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A Synthesis of Modern Rail Transportation Engineering Practices

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A SYNTHESIS OF MODERN RAIL TRANSPORTATION ENGINEERING PRACTICES

by

Donald D. Cook

A THESIS

Presented to the Faculty of
The Graduate College in the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Master of Science

Department of Civil Engineering

Under the Supervision of
Dr. Edward R. Post
Dr. Patrick J. McCoy
Dr. Edward N. Wilson

Lincoln, Nebraska

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CHAPTER I

INTRODUCTION

The history of the United States, more than any other country in the world today, has been the history of transportation. In no other country has such an extensive and intensive transportation system been created, and in no other country has so great an area been welded into a cohesive, interdependent, economic whole. The result was, in the first instance, brought about by the railroad. It has been furthered by the waterways, the highways, the pipelines and the airways, but it was railroad transportation that set the pattern as it exists today and made the development possible.9

However, since before World War II the railroads have suffered a long decline from the predominant economic position once held in the United States transport market. Their reduction in the relative share of the market and the erosion of profitability have been fully analyzed. The decline of the railroads, including the insolvency of eastern railroads and today's precarious financial state of several major midwestern railroad companies is a consequence of past government policy, present traffic conditions and worsened operating capabilities of the railroad plant.24

The 1970's will be recorded as the decade in which the United States railroad problem became critical. The decade
began with the collapse of the nation's largest railroad company, the Penn Central, into bankruptcy in 1970. The damage to railroad facilities by hurricane Agnes in 1972 and the recession of 1973-76 further aggravated an already desperate situation for the northeastern railroads. The federal government responded with legislation forming the National Railroad Passenger Corporation (Amtrak) in 1971; the United States Railway Association (USRA) in 1973; the Regional Rail Reorganization Act (3R Act) in 1974; and the Railroad Revitalization and Regulatory Reform Act (4R Act) in 1976.

Legislation has been helpful, but railroad problems are still serious throughout the United States. The most critical problems in the United States are in the areas of finance, marketing and industry structure of the systems. Railroads must improve their service to customers if they are to compete effectively in today's multimodal transport market. They must accurately determine their costs in order to establish effective, profitable rates. They must upgrade, and in many cases rehabilitate, a physical plant that is a holdover from bygone days. They must modernize both labor agreements and route structures dating from the era of the steam locomotive.

The 1970's will also go down in history as the decade in which the University of Nebraska - Civil Engineering Department expanded its academic interest to include the field
of transportation. Railroad transportation and activities related to the instruction of planning, design and operation of railroads become a most important part of the transportation curriculum when viewed in the above context. Unfortunately, no modern comprehensive textbook exists for use in a rail transportation course.

The intent of this thesis is to provide a comprehensive source of data for use in the course of study in Railroad Transportation being developed by the University of Nebraska - Civil Engineering Department.
CHAPTER II

CARS AND LOCOMOTIVES

A general knowledge of locomotives and cars using railroads is essential in planning and designing facilities for their use. This chapter will discuss the physical characteristics of locomotives and cars presently using the railroads of the United States. A brief discussion of the major components common to these vehicles is included. No attempt is being made to cover all of the many types of specialized equipment being used.

A. MAJOR COMPONENTS COMMON TO CARS AND LOCOMOTIVES

1. Brake Equipment. The straight air brake was the original form of the Westinghouse Air Brake. With this form of brake, the compressed air in the main reservoir supply is applied directly to the brake cylinders on each car or unit to produce the braking effect. A valve in the cab admits air stored in the reservoir to the brake cylinders through a pipe to apply the brake and hold it there until the air is exhausted back through the valve to release the brakes.

The automatic air brake is designed so that the brakes apply automatically in case air escapes from the system. To accomplish this, an auxiliary reservoir is added to each car which stores a supply of compressed air.
air sufficient to operate the brake on that vehicle.

The straight-air system is today utilized only for locomotive brakes and certain types of electro-pneumatic brakes where it is protected by an auxiliary automatic brake system. All locomotive brake systems consist of two main portions: the automatic portion for regulating brake pipe pressure controlling both the locomotive and train brakes, and the independent portion for controlling the straight-air system on the locomotive only.

Introduction of dynamic braking on locomotives has transferred a major portion of the work of retarding trains from cars to the locomotive or power units. The air brake system, however, must be fully capable of controlling and stopping the longest of trains from the highest of speeds in event of failure of the electric braking system.

Diesel switching locomotives, normally operated as single units, have usually been fitted with a refined version of the equipment formerly used on steam locomotives. The equipment is capable of multiple-unit operation, but does not incorporate all the precision of control possible with more sophisticated brakes.

Introduced in 1933 and made mandatory on all cars in interchange service, the "AB" Freight Brake Equipment featured the "AB" Control Valve. The additional
components consisted of a brake cylinder and a two-compartment auxiliary and emergency reservoir. On the "AB" Control Valve pipe bracket, to which all pipes are permanently connected, are the two operating portions: the service portion and the emergency portion. Using emergency reservoir pressure for the initial recharge of auxiliary reservoir assists in securing a positive release of all brakes after a service application. The discharge of brake cylinder and auxiliary reservoir air into the brake pipe during release assists in accomplishing the same result after an emergency application.

Freight cars with the "AB" Control Valve must be equipped with a brake cylinder release valve which makes it possible to exhaust the cylinder and release the brakes on the car without draining the emergency and auxiliary reservoirs. This speeds the preparation of cars for switching and also cuts the time for recharging the train brake system after cars are assembled in trains.

2. Couplers. By Act of Congress at the turn of the century, it became mandatory for railroads engaged in interstate traffic to equip their cars with automatic couplers which were capable of coupling on impact, and uncoupling without the necessity of a man going between cars.
In the years following, many design improvements were made to the coupler to improve its operation and meet the ever increasing demands of the railroad's greater draft loads and higher speeds. A new design Type E coupler was adopted by the railroads as Standard in 1932. It has existed as a Standard for freight car equipment to the present time, and like its predecessors has undergone numerous design modifications including continual metallurgical advancements to improve the physical properties of steels used in its manufacture.

Designed specifically for passenger cars, the Tightlock coupler was adopted as an alternate standard in 1937, advanced to Standard in 1947, and became mandatory on new passenger equipment built after 1956. In addition to adding to passenger comfort by virtually eliminating free slack between cars, its design provided a safety feature that prevented vertical disengagement of couplers during derailments, thus resisting car overturning and telescoping in collisions. This safety feature, provided by the H Tightlock coupler, remaining coupled in accidents significantly improved the railroad's passenger safety record.

Recognizing the distinct safety features of the Tightlock coupler for passenger service, the Association of American Railroads asked the Standard Coupler
manufacturers to develop a similar but less sophisticated design coupler for freight equipment. Consequently, in 1947 the Type F Interlocking Coupler was first introduced. By design it does not allow vertical disengagement when mated with a like coupler; and is furnished with a support shelf that will retain an E coupler in the event of a failure of pull-out. An alignment control feature on the shank counteracts lateral car forces and coupler jackknifing under buff loading, thus reducing rail turnover and derailment tendencies. The F Interlocking coupler is furnished in various shank lengths up to sixty inches to allow curve negotiation for longer cars. It was adopted as a Standard in 1954, and by federal legislation, its application to tank cars transporting hazardous materials became mandatory on those cars built after January 1, 1971.

The most recently adopted Standard freight coupler is the E/F coupler that is furnished in both forty-three inch and sixty inch effective shank lengths. By design, the coupler head is the Standard E, and the shank is the Standard F Interlocking coupler. The first Standard E/F coupler was adopted by the AAR in 1966, and is widely used on the longer type freight cars as an alternate to the F couplers with similar shanks.
In order for a coupling to be made between two knuckle type couplers used on North American railroads, at least one of the knuckles must be in open position. In the field of specialized or non-AAR Standard couplers, used within industries or for particular purposes, a variety of designs are available.

Hook type couplers of different designs are used on most rapid transit cars. Many are arranged to be operated within the car body, as well as at ground level. They incorporate automatic air and electrical connectors so that brakes and controls are ready for operation when cars are coupled.

The rotary shank coupler, which allows coupled open top, full-size railroad or mine cars to be unloaded in car dumpers without uncoupling is prevalently used in unit train operations transporting bulk material such as coal.

3. Car and Locomotive Trucks. As early as 1831 the four-wheel truck was introduced on the American railway scene. Today the four-wheel, swivel truck continues to be the standard for practically all conventional freight cars and for passenger cars, except the very heaviest. The four-wheel arrangement makes possible a low truck structure, a feature most important in freight-car design.
Conventional passenger car trucks, most of which are of the pedestal type and are fully equalized, can have much softer springing than is possible in standard freight car trucks. With their equalization and swing suspension systems, four-wheel road locomotive trucks are similar to those used on passenger cars, differing only in their heavier construction and arrangements for mounting of traction motors.

Some very light truck designs have developed for use under transit and suburban cars. These designs, like those used under locomotives, must incorporate arrangements for mounting of traction equipment. A number of these trucks transmit carbody loads directly from side sills into the side frames without the normal complicated load paths through center plate and bolster. Further weight savings have been achieved by using inboard journal roller bearings which make possible shorter axles and narrower frame structures. Some of the light-weight trucks incorporate air springs, either for carrying the entire car weight, or to serve as a leveling system in conjunction with coil springs in order to maintain the carbody at a uniform height above the rail.

Suspension systems in all types of trucks are of critical importance in assuring a satisfactory ride. The staggered rail joints which are standard in North
America introduce a different design problem from that encountered in those parts of the world where joints are opposite each other. Springs for standard freight car trucks are specified by the AAR Mechanical Division. Bolster spring action is usually controlled by snubbing springs, by friction dampers, or by hydraulic shock absorbers. Some type of mechanical system for preventing the development of harmonic carbody motion is incorporated in all current truck designs, passenger, and freight.

The center plate about which trucks swivel must not only function as a pivot, but also normally carries the entire carbody weight into the truck structure. Although only a small angular motion is sufficient in this bearing to permit trucks to negotiate even the sharpest of curves, there was little concern until recently about the bearing surfaces. While locomotive and passenger car designers had previously worked to incorporate lubricating systems and special surfaces which would stand up under heavy loads while also functioning to prevent undue truck oscillation, the center plates for freight car trucks consisted of rough castings or forgings lubricated at extended intervals with heavy grease. Excessive center-plate wear, poor truck swivelling, and uneven loading of journal assemblies were found to result from this
arrangement. Center plate liners of hardened steel are now required in truck center plates of new and rebuilt cars of the heavier types; and a series of extreme-pressure lubricants must be used in all center plates for the periodic lubrication.

The railroad car wheel and axle assembly constitute a highly stressed mechanical system. The wheel must not only support its share of the car weight but must also, by the action of its flange, serve to steer the vehicle along the rail. Because of the rigid mounting of wheels on the axle, the wheel may be subjected to torsional stresses imposed by the different distances which the wheel may have to traverse when rounding curves. Finally, in addition to these mechanical loads, the heating produced by tread breaking may impose stresses much higher, and more likely to cause distress, than any other external force.

Wheels and axles used under locomotives and self-propelled cars are subjected to additional torsional forces as they transmit traction torque and braking forces from axle-mounted gearing to wheel treads. As wheel slips develop and subside, additional centrifugal forces are developed in the wheel structure.

For many years the cast-iron wheel was the standard for American freight cars. The higher loads and speeds which have characterized railroading in the past fifty
years finally exceeded the capacity of the cast-iron wheel. In 1961 the railroads acted to eliminate all such wheels from interchange service. About seventy years ago the wrought-steel or forged wheel was first produced in the U.S. These wheels quickly became standard on passenger cars, and subsequently on locomotives. All early designs were of the multiple-wear type. In 1925 the production of one-wear wrought steel wheels was started and this was followed in 1926 by the two-wear wheel.

The decade of the 1950's saw the introduction of several designs of cast-steel wheels. While the earliest designs were of the one-wear type, the latest refinement is the two-wear wheel. Following service tests, revisions were made in original designs and the cast-steel wheel is now a standard. All cars built since 1957 have had to be fitted with either wrought-steel or cast steel wheels.

Freight car wheel diameter in the U.S. was thirty-three inches for many years. After difficulty with rails caused by high load concentrations, the AAR Mechanical Division acted in 1960 to require that thirty-six inch wheels be used on freight cars of over seventy ton nominal capacity. Since then the Division had adopted a twenty-eight inch wheel for seventy ton low-deck piggyback cars, and a thirty-eight
inch wheel for cars of 125 ton capacity. While the thirty-six inch wheel has been standard for mainline passenger cars for many years, transit and suburban equipment is usually fitted with wheels of smaller diameter. Locomotives normally have thirty-six, forty, and forty-two inch wheels.

Heavier cars and locomotive loading have produced axle problems. The raised-wheel-seat axle is now the AAR standard for freight service, being given this status after the former standard black-collar axle had been found to be less than satisfactory for current service conditions. Axles are now machined over their entire exteriors, rather than being left in the as-forged condition, in order to eliminate sources of stress concentrations.

4. Diesel Engines. Diesel engines used as prime movers in diesel-electric locomotives have capacities up to 4,000 horsepower for traction. Both two-cycle and four-cycle engines are used. All high-horsepower engines are equipped with turbochargers to obtain more power and greater efficiency from the engine.

The engine in each diesel-electric locomotive unit has an individual cooling water system in which the water is circulated by a centrifugal pump, gear driven from the engine crank shaft.
The water temperature into the engine is automatically maintained by thermostatically controlled shutters and a fan. The mechanically driven fan, revolving in a horizontal plane, draws air through the side openings and discharges it upwards through the radiators.

