to promote this kind of consolidation and could ultimately offset the capital costs of modernization.

The complex problem of routing traffic over the U.S. rail system arises because of the intricate pattern of intercity freight competition. Not only does the rail industry compete with the trucking and water carrier industries, but each railroad competes with neighboring railroads. Yet at the same time, the competing railroads must cooperate to provide good service for interline shipments. The first problem caused by the Balkinization of the industry is that cars do not move on the most appropriate trains as was assumed in the third section of this paper. Because rate divisions are typically based on distance, each road has a great incentive to transport a shipment the longest possible distance on-line, even though a different routing might provide faster and more reliable service to the customer. A second problem occurs when parallel roads merely offer shippers a choice between various poor levels of service because no single road has the traffic volume to justify direct train service. A third related problem is that even if several roads offer through service between two metropolitan areas, they may each offer only a single train departure, all at approximately the same time each day. In a more rational Interstate Rail Network, the various railroads would offer departures at regular intervals from one or two jointly operated classification yards.

In conclusion, resolution of the problems discussed in this section would do much toward creating an Interstate Rail Network capable of providing high quality rail transportation to all shippers.

FOOTNOTES

1 Reebie Associates, **Toward an Effective Demurrage System,** NTIS report no. PB212-069, July 1972, p. 40.

2 Lang and Martland, **Reliability in Railroad Operations,** Studies in Railroad Operations and Economics, volume 8, MIT Department of Civil Engineering, 1972.

3 Reid, O'Doherty, Sussman, and Lang, **The Impact of Classification Yard Performance on Rail Trip Time Reliability,** Studies in Railroad Operations and Economics, volume 4, MIT Department of Civil Engineering, 1972.

4 Kerr, Sussman, and Martland, **Models for Investigating Train Connection Reliability at Rail Classification Yards,** Studies in Railroad Operations and Economics, volume 14, MIT Department of Civil Engineering, 1974.

5 Martland, **Improving Railroad Reliability: A Case Study of the Southern Railway,** Studies in Railroad Operations and Economics, volume 12, MIT Department of Civil Engineering, 1974.

6 Bureau of the Census, "Special Tabulation: 25 Production Areas to 59 Market Areas," **1967 Census of Transportation Commodity Flow Data,** Washington, D.C.

7 Association of American Railroads, Car Service Division, "Operation Snapshot Summary," Summary Report of Ad Hoc Task Force Committee on Freight Service Performance Improvement, April 1971.

8 National Railway Publication Company, **Official Guide of the Railways,** volume 106, no. 6, New York, New York, November 1973, p. 51.

9 "East-West Gateway Coordinating Council Comprehensive Areawide Railroad Consolidation and Relocation Study," Research conducted for the Federal Railroad Administration under Contract DOT-FR-20023.

10 DeLeuw, Cather and Company, **Coordination and Consolidation of Freight Services in the Northern New Jersey Area,** preliminary report to the New Jersey Department of Transportation, July 1973.

11 The Penn Central recently completed a study of the possibilities for rationalizing rail operations in Philadelphia.