5. Diesel-electric Transmissions. The electrical transmission of the diesel-electric locomotive serves to convert the mechanical energy of the diesel engine into electrical energy by means of the traction generator and then to reconvert the electrical energy back to mechanical energy by means of traction motors. The turning of the traction motor shaft causes the locomotive axles and the wheels to turn.

Both d.c. and a.c. generators are now in use. On the d.c. generators, the generator armature, rotated by the diesel engine is electrically connected through brushes to the traction motor circuit. On the a.c. generators the current through the armature is converted by rectifiers to d.c. current for the traction motor circuits.

There are basically two types of d.c. generators now being used, differing principally in the excitation system through which the power output of the generator is controlled, being either self-excited or excited with the use of an exciter-generator or d.c. auxiliary generator. Both types of generators have a starting wiring
that enables them to run as series motors to start the engine.

The electrical power from the main generator is distributed to the traction motors. Each motor is geared to a pair of wheels, thus the wheels on all axles motor mounted are drivers. Electromagnetic power contractors connect the main generator to the motors through circuits that control operating characteristics. These circuits will change automatically to permit full power utilization over the complete range of locomotive operation. These power circuit changes are called transition. The locomotive is reversed by changing the direction of current flow through the traction motor field winding, while the current direction through the armature remains the same. This is accomplished by electromagnetic reversing contactors. These contacts establish the circuits necessary for operation in either direction.

The traction motors are series wound to provide the high starting torque characteristics desired for locomotives. They are designed for heavy duty operation and are cooled by means of an external blower located in the locomotive unit. Locomotives equipped with dynamic braking use the traction motors as generators to retard the rate of travel when descending grades or slowing down the train.
6. **Excitation.** The purpose of the excitation system is to insure that the traction generator, i.e., the power required to rotate the generator armature, matches the capability of the diesel engine throughout its entire speed range. If adequate control of generator demand is not provided, one of the following will occur:

a. If the generator demand exceeds engine ability, the engine will slow down (bog) with still further loss of power. The locomotive will be unable to perform its job and damage to the engine may result.

b. If generator demand is less than engine ability, the governor will reduce fuel to prevent the engine from overspeeding, but it will not be possible to utilize the full rate power of the engine, and the locomotive will not be able to pull its rated load.

The excitation system must also impose electrical limits on the main generator, i.e., maximum voltage and current to avoid the possibility of damage to insulation by high voltage or excessive current.

In a locomotive, the load on the main generator at any fixed engine speed varies as locomotive track speed increases due to the counter-EMF created by the rotating armatures of the traction motors. The load is also changed by shunting the traction motor fields or changing connections from series to parallel. Therefore, the excitation controls must act to keep generator horsepower
demand constant over a wide variation of terminal voltage.

B. DIESEL-ELECTRIC LOCOMOTIVE

Diesel-electric locomotives are by far the dominant form of motive power on American railroads, accounting for 99.17 per cent of the present fleet. The diesel-electric locomotive was introduced for switching service as early as 1918, but had a relatively slow growth until the end of World War II when accelerated application occurred. By 1958, the United States railroads were virtually completely dieselized, with the total number of units in service remaining relatively constant at about 28,000.

For freight operations, three general locomotive types are most commonly used; the general purpose locomotive, a four-axle, 260,000 pound, 2,000 horsepower unit for multi-duty main and secondary line service; a four-axle, turbocharged, general purpose, 3,000 horsepower unit designed for a full range of main line freight operations; and a six-axle 3,000 horsepower, heavy-duty freight locomotive for main line, high tonnage operations.

The six-axle, 3,000 horsepower, heavy-duty freight unit illustrates the advanced level of diesel-electric locomotive development in terms of tractive capability, efficiency, reliability, and low maintenance achieved in the United States.
In addition to its excellent energy conversion efficiency the diesel-electric locomotive has enviable pollutant emission characteristics. Based on a heavy-duty cycle, current 2,000 horsepower Roots blown and 3,000 horsepower turbocharged locomotives manufactured by General Motors have the emission characteristics shown in Figure 1.

Diesel-electric locomotives in the United States have evolved as the optimum solution to the requirements for railroad freight motive power. The direction of this design evolution has been influenced by the requirements and restraints of the American freight rail mode. Notable factors include the allowable axle load of 65,000 pounds, the large loading gauge of ten feet, six inches width by fifteen feet height, the economy of long trains which require large tractive effort capability for the ruling grade and high power capability for speed. These restraints, coupled with prime mover and transmission development for efficiency and reliability by unified manufacturers have resulted in freight locomotives reaching a power level of 3,000 horsepower on four axles. At these levels of power it is possible to exploit the allowable axle load under widely varying track conditions to obtain tractive effort equivalent to 18-20 per cent adhesion. Additional power cannot be utilized at low speed without improvement in wheel-to-rail adhesion. Adhesion can be improved to the twenty-five per cent level using advanced wheel creep control systems now being evaluated,
Figure 1.8

Gaseous Emissions from EMD Model 645 Locomotive

CO

ROOTS BLOWN
TURBOCHARGED

HC

10.8

13

14

3.2

0.8

1.1

0

15

GRAMS/BHP/HOUR

NOx
thereby permitting an increase in power to about 3,500 horse-
power on four axles.

Increases in power above this level in the future will
require use of six axles with corresponding adhesion improve-
ment. Six-axle locomotives of 4,200 horsepower have been
evaluated since 1970 and power ratings of up to 4,500 horse-
power are being developed.

Locomotive builders prepare tractive effort/speed curves
for each of their models (Figure 2), based upon the capacity
of the electrical transmission system and the limitations of
the diesel prime mover. The continuous tractive force rating
of a diesel-electric locomotive is based on the thermal capac-
ity of the traction motors and is the minimum speed at which
the unit may be operated without motor damage under full-
throttle conditions. This is the speed at which traction
motor blowers are able to supply sufficient cooling air to
stabilize motor temperature at a safe point. Improvements
in electrical insulation and changes in the transmission
itself have acted to remove some of the thermal limitations
of early locomotive models.

Tonnage ratings for a diesel-electric locomotive over
any route must be carefully calculated. The rather indis-
criminate multiple-unit operation of units of varying
horsepower with combinations of four and six traction motors
can present the potential for overloading and overheating of
motors unless steps are taken to assure that the engineman
FIGURE 27
TRACTIVE EFFORT CURVES

U 30C Locomotive

SD 38-2 Locomotive
has a true picture of the currents involved on all units under his control. While, once the computation of drawbar pull and speed, elapsed time over any segment of a run, and limitations imposed by traction motor heating were laborious manual calculation, the computer has changed all this. Locomotive builders and individual railroads now have readily accessible programs which enable the rapid and comprehensive calculations of all types of locomotives and all possible combinations of units, over runs of any length. It is simple also to calculate fuel consumption in order that it can be determined what the minimum number and size of units would be to use the least quantity of fuel for any movement. Because of the fuel economy of the rail mode, the ability to tailor locomotive output to any desired train performance is a further advantage.

A listing of locomotives typical to the industry is shown in Table I.

C. FREIGHT CARS

Concentration on large-volume freight operations in the past two decades has been railroads and private-car lines steadily pushing up average freight-car capacity and regularly setting new highs in volume and/or weight carrying ability in individual car designs. High-capacity four-wheel trucks under span bolsters at both ends are used to produce larger freight cars. Decisions about car size and running
gear involve economic, traffic and operating considerations as well as engineering.

Frequently the nominal capacities of freight cars have caused confusion, even in railroad circles. This was further complicated over the past few years as the car formerly known, for instance, as a seventy ton model is now often designated as a seventy-seven ton car. The increases in nominal capacities occurred across the board as Table II shows.

The nominal capacities assigned by the AAR Mechanical Division are really an indication of the axle and journal size. For example, a car having the conventional pair of four-wheel trucks and, consequently, four axles with journals of six inch diameter and eleven inch length now has a permissible gross rail load (light weight of car plus lading) of 220,000 pounds. This permissible load on the rail takes into account the strengths of bearings and journals and the axles and wheels which must be used with them. Until August 1963, the permissible gross rail load for a car with four axles having six inch by eleven inch journals was 210,000 pounds. At that time the AAR Mechanical Division acted to raise the gross rail load of most cars in order to improve the railroads' competitive position. It has been determined that bearings, axles, wheels, and rails would stand the heavier loading.

This gross rail load, however, is not the nominal capacity of the car. The seventy ton car, for example had a
### TABLE II

#### AVERAGE FREIGHT CAR CAPACITY

<table>
<thead>
<tr>
<th>Year</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1929</td>
<td>46.3</td>
</tr>
<tr>
<td>1939</td>
<td>49.7</td>
</tr>
<tr>
<td>1944</td>
<td>50.8</td>
</tr>
<tr>
<td>1947</td>
<td>51.5</td>
</tr>
<tr>
<td>1951</td>
<td>52.9</td>
</tr>
<tr>
<td>1955</td>
<td>53.7</td>
</tr>
<tr>
<td>1960</td>
<td>55.4</td>
</tr>
<tr>
<td>1961</td>
<td>55.7</td>
</tr>
<tr>
<td>1962</td>
<td>56.3</td>
</tr>
<tr>
<td>1963</td>
<td>56.8</td>
</tr>
<tr>
<td>1964</td>
<td>58.3</td>
</tr>
<tr>
<td>1965</td>
<td>59.7</td>
</tr>
<tr>
<td>1966</td>
<td>61.4</td>
</tr>
<tr>
<td>1967</td>
<td>63.4</td>
</tr>
<tr>
<td>1968</td>
<td>64.3</td>
</tr>
<tr>
<td>1969</td>
<td>65.8</td>
</tr>
<tr>
<td>1970</td>
<td>67.1</td>
</tr>
<tr>
<td>1971</td>
<td>68.4</td>
</tr>
<tr>
<td>1972</td>
<td>69.6</td>
</tr>
<tr>
<td>1973</td>
<td>70.5</td>
</tr>
<tr>
<td>1974</td>
<td>72.8</td>
</tr>
<tr>
<td>1975 Est.</td>
<td>73.9</td>
</tr>
</tbody>
</table>

Annual gains in average carrying capacity of railroad freight cars, an unbroken trend since record-keeping began, have been especially pronounced in recent years. In 1975 the average advanced to about 73.9 tons at year-end. New cars installed in 1975 had an average capacity of 89 tons, compared with a 62-ton average for cars retired.
permissible gross rail load of 105 tons (210,000 pounds). At the time the nominal capacities came into use many years ago, the car which could carry seventy tons would normally have weighed approximately thirty-five tons. While the load-to-empty weight ratio improved considerably as car designers became more adept and new high-strength alloys were introduced in carbuilding, the car on six inch by eleven inch journals continued to be known as a seventy ton model, even though many of them weighed considerably less than thirty-five tons.

1. **Load Limit.** The maximum permissible weight that can be loaded into car is calculated by deducting the light weight of car from the total allowable weight on rail for applicable axle size. Shown below:

<table>
<thead>
<tr>
<th>Journal Size (Inches)</th>
<th>Total Weight On Rail (4 Axles Per Car)</th>
<th>Nominal Capacity (Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4⅛ x 8</td>
<td>103,000</td>
<td>60,000</td>
</tr>
<tr>
<td>5 x 9</td>
<td>142,000</td>
<td>88,000</td>
</tr>
<tr>
<td>5½ x 10</td>
<td>177,000</td>
<td>110,000</td>
</tr>
<tr>
<td>6 x 11</td>
<td>220,000</td>
<td>154,000</td>
</tr>
<tr>
<td>6½ x 12</td>
<td>263,000</td>
<td>200,000</td>
</tr>
<tr>
<td>7 x 12</td>
<td>315,000</td>
<td>250,000</td>
</tr>
</tbody>
</table>

When the car owner chooses to reduce the load limit a star symbol (*) must be applied immediately to the left of the stenciling "LD-LMT". This fixed load limit
must only be altered by car owner, or with owner's permission.

2. **Nominal Capacity.** The capacity for which car was constructed is calculated in multiples of 1,000 pounds, for the applicable axle size, shown above.

   a. When a car owner chooses to reduce the nominal capacity for any reason, a star symbol (*) must be applied immediately to the left of "CAPY" stenciling. This fixed capacity must only be altered by car owner, or with owner's permission.

   b. Stenciling must not be altered where the new nominal capacity would exceed that shown above.

   c. Stenciling must not be altered where the car is stenciled for nominal capacity greater than shown above.

   d. The nominal capacity of car must never exceed the load limit.

Many variations of nine basic types of freight cars are required to move the commodities and constantly growing number of industrial products which make up the commerce of North America. Since transportation has ceased to be a railroad monopoly, freight cars have become the one railway facility of which the shipping public is always conscious, both with respect to quality and quantity. Cars which require little or no packaging of the shipper's product, which are convenient to load
and unload, which protect the lading from damage and which are available when the shipper wants them, tend to attract traffic to the railroads. The growing variety of freight cars is the result of the effort of the railroads to meet the shippers' needs.

In order to define the various types of freight trains cars the Mechanical Division of the AAR has adopted a series of Designation Classification Letters and Definitions which are revised from time to time to meet changing conditions. The general groups used by the AAR are as follows:

Class "X" -- Box Cars
Class "S" -- Stock Cars
Class "R" -- Refrigerator Cars
Class "F" -- Flat Cars
Class "G" -- Gondola Cars
Class "H" -- Hopper Cars
Class "T" -- Tank Cars
Class "L" -- Special Cars
Class "N" -- Caboose Cars

3. **Box Cars.** Box cars are primarily employed to transport valuable commodities and products requiring protection from the weather or against breakage. Besides the plain type of box car intended for ordinary freight traffic there are box cars made to accommodate the products peculiar to certain industries, such as, automobile
parts, lumber, grocery products, appliances, and some bulk materials. Nearly a third of the cars in service (550,000 in 1974) were classed as box cars. Over thirty-five per cent of these were so equipped that they were assigned to specific services. In addition to the "X" class cars, a substantial number of refrigerator cars also carry similar commodities.

Box cars of forty and fifty foot lengths in either forty or fifty ton capacities constituted practically all the models built in the forty years ending about 1960. The AAR Mechanical Division, in cooperation with the American Railway Car Institute, even prepared highly standardized designs which were the basis for hundreds of thousands of single-sheathed and double-sheathed cars built over the four decades. Starting in the early 1960's, the increases in length, cubic capacity and weight carrying ability, which were being sought for all types of freight cars, produced a series of spectacular jumps in box-car size and capacity. The sixty and eighty-six and one-half foot cars in seventy and one hundred ton designs were introduced initially for automobile parts service. Other high-cube designs have also been developed for household appliances.

As the use of lift trucks and other materials handling equipment has grown, there has been increasing emphasis on door openings through which these machines can
maneuver readily. Shippers have been seeking wider door openings. There are now several types of cars on which the entire side opens to facilitate materials handling operations. Another popular arrangement has been a combination of a single sliding door and a single plug door on each side of the car to give the opening normally produced by the double sliding door arrangement. The plug door (single and double arrangements) has been used exclusively on a growing number of cars.

The insulated box car has been increasingly popular. This type of car now handles many of the shipments which formerly moved in heated refrigerator cars. Many shippers also specify them for shipments which could be damaged by condensation.

The loss of livestock traffic and changes in distribution which result in live animals being transported relatively short distances to packers and the processed meat subsequently being transported long distances in refrigerator cars and piggyback trailers has resulted in a steady decline in the number of stock cars in service. At the end of 1975 there were under 4,500 stock cars.

4. Gondola Cars. At the end of 1975 the railroads of the U.S. owned almost 187,000 gondola cars. These cars are used primarily for carrying ore and coal, forest products, steel products and machinery. These shipments require several types, including the basic
gondola with fixed ends and solid floor; extra-long ladings often move in cars with drop ends; bulk ladings once moved in large volume in drop-bottom gondolas, but the fact that such cars are not completely self-cleaning has seen their numbers decline.

Because of its extensive use of gondola cars, the steel industry has encouraged the development of high-capacity, high-side cars. A significant proportion of recent gondolas have been of one hundred ton capacity; the sixty-five foot car has become of greater importance as mills produce longer structural shapes, pipe and plates. Many recent cars have been fitted with bulkhead ends and high sides to simplify the load-securement problems associated with traditional low-side designs. Floors are of either steel or wood, although the use of load dividers and tie-downs has reduced the amount of extra blocking which once made the wood gondola floor of great importance.

Because many coal and ore-handling installations have been equipped with car dumpers, high-capacity gondolas have gained considerable importance in movement of bulk materials. The simplified construction and greater lading capacity per unit length made possible by gondolas has led to their adoption in place of hopper cars when suitable dumpers are available. Special high-cube gondolas are often used for the movement of wood
chips and saw dust; again special unloading facilities are usually required because the car is not inherently self-clearing.

5. **Hopper Cars.** Although hopper cars long constituted the second largest classification of railroad freight equipment (after box cars), the emphasis on bulk movements by railroads has pushed this type of car into first place. In 1975 there were 364,000 open-top hoppers, 158,000 railroad-owned covered hoppers, and 70,000 privately-owned covered cars.

Open-top hopper cars are used most extensively in the movement of coal. Other high-density commodities which move in these self-unloading cars include stone, ballast and ore. When built with high-cube bodies, the cars are used for movement of low density materials such as coke, saw dust and wood chips. Except when designed for extremely low-density ladings, these cars now are almost always built in one hundred ton capacities. The growing use of such cars in unit trains has led to the development of powered door operating arrangements, some of which are completely automatic. Such arrangements allow trains to increase the utilization of the cars.

The covered hopper car represents one of the great railroad growth patterns of recent decades. Total ownership increased from about 50,000 covered hoppers in 1955 to well over 200,000 in 1974. Built first in large
numbers during the 1920's for cement service, the past twenty-five years have seen the covered hopper utilized for a steadily growing number of bulk products requiring protection in transit. The car makes possible bulk movements of materials formerly shipped in bags and barrels or handled in bulk in box cars fitted with grain doors. Some cars have been fitted with humidity control equipment for handling chemicals and food products; a recent development is the use of insulated covered hoppers fitted with mechanical refrigeration equipment for bulk movement of perishables.

Many covered hoppers must be lined or built of corrosion-resistant materials to prevent contamination of ladings or damage to the car bodies. Designers have produced many different body arrangements to maximize cubic capacity. Four-axle covered hoppers range up to 125 tons in capacity; bodies range from approximately 2,000 to 7,300 cubic feet.

6. **Tank Cars.** Transportation of bulk freight in liquid or semi-liquid form requires the use of a growing number of tank cars. The diversity of designs has increased rapidly in the past two decades. While the tank car was first developed a century ago to transport crude oil and petroleum products, today's tank cars are also moving the products of America's rapidly expanding chemical industries. There were approximately 170,000 tank cars in service in 1975.
Among the products moved are liquefied petroleum gases; liquefied gases such as carbon dioxide, oxygen and hydrogen; chemical intermediates; polymers; anti-knock compounds; anhydrous ammonia; chlorine; alcohol; vegetable and fish oils; fruit juices; wine and syrups. Because of the hazardous nature of many of the products moved in tank cars, railroads have long been concerned with assuring their safe transportation. The Master Car Builders Association first issued tank car specifications in 1903. These have been expanded to become the basis for present AAR specifications for tank cars.

During the past twenty years, tank cars have increased rapidly in size. Most cars are now in the one hundred ton, 30,000 gallon range; many are much larger. Because of the wide range of densities of liquids which must be transported, the relation of cube and weight-carrying capacity have received careful study by tank-car engineers. The practice of using the structural strength of the tank to transmit draft and buffing forces has become an accepted feature of design; most tank cars are now built without center sills. To maximize tank volume, there are an increasing number of tank cars mounted on pairs of six-wheel trucks or on span bolsters over pairs of four-wheel trucks at each end of the car. Such cars have reached capacities as high as 60,000 gallons.
7. **Flat Cars.** Flat cars have become increasingly important over the past few years as piggybacking and container services have grown. While the American freight car fleet has been decreasing in size, the number of flat cars has increased. Over 141,000 were in service at the end of 1975.

Despite the present prominence of the piggyback and container cars, the conventional flat car continues to play an important role in rail transportation. Bulkhead type flat cars have become the accepted equipment for transporting pulpwood, plywood, and plaster board.

The bulkhead car is now used for transporting finished, packaged lumber because of the ease with which such lading can be handled by forklift trucks. Bulkhead cars are also utilized for moving other types of manufactured products, including pipe, poles, and similar long items, which formerly were difficult to move successfully because of their tendency to shift, requiring frequent adjustment.

The tendency to shift is being overcome with the application of sliding-sill or end-of-car cushioning to flat cars. Equipment of high precision, such as printing presses and rocket components, is now moved regularly on cushioned flat cars. Flat cars fitted with weatherproof hoods are used for moving coiled steel. Like the covered gondola, this type of car makes possible shipment of
steel products without expensive packaging and is so
to cars for handling cargo containers,
loaded that it is readily handled by overhead cranes.
many special containers cars are in service. These are
designed for carrying a single type of product. They
include a wide variety of chemical and mineral products
which are shipped in steel containers, rubber bags and
other types of specialized containers.

Just as bulkheads and cushion underframes have sim­
plified the blocking, bracing and securing of many of
the traditional loads handled on flat cars, there is
now a trend to equip flat-car decks for the easy loading
of specific manufactured products. Typical of such
installations are cradles for transporting automobile
frames, racks for holding automobile parts and tie-downs
for securing agricultural machinery. In a relatively
short time the special flat car for farm machinery with
its adjustable tie-downs has become an accepted trans­
portation tool. Not only are shippers' loading and
unloading problems simplified but railroads are also
being relieved of the problem of clearing car decks of
blocking prior to delivery of cars and subsequent loads.
The life of car decking is also extended significantly.

In addition to their use for moving trailers, con­
tainers and all types of highway vehicles, long flat
cars are now being used for transportation of extra-length
loads such as poles and pipe which formerly would have had to be loaded on one flat car with an idler car at one or both ends. Many of the earlier piggyback cars, no longer suitable for handling today's longer trailers, are now being utilized in this general service. In addition, there are increasing numbers of long flat cars being built specifically for such use. In addition to the former standard length of fifty-two and one-half feet, general service flat cars are now being built in lengths of sixty, sixty-five, and even seventy feet.

While much attention has been given to the ultra-high capacities and unusual body arrangements of many types of cars introduced over the past few years, these features have long characterized many of the special flat cars. Capacities of up to 300 tons have long been possible in flat cars having special running gear arrangements. Other features have included depressed centers, well holes which can accommodate the tallest possible loads, and bodies which can be disassembled so as to simplify the loading or unloading of excessively large pieces of machinery.

One of the biggest problems confronting piggyback car owners and designers is the increasing length and width of highway trailers. Designers have resorted to various methods for reducing the deck height of piggyback cars so that the highest of trailers may be handled
without clearance restrictions. This has led to the adoption of a standard twenty-eight inch freight car wheel with a diameter five inches smaller than that of the conventional thirty-three inch wheel. This has been done because wheel size is the principal determinant of car deck height.

Several features have been found desirable in highway trailers intended to be moved piggyback. These include heavy-duty hinges and latches for rear doors, reinforced nose ends, extra-heavy fifth-wheel construction, and more substantial landing gear. Because of the handling at piggyback terminals, side sills and side construction of trailers were found to require strengthening.

The importance of overall trailer length as it affects the length of flat cars has led to development of underbody mounting of refrigeration units for trailers. The complications involved in servicing refrigerated trailers and containers while enroute on piggyback cars has led to use of fuel tanks of capacities much higher than are considered conventional for over-the-road trailers.

8. Refrigerator Cars. The refrigerator car, by creating a nationwide market, has played a major role in the creation of industries such as the cultivation of citrus fruit in Florida, Arizona and California, melons and
peaches in Georgia, apples in the Northwest and other fruits and vegetables on a large scale in other areas where climate and soil are suitable. Refrigerator cars protect all types of perishable food products from the effects of the heat of summer; heater cars protect them from the cold of winter.

About 1945 the production of frozen orange juice concentrate began in Florida. In a decade, the production of orange concentrate has grown to about seventy million gallons; the industry had spread to Arizona and California and included grapefruit and lemon juices.

It soon became evident that refrigerator-car temperatures which could be maintained by the use of ice and salt as the refrigerant were not low enough to protect the quality of the frozen products, and the development of the mechanical refrigerator car began. This was participated in by the refrigerator car lines and the manufacturers of the refrigerating equipment. By the end of 1973 there were 25,000 mechanical refrigerator cars in service in a fleet of 105,000.

The mechanical equipment for car refrigeration includes a power plant, usually a diesel-electric unit, a refrigerant compressor, a refrigerant condenser and fan, an evaporator and a fan or fans for the distribution of the cooled air through or around the lading. Defrosting is usually done automatically by electric coils mounted
in the evaporator, which are also utilized for car heating when heat is called for by the thermostat. This equipment is mounted in one end of the car.

While originally designed for the transport of frozen foods and juice concentrates, the mechanical refrigerator car has been growing in popularity with shippers of all types of products requiring controlled temperature transportation. Today the cars built for "deep-freeze" service are almost always of the "all-purpose" type capable of maintaining temperatures from minus seventy to plus seventy degrees Fahrenheit.

The AAR Mechanical Division now requires a minimum of four inches of insulation in sides and ends of refrigerator cars and four and one-half inches in floors and roofs. Almost all cars now built have polyurethane foamed-in-place insulation; its effectiveness has progressed to the point that heat leakage of a seventy ton, 4,000 cubic foot car is only about one-half that of the ice-bunker car insulated with the fibrous materials which were formerly standard.

Mechanical refrigerator cars in their "all purpose" role have been equipped with increasing numbers of special features such as cushion underframes, load dividers, wide doors, high-capacity floor racks for larger lift truck, sidewall fillers to accommodate palletized loads, and fiberglass-reinforced plastic interior wall
linings, in addition to their temperature control equipment. This has extended their all-purpose capabilities, allowing them to be used for return hauls of non-perishables, which can be handled to advantage in cars providing protection from weather extremes even when the temperature control equipment is not operating.

9. **Caboose Cars.** Caboose cars are normally used as the last car on freight trains in which the crew rides and the conductor makes out and keeps his records. Supplies and signal materials are carried along with emergency tools. Modern cabooses are usually of all-steel construction with two four-wheel trucks of special design for easy riding. For better observation of running gear on trains the side-bay type has been built for a number of roads, while others still retain the roof cupola style. A recent development, claimed by some to give trainmen an improved observation post, is the extra width cupola which extends beyond the car’s sides about the same distance as the side bays. To enhance crew comfort, these cars are often fitted with sliding-sill or end-of-car cushioning. Much attention is also given to sound deadening.

Radio communication equipment is an accepted feature of most cabooses now built. Even though the power requirements of the latest style train radio equipment are modest, most new cabooses are being equipped with axle generators,
belt or shaft driven, to supply current for electric lighting and refrigeration. Oil heaters, toilets, and permanent water tanks are also standard features of most recently built cabooses.

About 15,000 caboose cars are owned by railroads of the United States.

D. PASSENGER CARS

With the demise of the passenger services of individual railroads, the design of passenger equipment has become the function of agencies such as Amtrack, Auto-Train, transit districts and the carbuilders. By 1974 the orders for new cars were for units not greatly different from those that had been produced twenty years earlier. The new cars did have the benefit of new materials and some new fabrication techniques, but the basic soundness of the eighty-five foot vehicle with a pair of two axle trucks capable of being assembled into trains of varying lengths to meet traffic requirements was being confirmed by the large orders being placed for both intercity and commuter cars.

Weights of passenger cars have been minimized by the use of aluminum, stainless-steel, or low-alloy high-tensile steels. The monocoque concept in which the shell of the car is a structural element and bears portions of the static and dynamic loading is a fairly recent advancement in passenger car design. The previous practice had been to carry all loads in the car
framing and have the sheathing perform as an environmental envelope for the interior.

Plastic-faced panels, synthetic carpeting, polycarbonate glazing, and new upholstery materials were introduced into passenger car construction in an attempt to minimize maintenance. Such products are now used routinely in both new car construction and the rebuilding of existing cars.

The transition from steam to electric heating is now taking place. This is but one phase of the climate control challenge which is presented by all contemporary passenger equipment. Air conditioning has become an accepted feature of all types of rail passenger vehicles and represents an electrical load approaching that necessary for heating. The supply of electrical power for these processes is now generally a trainlined alternating current system for locomotive-hauled trains. Multiple-unit cars, whether of the intercity, commuter, or transit type, can rely on their individual current collecting systems for an electrical power supply for the so-called "hotel" services which include also ventilation and lighting. The electro-mechanical air conditioning systems now supplied for passenger cars are designed to be operated from the trainlined power source at standard voltages, permitting the use of conventional components utilized in building air conditioning. The result is plug-in modules and components which can be removed and adjusted off the cars, allowing the vehicles to continue in service with cooling and heating systems in
operation. Standardized components can also be used in lighting systems.

Self-propelled equipment has received major attention during the past decade. The challenges presented by such equipment in intercity service are numerous. Utilization of fixed-consist trainsets can restrict one of the basic advantages of rail passenger service—the ability to expand or contract passenger capacity in direct relation to the market. This can be done, not only on a day-by-day basis, but also on a trip-by-trip basis. The multiple-unit car, whether powered by electric traction motors or diesel engines, represents the ultimate in such operating flexibility since the power-to-weight ratio of trains of such cars does not vary, as is the case when cars are added or removed from a locomotive-hauled train. This means that schedules can be met consistently, regardless of the length of trains being operated. Self-propelled cars can also achieve acceleration and deceleration which would not be practical for locomotive-hauled trains.

There were 6,534 passenger train cars in service at year end 1975, including equipment owned by Amtrak and Auto-Train.

E. RAILWAY SERVICE CARS

Maintenance of the railway roadbed, building of new lines, and general construction work in connection with railroad
operations requires the use of many types of special service cars. These include dump cars, motor and hand cars, locomotive cranes, power shovels, pile-drivers, ditchers, flangers, snow plows, sweepers, and various other special cars for transporting the materials used and the men engaged in maintenance service. Wrecking, instruction and dynamometer cars are also included in the service car group.

Automotive highway equipment is coming into use for the performance of some of the functions formerly performed by rail service cars, thereby reducing interference with revenue rail traffic and increasing the productiveness of maintenance-of-way forces. Included are units equipped for movement over both highway and rail, particularly inspection cars.

F. FUNDAMENTALS FOR DESIGN, FABRICATION AND CONSTRUCTION OF FREIGHT CARS

Specifications for the design, fabrication and construction of freight cars have been adopted by the Association of American Railroads. The need for this information had been recognized for quite some time, and in 1962 an AAR special task force was formed and directed to prepare these specifications. The task force, in collaboration with engineering committees of the carbuilders and others, prepared a set of proposed requirements which were submitted to interested AAR committees, and later to member roads for a letter ballot. These specifications were adopted and made effective on September 1, 1964.
Adherence to these specifications as minimum requirements in the design and construction of freight cars is mandatory for all cars intended for interchange service.

While many of these requirements are not retroactive, it is recommended that they be followed insofar as practicable when repairing or rebuilding freight cars.

These specifications do not establish or dictate the configuration of the car structure, but rather permit the engineer to exercise his ingenuity, thus encouraging the development of new ideas and improvements in car design. They do, however, stipulate maximum stresses and minimum design criteria.

A portion of the specifications relating to geometric design and loading characteristics of the track and roadbed structure is presented as follows:

1. **Section 2.1.1. Scope**
   
   The basic design data in this section apply to all cars intended for interchange service.

2. **Section 2.1.2. Limiting Outline**

   Where cars are intended for unrestricted interchange service, they must comply with the requirements of Plates B and B-1 (Figure 3).

   Cars having outside dimensions which exceed those of Plate B to a limited extent may be built for limited interchange service provided none of these outside dimensions go beyond those as outlined in Plates C and C-1 (Figure 4).
NOTE: The reduction in width is predicated on the base car on a 13° curve. The maximum widths shown are based on the center of car which usually governs. End swingout should be checked on unusually long overhangs.

FIGURE 37
CAR WIDTH CRITERIA
(Plates B and B-1)
NOTE: The reduction in width is predicated on the base car on a 13° curve. The maximum widths shown are based on the center of car which usually governs. End swingout should be checked on unusually long overhangs.
The above diagram supplements Charts B-1 and C-1 covering changes to be made in the width of freight cars shown on the two following pages. It shows additional information, including lines for cars on 13 degree and 15 degree curves. It also shows the swingout in inches that is not included in Plates B-1 and C-1.

FIGURE 57

SUPPLEMENT TO PLATES B-1 AND C-1
PROCEDURE FOR OBTAINING CAR WIDTHS BETWEEN C OF TRUCKS

1. Find max. width of car from plate B-1 or C-1
2. Use curve "y" to find dim. A for point desired
3. Add dim. A to max. car width for point desired. (Width not to exceed 10"-8")

Example: Given 85.0" flat car 62.0" truck centers
max. width 9.33" from plate B-1
B+20.0" (refer to fig. 1)
from curve "y" dim. A + 4.09"
max. width at point B+9.5" + 10.99" = 10.49" = 10'-5.49"

PROCEDURE FOR OBTAINING CAR WIDTHS BEYOND C OF TRUCKS FOR PLATE B-1

1. Find max. width of car from plate B-1
2. Use curve "y" to find dim. A for point desired
3. 23.5" + dim. A + max. width of car from plate B-1 = car width at point desired (Width not to exceed 10'-8")

Example: Given 85.0" flat car 62.0" truck centers
max. width 9.33" from plate B-1
C+42.6" (refer to fig. 1)
from curve "y" dim. A + 4.09"
max. width at point C + 23.5" + 4.09" = 27.64" = 2'-3.64"

PROCEDURE FOR OBTAINING CAR WIDTHS BEYOND C OF TRUCKS FOR PLATE C-1

1. Find max. width of car from plate C-1
2. Use curve "y" to find dim. A for point desired
3. 23.5" + dim. A + max. width of car from plate C-1 = car width at point desired. (Width not to exceed 10'-8")

Example: Substitute plate C-1 car widths in previous example.

Method for obtaining maximum allowable width of car, other than at centerline of car, for unrestricted (Plate B-1) and limited (Plate C-1) interchange service.

FIGURE 67

CAR WIDTH CRITERIA (Plate D)
Limiting Outline Plates B and C are based on cars having maximum truck centers of forty-one feet three inches and forty-six feet three inches respectively. Cars having truck centers exceeding these dimensions must have width reduced to compensate for the increased swingout at center and/or ends of car on a 13 degree curve so the extreme width of car shall not project beyond the center of track more than the base car. Reduction in width of car for various truck centers is shown on Plates B-1 and C-1.

3. Section 2.1.3. Vertical Center of Gravity

Height of center of gravity of fully loaded car (including weight of trucks) shall not exceed ninety-eight inches above top of rail.

Note:

For calculating the center of gravity of loaded car:

a. Box cars to be loaded to eaves and to load limit capacity.

b. Covered hopper cars to be loaded to eaves and to load limit capacity.

c. Open top cars, except flat cars, to be loaded with ten inch average heap and to load limit capacity.

d. Center of gravity of flat cars to be determined for empty cars only.

4. Section 2.1.4. Horizontal and Vertical Curves

2.1.4.1. General

Cars shall be built to negotiate the minimum curves
possible with the use of standard or alternate standard couplers, yokes and strikers, but in no event shall exceed minimum radius curves specified in 2.1.4.2. and 2.1.4.3.

2.1.4.1.1. Cars shall be designed to operate over the respective horizontal curves without interference between trucks, car body, and brake rigging.

2.1.4.1.2. Cars shall be designed to operate over the respective vertical curves without interference between: (a) Carbody, including attached parts and trucks; (b) Carbody, including attached parts and track structure or retarders; (c) Trucks and track structure or retarders. The design shall include allowance for truck springs deflected to 75 per cent of their total travel, plus maximum wear of two inches, plus body deflection when applicable.

2.1.4.2. Horizontal and vertical curve negotiability shall be computed in accordance with 2.1.4.4.

2.1.4.2. Horizontal Curves (Right and Left)

2.1.4.2.1. Cars coupled to Base Car

<table>
<thead>
<tr>
<th>Length over Pulling Faces of Couplers</th>
<th>Minimum Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less Than 50 ft.</td>
<td>185 ft.</td>
</tr>
<tr>
<td>50 ft.-0 in. to 56 ft.</td>
<td>215 ft.</td>
</tr>
<tr>
<td>56 ft.-1/8 in. to 63 ft.</td>
<td>250 ft.</td>
</tr>
<tr>
<td>63 ft.-1/8 in. to 70 ft.</td>
<td>275 ft.</td>
</tr>
<tr>
<td>70 ft.-1/8 in. to 75 ft.</td>
<td>300 ft.</td>
</tr>
<tr>
<td>75 ft. plus</td>
<td>350 ft.</td>
</tr>
</tbody>
</table>
2.1.4.2.2. Cars Uncoupled

For cars having truck centers of 46 feet 3 inches or less . . . 150 foot radius. For cars having truck centers greater than 46 feet 3 inches . . . 180 foot radius.

2.1.4.3. Vertical Curves (Concave and Convex)

2.1.4.3.1. Cars Coupled to Base Car

For cars having truck centers of 41 feet 3 inches or less and overhangs of 5 feet 6 inches or less . . . 785 foot radius.

2.1.4.3.2. Cars Uncoupled

For cars having truck centers of 41 feet 3 inches or less . . . 500 foot radius. For cars to be unloaded by rotary car dumper . . . 276 foot radius.

2.1.4.4. Curve Negotiation--Standard Method of Calculation of Minimum Radius for Coupler Clearance

This method may be used to determine the minimum horizontal or vertical curve and tangent any two coupled cars can negotiate. Tables are included giving dimensions pertinent to the standard coupler applications when draft gears are in normal position. The formulae presented are simplified empirical equations resulting from studies of exact methods and actual car service data.

2.1.4.4.1. Placement of Cars

In all instances the curve tangent condition with no easement is the most critical. In this condition one car is on tangent and the other on curve. If different
length cars are involved, the shorter of the two is placed on tangent.

2.1.4.4.2.1. Horizontal Curves

The car for which curve negotiation is to be determined shall be coupled to a base car equipped with B-E60A-HT coupler, B-Y40 yoke, striker AAR PL 532-B and having the dimensions listed below:

Length over pulling face of couplers 44 ft. 7 7/8 in.
Length over strikers 42 ft. 3/8 in.
Truck centers (T.C.) 31 ft. 1 3/8 in.
Overhand (T.C. to striker face) 5 ft. 5 1/2 in.
Horn Clearance 0 ft. 3 3/4 in.

2.1.4.4.2.2. Vertical Curves

The same base car as for horizontal curves is to be used except when equipped with Type F Interlocking Couplers C-F70B-HT, B-Y45 yoke and SlC strikers. The dimensions then become:

Length over pulling face of couplers 44 ft. 8 3/8 in.
Length over strikers 42 ft. 1/2 in.
Truck centers (T.C.) 31 ft. 1 3/8 in.
Overhand (T.C. to striker face) 5 ft. 5 3/4 in.
Horn Clearance 0 ft. 3 in.

5. Section 2.1.5. Standard Nominal Dimensions

(All vertical measurements to be made on level tangent track.)
2.1.5.1. Height from top of rails to lowest part of trucks, with truck springs solid and maximum wear conditions must not be less than 2 3/4 inches.

2.1.5.2. Height from top of rails to center of coupler new car, (empty car) . . . 34½ inches.

2.1.5.3. Height from top of rails to body center plate wearing surface (empty car) . . . 25½ inches.

2.1.5.4. Distance from center line of car to center line of body side bearing . . . 2 feet 1 inch.

2.1.5.5. Height from body center plate wearing surface to body side bearing wearing surface . . . 4 5/16 inches.

2.1.5.17. Axle Sizes, Capacities and Body Center Plate Diameters

<table>
<thead>
<tr>
<th>Nominal Capacity</th>
<th>Axle Designation And Journal Size</th>
<th>Maximum Gross Weight On Rails Per Lb.</th>
<th>Diameter Of Body Center Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Ton</td>
<td>B-4¾ in. x 8 in.</td>
<td>103,000</td>
<td>11 3/4 in.</td>
</tr>
<tr>
<td>40 Ton</td>
<td>C-5 in. x 9 in.</td>
<td>142,000</td>
<td>11 3/4 in.</td>
</tr>
<tr>
<td>50 Ton</td>
<td>D-5¾ in. x 10 in.</td>
<td>177,000</td>
<td>11 3/4 in.</td>
</tr>
<tr>
<td>70 Ton</td>
<td>E-6 in. x 11 in.</td>
<td>220,000</td>
<td>13 3/4 in.</td>
</tr>
<tr>
<td>100 Ton</td>
<td>F-6½ in. x 12 in.</td>
<td>263,000</td>
<td>13 3/4 in.</td>
</tr>
<tr>
<td>125 Ton</td>
<td>G-7 in. x 12 in.</td>
<td>315,000</td>
<td>14 3/4 in.</td>
</tr>
</tbody>
</table>

Note:
The total weight on rails shown in table above is for four wheel trucks, four axles per car. For cars having six wheel, eight wheel, etc., trucks, the total
weight on rails is proportional to the number of axles under car.

2.1.5.21. Jacking Pads

All cars:

Height from top of rails to jacking pad—25 in. min. 45 in. max.

6. Section 2.2.1. Maximum Gross Weight on Rails

The maximum gross weight on rails is the limit weight of car (2.2.5.) plus the maximum weight of lading.

7. Section 2.2.2. Dead Load

The dead load is the weight of car body structure, all fixtures permanently attached thereto, and all appurtenances considered part of the car. For stress analysis it shall be permissible to use the estimated light weight of the complete car less the weight of the trucks.

8. Section 2.2.3. Load Limit

The load limit is the maximum weight of lading and is the difference between the stenciled light weight of car and the maximum gross weight on rails.

9. Section 2.2.4. Live Load

The live load is equal to the load limit, or any percentage thereof specified for design load.

10. Section 2.2.5. Light Weight

The light weight is the total weight of the empty car including trucks and all appurtenances considered part of the car.
11. **Section 2.2.6. Nominal Capacity**

The nominal capacity is any capacity, in multiples of 1,000 pounds, stenciled on car, based on its light weight, journal size, and gross weight on rails. In no event may the nominal capacity as stenciled on car or as shown in equipment register exceed the load limit.

12. **Section 2.2.7. Cubic Capacity**

The cubic capacity is the available loading space of the car. The cubic capacity shall be calculated in cubic feet based on the inside dimensions shown on the design drawings.

For box, refrigerator, and stock cars, the cubic capacity shall be used on the length between end walls and an inside height equal to the distance from top of floor or floor racks to lowest point of carline, roof, side plate, or other structure, whichever is lower. The inside width should be at the narrowest points between belt rails, etc., and on cars with side wall fillers the distance between fillers when collapsed against side walls.

For open top hopper cars and gondola cars, the cubic capacity shall be calculated as the volume below top of sides.

For covered hopper cars, the cubic capacity shall be calculated as that volume below the lowest portion of the hatch frames.
An example of the stenciled information mentioned in the foregoing and related data is shown in Figure 7.
CAR HIEROGLYPHICS
CHAPTER III

PASSENGER AND FREIGHT TERMINALS

Terminals are of major importance in rail transportation. A terminal is more than a place where the line-haul for freight and passengers stops and starts. It is a place where various necessary carrier operations take place, where changes in the shipment occur, and where various special services are performed for shippers.

A terminal provides a point of consolidation. This function is performed for the transportation of both freight and people. People are consolidated or concentrated into groups in the terminal according to the size of the transportation vehicle. People load themselves into trains thereby simplifying the problem of getting the concentration to be shipped onto the vehicle.

With goods, the concentration is similar. Freight moves to a terminal point, either by carrier-provided pickup vehicles or by the shipper's own actions, and is consolidated or concentrated into car load lots. The terminal provides the point for this concentration.

The function of dispersion is the opposite of concentration. This is also an important function of terminals which is performed for both people and goods. In intercity transportation, the terminal is the point of destination. From the terminal people disperse to their homes, offices,
jobs, and so forth; goods disperse to their ultimate destination. Again, the fact that people unload themselves and generally provide their own dispersion makes this function fairly simple in passenger transportation. However, in the movement of freight, the delivery aspect of the dispersion function is expensive and time-consuming. The function remains the same whether the goods are in LCL (less than car load) or carload lots.

The two functions of concentration and dispersion are often carried on simultaneously, of course.

Terminals provide a place where shipments are serviced in various ways. In passenger transportation, the provision of waiting rooms and ticketing are the prime shipment-service functions of terminals. In the transportation of goods, the same functions take place but in a somewhat more complicated manner. Thus terminals provide storage and elevation for goods being shipped, and protection for goods against the elements, theft, and damage. This is, essentially, the same service as a passenger waiting room provides. Terminals likewise provide a point at which routing and billing of shipments take place.

Terminals require large amounts of geographical space. This land is usually expensive prime industrial land. Much of the fixed cost of railroads is involved with expensive terminals in prime locations.
A. PASSENGER TERMINALS

1. General. The designation "passenger terminal" as here employed includes all the facilities for the passenger station proper, mail and express service, track and street approaches, and such other auxiliary or accessory features as may be included within a prescribed boundary or terminal zone.

The engineer having charge of the design of a contemplated terminal should make investigation of terminal situations similar to the one in contemplation; examine the facilities there provided and see how they function; obtain comments from the men operating the terminals visited; get their suggestions as to improvements which experience has taught them might be made to advantage.

A passenger terminal project should be located and designed to coordinate as far as reasonably practicable with other civic activities. Frequently it is found desirable to make general civic improvements at the same time the terminal is being constructed. Modification of street approaches is almost always involved. The costs should be assumed by the parties benefited. Close cooperation between the terminal committee, the planning board of the city, executive officers of the city, and perhaps other civic groups is necessary.
The design of a passenger terminal should provide for anticipated demands during at least the first twenty years of its life, and provision should be made for such subsequent expansion as may be reasonable under the circumstances.

The site for the terminal should have a balanced maximum composed of the following characteristics:

a. Accessibility—having due regard to modern methods of transportation, land values, and economic requirements.

b. Sufficient size and suitable shape to provide for a proper number and length of tracks, and to provide for future growth of both.

c. Ease of approach from all the associated rail lines, without excessive curvature or gradient, and preferably without grade crossings.

d. Room for proper bypass tracks and for the spread of ladder tracks to provide for free movement and to prevent a tie-up of the yard from derailment at the throat.

e. Room for auxiliary facilities conveniently located, such as:

   (1) Baggage, mail and express.

   (2) Parking space for sleeping, private and business cars.

   (3) Automobile parking.
2. **Track Arrangement.** The track arrangement should take into account the following considerations:

a. The track layout should be such as may be required to accommodate without interference the contemplated schedule movement of trains and the tributary switching movements to and from the station, with a margin for extra sections or delayed trains, as well as for any predictable increase in volume of traffic.

b. The track layout should be designed with turnout lengths as required for the proper signal indications, and necessary clearances as required for operation of track circuits so that a system of fixed signals or interlocking may be installed whenever desired without restricting the use of any of the routes or the necessity of additional track changes.

c. Station tracks should be provided sufficient in number to accommodate at one time the contemplated schedule movement of trains, with a liberal margin for extra sections and off-schedule arrivals or departures, and should be of such clear length and lateral spacing as may be required to fit the station platform layout and to accommodate without congestion the essential functions of the station platform service.

d. A sufficient number of station tracks long enough to accommodate the maximum length trains,
and so located as to assure flexibility of operation, should be provided. Possibility of future increases in lengths of trains should be considered.

e. The through and loop types of station are superior to the stub station from the standpoint of train operation.

f. Freight or industry connections on the station approach tracks or on lines within or adjacent to the terminal zone should be so arranged as to avoid or minimize interference with passenger train traffic.

3. Street Approaches. Street approaches should receive particular attention in the overall planning to provide convenient access and sufficient capacity but bypassing areas of traffic congestion. Separate routes should be provided so that pedestrian traffic and vehicular traffic can be safely and expeditiously handled. Ample accommodation for vehicles handling mail, baggage and express should be provided in a manner that will not impede the free movement of public transportation vehicles, private conveyances, and pedestrian traffic.

The desirability of providing subways for pedestrians to reach the opposite sidewalks of adjoining streets without crossing at grade should be considered. Subsequent installation of service facilities may make it impractical to provide such passageways in the future.
Ample provision should be made for convenient access to public transportation services and taxicab service within or adjacent to the station. It is essential that taxicabs be able to promptly reach an unloading point, move freely to a holding area, and to reach a loading point for passengers leaving the station without interference to other vehicular traffic.

4. Station Proper. The station proper includes all the facilities required for the complete accommodation of passengers and their belongings between the public entrances and the trains: also such facilities as the railway company shall provide for the handling of mail and express.

The following considerations are important in the design of the station proper:

a. All of the essential functions of the main building should be served on a common floor level, or levels so nearly common as to be connected by moderate ramps, and so related if possible to the station track level that no stairways shall be required to reach the station platform level in stub end stations or to reach the thoroughfares over or under the tracks, as the case may be, in through stations.

b. The lobby should front upon the principal public entrances and exits, and it, solely or together with
the passenger concourse, should be the business area of the station. The principal station facilities, such as information booths, ticket office, baggage check counter, parcel check room, telephone and telegraph facilities, parcel checking lockers, etc., should be located in proper sequence along the line of travel and clearly indicated to avoid confusion and to reduce the walking distance of passengers to a minimum.

c. An adequate and conspicuous train bulletin board and a public announcing system should be provided.

d. Unless its function is combined with that of a waiting room, a separate passenger concourse is essential in a large station. Such a concourse is used effectively in many stations as a passageway which permits arriving passengers to reach the street or departing passengers to enter from the street without passing through the lobby.

e. It should be possible, and is exceedingly advantageous in the case of suburban service for passengers to travel between the passenger concourse and the street without passing through waiting room or blocking its exits.

f. The elimination of conflicting lines of travel is very desirable and should receive careful study in the design of the station, particularly as regards
the segregation of inbound from outbound passengers, and of commuters from through passengers.
g. The required clear width of passenger concourse depends upon the character and amount of traffic and the number of its entrances and exits. The concourse should be large enough to permit the gathering of a full trainload at a gate without a blockade, but should be so arranged that it will not be a convenient thoroughfare for people who are not passengers.
h. A train concourse is advantageous, as it permits serving of one station platform by several gates or, conversely, the serving of several platforms from one train gate. In stub stations it permits trucking from one platform to another without entering the passenger concourse.
i. Ticket offices should be located adjacent to the direct line of travel, so arranged that passengers waiting to secure tickets will not interfere with the general flow of traffic.
j. The baggage check rooms should be easily accessible to inbound and outbound passengers and where the amount of business justifies, separate counters should be provided for receiving and delivering baggage. Self-service checking lockers should be installed at convenient locations.
5. **Passenger Ramps.** Ramps provide ideal means for movement of passengers to and from station platforms if they can be so installed as not to increase materially the distance traveled by passengers, and do not materially decrease the space on the station platform available for the accommodation of trains. Good results can be accomplished in many cases by the use of both stairways and ramps.

The gradient for passenger ramps preferably should not exceed 7 percent. The ramp surface should be finished with an abrasive or non-skid material.

6. **Station Platforms.** In planning a passenger terminal it is important to devise a coordinated arrangement between the track layout and the station proper which will, at reasonable cost, provide maximum convenience, expedition, and economy in rendering all the platform services.

Particularly at heavy duty stations, it is extremely desirable that baggage, mail and express trucks shall not ordinarily have to traverse or occupy platform space being used for the accommodation of passengers.

Determination of the type of platform (i.e., combined or separate trucking and passenger) best suited to a particular situation is dependent upon the character and volume of the various kinds of traffic handles, the type of station (i.e., stub, through or loop), the
location and type of approaches to the platforms for the various kinds of traffic, the relation of the various approaches to each other, the relative lengths of platforms and trains, space available for station track and platform development, and the method of operation.

7. Relative Size of Facilities. The relations which should exist between business handled and the size of facilities is subject to variation due to local conditions, class of traffic, type of service rendered, large variation in estimates of normal rush-hour business handled, and the varying ideas of what constitutes adequate service.

The following tables represent, under average conditions, the relation which should exist between business handled and the size of through passenger (not suburban) station facilities.
<table>
<thead>
<tr>
<th>Station Facility</th>
<th>Unit</th>
<th>250</th>
<th>500</th>
<th>750</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of main waiting room</td>
<td>100 sq. ft.</td>
<td>30</td>
<td>53</td>
<td>72</td>
<td>89</td>
<td>112</td>
<td>128</td>
<td>155</td>
<td>178</td>
<td>200</td>
</tr>
<tr>
<td>Seating capacity of main waiting room</td>
<td>No. of seats</td>
<td>143</td>
<td>213</td>
<td>270</td>
<td>315</td>
<td>400</td>
<td>465</td>
<td>570</td>
<td>665</td>
<td>750</td>
</tr>
<tr>
<td>Area of women's waiting room</td>
<td>100 sq. ft.</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>14</td>
<td>17</td>
<td>23</td>
<td>29</td>
<td>35</td>
</tr>
<tr>
<td>Total area for waiting purposes</td>
<td>100 sq. ft.</td>
<td>55</td>
<td>88</td>
<td>116</td>
<td>137</td>
<td>167</td>
<td>195</td>
<td>238</td>
<td>275</td>
<td>306</td>
</tr>
<tr>
<td>Total seats in waiting areas</td>
<td>No. of seats</td>
<td>190</td>
<td>300</td>
<td>390</td>
<td>470</td>
<td>590</td>
<td>700</td>
<td>880</td>
<td>1050</td>
<td>1200</td>
</tr>
<tr>
<td>Total area of lobby, concourse and all waiting rooms</td>
<td>100 sq. ft.</td>
<td>80</td>
<td>152</td>
<td>208</td>
<td>256</td>
<td>320</td>
<td>376</td>
<td>472</td>
<td>552</td>
<td>624</td>
</tr>
<tr>
<td>Area of men's toilet rooms</td>
<td>100 sq. ft.</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>13</td>
<td>15</td>
<td>20</td>
<td>26</td>
<td>31</td>
</tr>
<tr>
<td>Number of men's water closets</td>
<td>Number</td>
<td>6</td>
<td>9</td>
<td>12</td>
<td>15</td>
<td>19</td>
<td>23</td>
<td>29</td>
<td>35</td>
<td>41</td>
</tr>
<tr>
<td>Number of urinals</td>
<td>Number</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>15</td>
<td>17</td>
<td>20</td>
<td>23</td>
<td>25</td>
</tr>
<tr>
<td>Number of men's lavatories</td>
<td>Number</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>13</td>
<td>18</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>Area of women's toilet rooms</td>
<td>100 sq. ft.</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>13</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Number of women's water closets</td>
<td>Number</td>
<td>7</td>
<td>9</td>
<td>12</td>
<td>14</td>
<td>17</td>
<td>19</td>
<td>23</td>
<td>27</td>
<td>30</td>
</tr>
<tr>
<td>Number of women's lavatories</td>
<td>Number</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>13</td>
<td>17</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>Area of ticket offices</td>
<td>100 sq. ft.</td>
<td>4</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>14</td>
<td>17</td>
<td>21</td>
<td>26</td>
<td>--</td>
</tr>
<tr>
<td>Number of ticket windows</td>
<td>Number</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>11</td>
<td>13</td>
<td>16</td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>Number of telephone booths</td>
<td>Number</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>13</td>
<td>19</td>
<td>25</td>
<td>31</td>
</tr>
<tr>
<td>Total area of dining and lunch rooms</td>
<td>100 sq. ft.</td>
<td>9</td>
<td>14</td>
<td>19</td>
<td>24</td>
<td>34</td>
<td>43</td>
<td>63</td>
<td>83</td>
<td>102</td>
</tr>
<tr>
<td>Number of seats in dining and lunch rooms</td>
<td>Number</td>
<td>34</td>
<td>53</td>
<td>72</td>
<td>93</td>
<td>129</td>
<td>173</td>
<td>249</td>
<td>327</td>
<td>407</td>
</tr>
<tr>
<td>Area of kitchen</td>
<td>100 sq. ft.</td>
<td>5</td>
<td>8</td>
<td>11</td>
<td>14</td>
<td>20</td>
<td>26</td>
<td>38</td>
<td>50</td>
<td>62</td>
</tr>
</tbody>
</table>
TABLE IV

SIZE REQUIREMENTS FOR BAGGAGE FACILITIES

<table>
<thead>
<tr>
<th>Station Facility</th>
<th>Unit</th>
<th>250</th>
<th>500</th>
<th>750</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of baggage room</td>
<td>100 sq. ft.</td>
<td>20</td>
<td>33</td>
<td>45</td>
<td>60</td>
<td>87</td>
<td>112</td>
<td>166</td>
<td>219</td>
<td>272</td>
</tr>
<tr>
<td>Baggage room tail-board frontage</td>
<td>Lin. ft.</td>
<td>38</td>
<td>62</td>
<td>79</td>
<td>95</td>
<td>125</td>
<td>150</td>
<td>194</td>
<td>230</td>
<td>263</td>
</tr>
</tbody>
</table>

| Parcel Check Room Facilities Required for the Indicated Number of Parcels Handled Daily |
| Unit |
| 250 | 500 | 750 | 1000 | 1500 | 2000 |
| Area of parcel check room | 100 sq. ft. | 4   | 6   | 8   | 10   | 14   | 18   |

| Hand-Baggage Facilities Required for the Indicated Number of Pieces of Hand-Baggage Handled Daily |
| Unit |
| 250 | 500 | 750 | 1000 | 1500 | 2000 | 3000 |
| Area of hand-baggage facilities | 100 sq. ft. | 4   | 6   | 7   | 8    | 10   | 12   | 16   |
B. CHARACTERISTICS OF PASSENGERS

The following characteristics of passengers are of general interest in the design of terminals in which a particular type of passenger is predominant.

1. Through Passengers.
   a. Transfer passengers occupy a station for a maximum length of time and require more extensive facilities per passenger than resident through passengers.
   b. Decreasing the time interval between incoming and outgoing trains decreases requirements per passenger for waiting room space and for certain other facilities.
   c. The number of passengers handled during the rush hour does not alone determine the size or number of facilities required. Local conditions must be studied, as they affect requirements of any particular situation.
   d. The size or number of facilities must be modified to make allowance for:
      (1) Time of arriving and departing trains, and the span in minutes between them.
      (2) The ratio between passengers commencing or terminating their journey and transfer passengers.
      (3) Number of hold-over passengers arriving or departing outside of the rush hour but occupying
space and requiring service during a portion of
the rush hour.
(4) Departure from a reasonably uniform spread
of passengers entering and departing within the
rush hour.

2. Suburban or Commuter Passengers.
   a. Suburban passengers occupy a station for a mini­
mum length of time and move faster than the through
passenger, therefore requirements in the way of
station facilities per passenger are substantially
less for a suburban passenger than for a through
traveler.
   b. When suburban business is heavy, it is desirable
to separate the through and suburban service, as
their requirements are not similar. This may be
done by handling the two classes of service at:
      (1) Different levels.
      (2) Different sides or ends of the station.
      (3) Different stations, one beyond the other.
   c. Indicator boards are the only directional infor­
mation required, as a rule, by commuters. They should
show track number, scheduled leaving time, and essen­
tial identification of train.

C. FREIGHT TERMINALS

The designation "freight terminal" as here employed
includes all the facilities provided by a railway company, or
by railway companies in common, or acting jointly, as the case may be, to handle freight to or from or through and within a given district on behalf of such railway company or companies.

Conditions of demand and feasibility vary widely, and generally each case of constructing an altogether new layout on a large scale, or of remodeling or consolidating an extensive existing layout, constitutes an essentially basic problem.

The engineer is confronted with the problem of designing various yards, each for its special functions; miscellaneous track for particular uses; freight station for the receipt and delivery of less than carload freight, or for its transfer or storage, or for the special handling of perishable freight, or for the receipt and delivery of carload freight in different categories; icing facilities for refrigerator and top icing carload business; facilities for handling rail-truck freight equipment; waterfront facilities, enginehouses and shops for the housing, servicing and repair of locomotives in service; locomotive fueling facilities; shops and facilities for the current repair of cars in service; power cranes for the loading, unloading and transfer of bulky or heavy cargo units; weighting facilities; heating and power plants; and a system of thoroughfare tracks that shall weave this complex assemblage into a unity of smooth and expeditious performance. Each of these features and its appurtenances, with a full knowledge of the average and maximum demands to be made upon it, must be carefully designed to fulfill its particular functions expeditiously and economically.
Each unit of the complete assembly must be located with relation to the whole, and must be interconnected to provide for all movements through and within the terminal in the shortest possible time and with minimum interference of one with another. Terminal delays constitute a very serious handicap to the expeditious movements of freight and a material decrease in such delays will justify a large investment. Increasing costs require that older freight terminals should be studied carefully for improvements to reduce operating and maintenance costs.

In any case where relief is sought because an existing terminal imposes excessive delays, a thorough study should be made to determine the advisability of providing a layout wholly new and correct in design, before attempting to remodel the existing facilities.

1. Freight Houses. Where there is a choice of sites, the following factors should be considered in the selection: (a) highway accessibility, (b) nearness to city pick-up, (c) space for future expansion, (d) proximity to existing switching service, (e) space for a new yard or proximity to existing supporting yard, (f) the possible inclusion of rail-truck freight facilities, (g) economies of location near terminal yards even though remote from city, and (h) relative land values.

The ultimate size of the freight house should be determined in advance from consideration of the type of
average amount of traffic to be handled through it in the first instance, the variation of the peak from average requirements and the probable growth of requirements during the period in which the cost of the structure can be amortized. The initial size should be determined by the immediate needs.

One factor in obtaining minimum operating costs will result when house tracks are placed between inbound and outbound freight houses or platforms with trucking connections. This factor applies to all large facilities. These connections can be in the form of tunnels, grade crossings, trucking bridges, or by extending the trucking platform around the stub ends of tracks.

The factors of design for a freight house, such as car capacity, tailboard frontage, floor area, width of house, platforms, conveyors, bridges, ramps and roadways; and in the case of a two-level house, the capacity of elevators if used, should be so correlated that no one factor will limit the capacity of the house.

The design and layout of the facilities should be such as to require the minimum amount of labor to handle freight, and where economically feasible, mechanization should be exploited to the maximum.

The economies of protecting the facility and operation from adverse weather should be considered.
The size and shape of the house should take into consideration the following: (a) the number of house tracks, (b) the number of cars to be set, (c) total tailboard length, (d) platform space required, (e) location of roof columns, (f) type of operation to be accommodated, such as transfer of freight between car and car, between car and truck, forwarder, shipping association, etc., and (g) the type of mechanical freighthandling equipment to be used, if any.

Platform widths should be arrived at by allowing from six to eight feet for each conveyor or motorized travel lane, with sufficient standing space outside of travel lanes for parking freight trucks. Standing space ten to fifteen feet wide adjacent to car side and that much or more at tailboard side is desirable. Larger standing areas may be required, depending on the amount of freight and length of time it is to be held on floor.

Space should be provided for offices, toilets, locker and lunch room, warm and cool rooms, cooperage shop, storage for blocking and bulkhead material, and maintenance shop for platform equipment.

2. Freight Transfer Station. A freight transfer station should be provided where it is desired to consolidate LCL freight from a greater into a lesser number of cars, or vice versa, or where it is desired to transfer package freight from foreign line cars into home line cars for forwarding to destination.
The width of transfer platforms should be sufficient to accommodate the parking of trucking equipment at tracks sides, and lanes for movement of the type of equipment used in moving freight from car to car.

3. **Produce Terminals.** Produce terminals are designed for expeditious and economical distribution of fruits, melons, vegetables, and sometimes butter, eggs and poultry, meat and meat products, frozen foods, fish and sea foods, and dry groceries.

Terminals should be located and designed to handle peak business. The location must be convenient for dealers, with easy access over wide and well improved highways and easy gradients. It should have convenient railway connections. A location adjoining a railway terminal yard is advantageous.

4. **Water Front Terminals.** A water-front terminal provides facilities for the transfer of shipments or cargoes from ship or barge to railway cars or trucks, and from railway cars or trucks to ship or barge. The facilities consist of docks, wharves, piers and warehouses, with loading and unloading equipment and necessary railway tracks and roadways for transfer purposes.

A dock is the facility at which ships are moored. A dock may be parallel to the shore line, in which case it is called a wharf. If a dock is built where ships can
be moored on both sides, the structure is called a pier. Wharves and piers may be open or covered, depending on the protection needed for the commodity handled. Some piers are used for short-term storage as well as the transfer of goods.

In designing a water-front terminal, consideration must be given to the type and quantity of freight to be handled, and to the trackage and track arrangement required so that proper switching to and from docks can be provided. The facilities on land are provided to economically load and unload commodities. Docks should also be equipped with necessary conveyors, pipelines, car dumpers, cranes, hoppers and any other facility necessary to handle special commodities.

Large structural cranes may be built over docks to extend over ships to facilitate the handling of loads. Conveyor systems may be built to move commodities in bulk or in units. Some important docks specialize in handling one commodity, such as ores, coal, grains, fruit, automobiles or equipment, or to transfer railway cars and certain merchandise.

Wharves may be served by tracks parallel to the wharf. Occasionally wharves are equipped with tracks constructed adjacent to the water's edge, and goods are handled directly between the ship and railway cars.
Piers are usually provided with tracks running down their center or along the edge. Transfer bridges are used for handling railway cars to and from ships, car floats or ferries.

Various yards for railway cars are a part of a waterfront terminal. A storage yard is usually necessary for cars held for loading or unloading and to accumulate special cars for a particular ship. A classification yard, with or without receiving and departure yards or storage and car repair yards, may be provided, depending upon the volume of traffic handled.

Adequate storage space (ground pier or covered warehouse) is essential for commodities awaiting shipment. The arrangement of these yards and storage space is important so there will be the minimum of interference in handling cars between the yards and unloading spots.

5. Rail-Truck Loading and Unloading Facilities. Three types of facilities are used for rail-truck loading:

a. *End loading* of railroad cars is accomplished by backing the tractor-trailer combination on a flat car or string of cars from a platform or ramp constructed to car-floor height.

b. *Side loading* can be accomplished by the use of a fork lift truck, a platform at car-floor height, or by the use of special equipment which permits separation of the trailer body from its wheels and transfer of the body to a flat car.
c. **Overhead loading** can be accomplished by the use of a traveling, overhead rail-mounted or tire-mounted crane. Either the entire trailer or the trailer body without wheels can be handled from the roadway adjacent to the track.

Determining factors relative to the location of the facility depend upon the potential volume of traffic, its origin and destination within the service area, the convenience of highway access and the necessity for economical and expeditious movement of railroad cars. As many as eight (90 foot) cars in a string can be efficiently used in end loading operations. A trailer parking area of at least one and one-half times the trailer capacity of the loading tracks should be planned. Many installations have a parking area with a capacity two or three times the track capacities.

There may be advantages to have the track area depressed in relation to the parking area, driveways and ramps. The tracks used to spot cars for loading should be on tangent.

The type of paving or surfacing of parking area, driveways and ramps should be selected to suit the intensity of use anticipated. The ramps may be of wood, concrete, or earth-filled crib construction. Platform walkways adjacent to tracks should be considered to provide easy movement of men from one car to another. Portable ramps can be used to eliminate need to turn cars.
Lighting and power outlets in the track area should be furnished to facilitate tie-down operations. Parking areas should be lighted if there is considerable night operation. Traffic lines will facilitate parking and handling of equipment.

The larger operations will require an office and locker room at the site. A truck scale may be required. Fencing may be worthwhile to assist policing.

6. **Automobile Transport Terminals.** The loading and unloading of finished automobiles requires equipment and plant that contribute to the overall expeditious distribution from assembly plants to local dealers. Automobile companies place a premium upon total time in transit and consider all aspects of equipment utilization, interest charges and delivered auto condition.

Loading is usually accomplished at an assembly plant, on automobile company property, by the automobile company, or its contractor. The actual facilities utilized are similar in nature to the unloading facilities; however, there are exceptions which must be given consideration on an individual basis. Exceptions can vary from loading inside the plant with multi-level cars handled by a transfer table to and from a support yard to simply driving the finished vehicle to a more conventional loading facility located at some convenient point other than the plant itself.
Unloading, on the other hand, is usually accomplished by the rail carrier or its contractor, on railroad company property, utilizing facilities provided by the railroad company. The contractor engaged by the railroad company to actually perform the unloading task will more than likely be the same organization engaged by an individual automobile company to prepare and deliver units via highway to dealers. It is, therefore, suggested that close consultation between all entities involved in the automobile distribution process be maintained during the design phase in order to assure an efficient and usable facility.

The following features should be considered in the selection and design of an automobile transport terminal:

a. Location of the terminal area should be selected for its proximity to dealers in the area in order to reduce highway mileage to the minimum. It should be located with respect to the railroads main trackage to minimize switching, spotting and pulling delays. Consideration should also be given to the potential of vandalism to avoid missile damage and theft.

b. The size of the facility, its trackage, ramping and vehicle storage areas, should be large enough to handle the maximum expected load under the proposed operating conditions. Some of the conditions to be considered are: the average work week, type and quantity of vehicles handled and the number of
agencies using the same facilities. The auto production and distribution process by its very nature requires a considerable degree of advance planning including volume predictions. (All of the auto manufacturers make rather good volume predictions which can be utilized for planning purposes.)

c. It is recommended that vehicular operating and storage areas be paved and as flat as possible, limiting loading and unloading angles to eliminate bumper damage. Gradients sufficient to keep all accumulation of water off the area should be provided.

Parking spaces should be clearly marked in an arrangement with ample center distances, thereby maximizing turning radii and minimizing door contact.

d. The entire area should be fenced and of such a nature as to discourage unauthorized entry and theft. A common solution is barbed-wire-topped chain link fencing. Gating and fencing should be so arranged as to segregate new car storage from employee parking. To minimize the possibility of theft, one auto manufacturer recommends that new vehicles can only be driven out of the storage area over a haul-away dock. Provision for checking employees and visitors in and out should be made. Locking devices on all gates are recommended.
e. Lights should be provided for the entire area of sufficient intensity to be adequate for loading, unloading, inspection and/or security.

f. Unloading Equipment: Unloading equipment should allow quick driveoff of automobiles. Where economically justifiable, the ramp should be power controlled vertically for adjustment to deck levels as well as horizontally to adjoining tracks. Manufacturers should be consulted regarding maximum ramp angle permitted.

g. The provision of a loading dock where highway trailers can be spotted for loading is recommended in order to reduce loading angle and decrease loading time. The preference of the specific contractor should be determined to assure compatibility with his equipment, the dimensions and extent of, or even the need for, this feature.
CHAPTER IV

SIGNALS AND COMMUNICATION

Communications and signals have been termed "the eyes and ears of the railroad." They make possible the fast and efficient service provided by modern railroad transportation. The use of radio and electronics in communication systems has greatly widened their effectiveness and usefulness. Procedures formerly impossible to accomplish are now easily performed with the use of modern communication devices. As an example, data is electronically transmitted from the field to computers located in central offices. The use of electronic equipment reduces paperwork, speeds up operations, and eliminates transportations and errors.9

The purpose of railroad signals is the transmitting of information to employees in charge of the operation of trains. Safety was undoubtedly the original purpose for which signals were installed and the fundamental principles were centered around this original purpose, although in actual application it is impracticable to separate the principles pertaining to safety from those pertaining to facility of train movement, and since they are so interrelated they will be stated without regard to either safety of train movement or the facilitation thereof.

The principles are submitted as fundamentals of fixed signaling regardless of whether they be of the semaphore,
color light, position light or color position light type. They do not refer to construction details, which details may properly be covered by specifications prepared, or in the course of preparation, by the Signal Section, Association of American Railroads.²

A. HISTORY ³,⁹,⁵³

Modern communication began when on May 24, 1844, Samuel Finley Breeze Morse sent the now historical first telegram—"What hath God wrought!"—over the first telegraph line from the chamber of the United States Supreme Court, then in the Capitol at Washington; to the Baltimore and Ohio Railroad station in Baltimore. The telegraph revolutionized world communications, and in this respect proved a great social, economic and educational force.

The railroads, throughout the early years, encouraged the expansion of the telegraph. They provided right-of-way for most companies, and trained dispatchers and agents to use the telegraph so that practically every railroad station became a telegraph office to serve the public. Because of the railroads' interest in the telegraph, it was not long before most of the important cities and towns in the country were served by a telegraph system.

The first record of the telegraph being used for train dispatching is credited to the Erie Railroad on September 22, 1851. The telegraph having been in service on a number of
railroads since 1844, it no doubt had been used in connection with the movement of trains prior to 1851.

Following Morse's invention of the telegraph many improvements were made by telegraph engineers in equipment and methods of transmission. The single line telegraph was followed rapidly by the development of several different types of repeaters which enabled transmission over greater distances. This was followed by the duplex whereby two messages, one in each direction, could be sent simultaneously over the same wire. In 1874 Thomas Edison invented the quadruplex whereby four messages, two in each direction, could be sent simultaneously. Single line repeaters and duplex were actively serving the industry at this time.

The first use of telephone for train dispatching was in 1879 on the nine mile narrow gauge Boston, Revere Beach and Lynn Railroad where call bells, transmitters and receivers were installed. The first known use for train dispatching on a standard gauge railroad was on the Ravenna Schenectady Branch of the New York, West Shore and Buffalo Railroad, now the New York Central, in January 1882.

From 1882 on there was a continual expansion of railroad telephone train dispatching; numerous types of calling systems came into use and were rapidly replaced by later and more modern types. The conventional telephone which was first used was replaced by a high impedance type of telephone necessary where a large number of instruments were
connected to the same circuit. The presently used type 501 telephone came into use about 1920.

Coming into wide use in more recent times are teletype, CTC circuits via microwave and microwave to remotely controlled VHF radio stations for both train dispatcher to train and telephone PBX to on-track and highway mobile radio communication. There is also movement toward the universal use of two separate point-to-mobile radio systems and utilizing inband UHF repeaters to bring these services into larger terminals pending the day when microwave radio is used on a system wide basis.

Another innovation is the use of speakers in yards. Speaker systems have become standard equipment in a majority of yards. These systems are on the desk type consoles located in the Yardmaster's towers. The Yardmasters have instantaneous access to the speakers located in the yard areas. Each low level speaker acts as a microphone which allows two way communications with the Yardmaster. Speakers are also equipped with push button arrangements which activate lights on the Yardmaster's console indicating to the Yardmaster that a call has been originated from a particular speaker.

B. AUTOMATED CAR IDENTIFICATION

One of the significant innovations that has been under-way for some years is a nationwide information system which is able to provide instant identification and location of
freight cars. Automated Car Identification (ACI) has been used by some individual railroads for several years. The extension of these individual systems into a nationwide network will provide several benefits:

1. A shipper will be able to pinpoint the location and progress of individual shipments.

2. The system will provide information that will readily identify locations where additional cars are needed, and locations where there are surplus cars.

3. By optimizing car movements based on identification of needs and surpluses, car utilization can be expected to increase by up to 10 per cent. This is equivalent to an increase of rolling stock by the same amount.

4. Maintenance procedures can be integrated with the information system. More optimal maintenance schedules will decrease maintenance costs.

The concept of the ACI system is essentially simple. A scanning device at yards and other recording points scans multicolored service stripes on the freight car which serve to identify it individually. The scanning device is capable of reading the identification at speeds up to eighty miles per hour in the most inclement weather. The scanned information is transmitted to the railroad's own computer which stores the input in an information data bank. By interconnections of the individual railroad's computers with a central computer system in Washington, information concerning
individual freight cars is available to all railroads on computer demand. This interconnecting system is known as Tele Rail Automatic Information Network (TRAIN). Delays in the implementation of the system have not been due to technological difficulties, but rather from the high cost of the computers for small railroads and incompatibility of existing computer systems. As these problems are resolved the system will be available on a nationwide basis.

C. SIGNALS

Signal installations have been important elements of the operating methods used by American railroads from the very earliest simple block signal systems to today's modern centralized traffic control system, which combines automatic block signaling, interlocking and communication facilities into an integrated traffic control system through which trains are both directed and protected by signals.

The four principal methods of operation employed on American railroads today are:

1. **Timetable and Train Orders, Alone**

   About one-half of the road mileage of U.S. railroads is operated by this method which involves movement of trains by authority of timetable schedules as modified by train orders. Most of the mileage operated by this method is single track line with extremely light traffic handled under favorable conditions.
2. **Timetable, Train Orders and Manual Block Signaling**

This form of operation is similar to that listed above, except that an independent block signal system supplements the basic authority for movement conferred by timetable and train order. The restrictive indication of the block signal supersedes any authority conferred by timetable and train order, but "clear" indication of the block signal cannot be accepted as authority for movement not previously conferred by timetable or train order. In the typical situation under this method, the operator at a wayside station acts as the instrumentality of the train dispatcher for delivering orders to trains and also acts in conjunction with stations on either side to display the proper signal so that use of the block between stations can only be authorized to one train, except in some cases where a second train in the same direction is permitted to enter the block under premissive restrictions.

This system of operation is predominantly a single track system used on approximately 25,000 miles of single track and less than 1,000 miles of double track line U.S. railroads. In general, it is used on lines of light or moderate traffic where relatively long blocks between offices can be tolerated.

3. **Timetable, Train Orders and Automatic Block**

This is also a "double-check" system in which the
signal system supplements the authority for movement granted by timetable and train orders. The block system is automatically actuated by the presence of a train in a particular section of track. The signals do not convey authority for movement beyond that already in possession of the train through timetable authority or train order rights. In this train actuated system, there is no need for personnel to operate the block system and the ability to provide much shorter "blocks" at low cost is present. About 33,000 miles of single track road and 22,000 miles of road with two or more main tracks are equipped for this operation on U.S. railroads.

The simplest type of signaling, providing only for safe separation of trains moving in the same direction, is required on double or multiple track lines where tracks have an assigned direction for movements. Train orders are usually quite simple for normal operation on double track and, in some cases, trains are authorized to proceed in the normal direction without specific train order authority. Train orders must, however, be used to authorize movements against the normal established current of traffic. Automatic signaling for single track lines is somewhat more complex, involving circuiting arrangements which must provide for both opposing and following movements.
4. **Train Operation by Signal Indication, Without Train Orders**

Under this system of operation, sole authority for movement of trains is conferred by indications of the signal system. Most of the 28,000 miles of road (34,000 miles of track) on U.S. railroads in this category can be classified as centralized traffic control and most of it includes the operation of interlocked groups of switches and signals within the territory. Control is vested in an operator or train dispatcher who uses the signal system to direct trains over the territory and to route them via the track of his selection. It is technically possible to provide a completely automatic traffic control system which would permit train movements to be made solely by signal indications.

D. **BLOCK SIGNALING**

Not long after the first railroad was built and traffic began to increase, it was recognized that following and conflicting trains would have to be kept apart in some manner. This resulted in division of the railroad into sections called "blocks", the use of which was governed by attendants at each end (usually a station). While some very early block systems are reported to have depended upon display of devices at one end of the block which could be seen from the other end, the first practical systems came after the availability of the electric telegraph system to railroad operation.
Authority for a train to occupy a block was indicated by a wayside signal or given by a token which the train would carry through the block.

The first wayside block signal consisted of a ball attached to a cord which was hoisted on a frame by a pulley arrangement. These signals were placed at the entrance to each block, where they could be seen by the approaching train. When the ball was raised to its highest position, the signal indicated that the block was clear. Thus, the origin of the familiarly used railroad term "highball". Not long after, the semaphore signal, operated by wires or pipe connections from the station, became the typical block signal.

American railroads sought to secure the safety advantages of block signaling without the heavy expenditures of manpower required for a system of short blocks and to minimize reliance on the human element for safety. Invention of the "track circuit" made it possible to have a train actuate its own protective signal and, thus, the first automatic block signal was born. The "track circuit" of the 1870's was nothing more than an arrangement wherein each block section was insulated from the adjoining section and an electrical circuit established by using the two rails as a path for the current. The basic continuous track circuit involved the application of energy from a battery across the rails at one end of the block, and a magnet device (relay) responsive to the battery energy at the other end (See Figure 8).
UNOCCUPIED BLOCK:
Track Current Flows Up
One Rail Through Relay
Coil, Returning Via
Other Rail. Relay Coil
Holds Armature Up,
Feeding Signal Current
to Green Bulb.

Signal Energy
Source

Green

Relay Coil
Energized

To Signal for
Advance Block

End of Block
Insulated Joints

Insulated
Joints

Coil De-energized
(Armature dropped)

Train Wheels Shunting
Track Circuit

OCCUPIED BLOCK:
Wheels of Train Furnish Low
Resistance Path for Current
in Track, Shunting Relay.
Dropped Armature Breaks Circuit
to Green Bulb.

NOTE: A power failure, broken connection in wire or
rail or burned out relay coil will drop relay and
call for Stop indication.

FIGURE 83
THE TRACK CIRCUIT
Interruption of the circuit would cause the relay to drop and the block signal to assume the "STOP" position. Interruption of the circuit came about when there was a train in the block, because the wheels of the train shunt the energy from the battery. Practically all advanced types of signal systems on American railroads have the track circuit as their foundation, and the track circuit has been employed to provide many functions not envisioned at its inception.

Early automatic block signal installations used primary batteries and motor-operated semaphore signals. As the signal art developed, various forms of light signals came into use, culminating in a signal called the "Searchlight" which is a very accurate mechanism arranged to project "Red", "Yellow" or "Green" indications through a single optical system (See Figure 9). In the middle 1920's a practical continuous cab signal system made its first appearance which, in effect, brought the automatic block signal into the cab of the locomotive. This system, in use on a considerable mileage of important railways, has for the most part supplemented rather than replaced wayside automatic block signaling.

From the first simple system of single block protection, automatic block signaling progressed to the interrelation of a number of consecutive blocks, with a system of signal aspects to meet most conceivable traffic situations. The block system has also been used to warn the train of a variety of conditions affecting train movement, other than the presence of another train.
COLOR-LIGHT

Main-line, high-speed use of 24-hour color-light signals became feasible in 1914 with the perfection of concentrated-filament lamps giving a satisfactory sighting distance in daylight with moderate current consumption. They are still favored by roads where curvature or other operating conditions prevent taking full advantage of the greater sighting distance of the more expensive searchlight signals. Roundels may be arranged in usual vertical row, or horizontally (Reading and Chicago & North Western), or in triangular grouping (New York Central and others). Design precautions are necessary to prevent sunlight reflections from producing false indications. Contrary to traffic signal practice, "Irish" arrangement (green on top) is usual.

POSITION LIGHT

Position-light signals were introduced in 1915, and are mostly restricted to Pennsylvania and affiliates (Norfolk & Western, Lehigh Valley). Single color permits use of fog-penetrating yellow in high signals, white in dwarfs. Indication can be read with one light in row out; each head can give four indications, including lower-quadrant 45-degree position used for permissive. Partial units may be used for interlocking and approach-medium indications requiring two heads. Lower unit being lighted only as necessary. Pennsylvania uses two special indications: circle of lights is instruction to lower pantograph; five bulb X is take-siding signal.

COLOR-POSITION

First used in their modern form in 1921, color-position signals are in use only on Baltimore & Ohio and related lines. Single main head is used, modified with lunar white or yellow markers above and below as necessary to provide high-, medium- and low-speed route indications, etc. Color of remaining lamp gives usable indication in case of filament failure. Lower-quadrant 45-degree position in lunar white is permissive aspect; upper white marker staggered to left with vertical green on main signal is approach medium aspect.

SEARCHLIGHT

Searchlight signals, using a single lamp and lens system to project three colors, appeared in 1910. Were improved in 1920 with compound lens system giving 1 mile range with as little as 3 watt power consumption. Relat-type mechanism moves miniature spectacle in optical path to provide varying aspects; since any reflected light will be of proper color, efficient mirror can safely be used behind lamp. Special deflecting lenses are used to provide best coverage for right- and left-hand curved track in approach to signal. Regular beam is extremely narrow — sights are provided on unit for accurate aiming at path of approaching cab.

FIGURE 93

TYPICAL SIGNALS
As the diagram in Figure 10 indicates, the two-block system is a somewhat crude approximation of the ideal train-spacing theory in which a train would carry along behind it a "zone of protection" exactly braking distance long at all times. With three-indication signals the zone of protection varies in a two to one ratio and a following train cannot move along uninterrupted closer than twice the braking distance in the rear.

This limitation would not be burdensome if traffic were evenly spaced throughout the day, or if it were not necessary for a train overtaking another to travel close behind its predecessor for some distance as the passing point is approached, or if all trains traveled at about the same speed and never had to make stops or observe slow orders. When very high-speed trains, particularly those including conventionally braked equipment, began to appear in the 1930's, however, the problem of track capacity became acute on many lines. Block lengths being determined by stopping distances for the fastest trains operated, respacing of signals would normally be indicated as the necessary prelude to hotshot schedules, with the result that slower trains would thereby be spaced so far apart that track capacity would be inadequate at times.

A general answer has been the installation of four-aspect, three-block signaling of critical sections of line, with a fifth aspect providing warning for four blocks in particularly
FIGURE 103
TWO BLOCK AUTOMATIC SIGNALLING
congested territory. As Figure 11 shows, multi-aspect signaling can provide for higher-speed trains with less sacrifice of capacity for slow trains, or it can handle denser traffic without delay while maintaining the same braking distance.

E. CENTRALIZED TRAFFIC CONTROL (CTC)²,³

The centralized traffic control system is a form of automatic block signaling in which control of certain signals has been vested in the train dispatcher, or control operator, for purposes of establishing priority for train movement in accordance with the wishes of the train dispatcher.

With the exception of the invention of better components and the design of cab signal systems, basic automatic block signaling has not changed appreciably through the years. The block signal system has been the vehicle for operation of train control and speed control systems which physically enforce obedience to signal indications.

The trend towards interdependence of signaling and communications systems on railroads is becoming more pronounced. C.T.C. is a combination of signal and interlocking components held together with a communication (control) network. Today's signal systems can be controlled from any desired location, whether adjacent to the territory controlled or far removed from the property. The communication system used for the control can be used as the vehicle for transmission of signal and interlocking indications and also to transmit data from outlying points to the central office.
RETAINING OLD SIGNAL SPACING BUT PROVIDING THREE-BLOCK SYSTEM WITH ADDITIONAL ASPECT (APPROACH MEDIUM) BETWEEN CLEAR AND APPROACH ALLOWS 25 PER CENT GREATER TRACK CAPACITY THAN RESPACING SIGNALS, WITH SHORT-BLOCK ADVANTAGE IN CASE RESTRICTIVE INDICATION IS EN- WOULD LIMIT SPEED AND CAPACITY.

FOURTH INDICATION MAY ALSO BE GIVEN BY DOUBLE YELLOW OR SINGLE FLASHING YELLOW ASPECT, RETAINING SINGLE RED, YELLOW AND GREEN FOR STOP, APPROACH AND CLEAR ASPECTS; NO SINGLE ASPECT HAS BEEN UNIVERSALLY ACCEPTED.

FOUR-BLOCK, FIVE-INDICATION SIGNALING EFFECTS A FURTHER INCREASE IN TRACK CAPACITY, IS USED MOSTLY IN APPROACH TO BOTTLENECKS WHERE TRAINS ARE LIKELY TO RECEIVE RESTRICTIVE INDICATIONS OFTEN, NEED TO BE ABLE TO RESUME SPEED PROMPTLY.

FIGURE 113

MULTIPLE ASPECT SIGNALING
The development of the interlocking machine from a simple mechanical device, capable of operating switches and signals in a very restricted area, to the very extensive modern route type systems of today, is a story of application of improved technology to the safety and economy of railroading.

Simple mechanical frames for operation of a group of switches were first mechanically interlocked to force a sequence of operation as a matter of safety. These devices, first developed in England, antedated automatic block signaling by several years. The first installations in the U.S. were of English manufacture.

In these early installations the machine consisted of metal stops attached to the levers, so arranged that the lever setting a signal to "Proceed" ("Clear") on any line could not be moved unless all signals permitting an adverse movement had been set to "Stop", and all switches had been set so that no train other than the one being cleared could enter the cleared tracks. Only when this had been done were the metal stops in such position that the desired signal could be moved to "Clear". Should a towerman try to set an arrangement of switches and signals which could bring on a collision, he would be balked. The machine would refuse to respond, all signals would stand at "Stop", and all movements would be paralyzed until he corrected the arrangement.
Later, additional safeguards were provided, the first being a drastic device designed to curb any engineer's impulse to "take a chance". This is the "derail", set usually a few hundred feet from the actual crossing in each track. The "derail" is a switch or other device, set in one rail, which will derail any train trying to pass the signal, when it indicates stop. All derails on opposing lines must be set, before "Proceed" can be given to any one line. There can be no temptation to take a chance. Should an engineer try to "run" a stop signal at an interlocking plant, he would find his train on the ground.

The second device was some form of locking installed to prevent any mistaken attempt by a towerman to change the signals, once a train had entered upon the protected tracks. This device was a detector bar, set on levers alongside the rail, moving when the switch or signal moved. So long as a train occupied the track the detector bar could not move, nor could a switch or a signal be reset. Because rails weighing more than eighty-five pounds to the yard are so wide that the bar might not strike a wheel passing over it, electric currents set in motion by the passing train now do the locking.

Interlocking developed along the lines of automation in several stages. The inventions of the track circuit, a more compact interlocking machine, and power switch mechanism made it possible to safely extend the control of interlocked switches and signals from a few hundred feet to distances of
several thousand feet. As these electrical components were added to interlocking, it made feasible the operation of more extensive layouts with fewer men.

A more compact relay interlocking machine was finally devised and, by the use of ingenious circuit schemes, it was possible to control from one point several groups of switches over a reduced number of control wires. These switches previously required a local interlocking. A further expansion of the area under control, which could be economically operated from a single machine, was the next development. This resulted from employment of high speed code control systems developed primarily for C.T.C., but capable of being used to operate complete interlocking groups of considerable size. These push-button type control machines have relieved lever-men of much routine manipulation at large interlockings. The machines can set up entire routes through an interlocking, and automatically select the most favorable route available. The only manipulation required involves pushing of two buttons, one representing the initial point of the route, and another representing the desired destination.

In the United States the trend in interlocking is towards consolidation and absorption of small interlocked locations in the C.T.C. system. In the twenty year period between 1938 and 1958, the number of interlocked locations (including those in C.T.C.) approximately doubled, while the number of locally
attended interlockings dropped nearly 40 per cent. In this same period the number of automatic interlockings also doubled.

G. SUMMARY

Modern signaling is developed from three fundamental indications which were approved by the American Railway Association in 1910; stop, caution, and proceed. These indications modified to meet present-day operating conditions are published by the Association of American Railroads in the current issue of the Standard Code.

The principles of railroad signaling as they relate to design, construction and installation of signal systems and to train operation are as follows:

1. **Reliability**

   This requirement is given priority over all other factors so that safety and facility of train movement may be obtained.

2. **Uniformity**

   Uniformity in aspects and indications is necessary to avoid confusion. One name and indication should apply to those aspects indicating the same action to be taken and the same aspect should not be used with any other name and indication.

3. **Simplicity**

   Consistent with requirements, simplicity is an
important factor in the design and construction of a signal system.

4. **Distinctiveness**

A signal system should give definite information for the safe and expeditious movement of trains. Signals used should be distinctive in design so that the aspects can be unmistakably determined by the employees operating trains. The action required by the indication of a signal aspect should be definite, readily understandable, and permit only one interpretation.

5. **Expansive Capabilities**

Light traffic and simple track layout requires a less elaborate signal system than does heavy traffic and more complicated track layout; however, the signaling for the light traffic or the simple track layout should, for economic reasons, be capable of expansion to provide for increasing traffic to the ultimate capacity of the railroad.

6. **Location**

Signals should, as far as practicable, be located:

a. To the right of and adjoining the track to which they refer.

b. Back of fouling point to protect converging and opposing train movements.

7. **Visibility**

Signals should be so located as to give the best
possible view to enginemen on approaching trains.

8. **Spacing**

Each roadway signal shall be located with respect to the next signal or signals in advance (which govern train movements in the same direction) so that the indication of a signal displaying a restrictive aspect can be complied with by means of a brake application, other than an emergency application, initiated at such signal, either by stopping at the signal where a stop is required, or by reduction in speed to the rate prescribed by the next signal in advance where reduced speed is required.

9. **Protection**

The protection desired must be given careful consideration and the installation should be in accordance with the recommended practices of the Signal Section, A.A.R.
CHAPTER V

MAINTENANCE OF WAY

Maintenance plays a major part in the present programs of American railroads. Modern high speeds and heavy equipment, accompanied by the increasing costs of labor and materials, impose significant problems upon maintenance-of-way personnel.\(^{25}\)

If undermaintenance becomes chronic, expenses accrue from slow orders, damage to lading due to rough track, derailments, overtime for train crews and the increased cost of equipment repairs required by wear and damage resulting from movement over rough track. One estimate is that one-third the cost of equipment maintenance can be attributed to this cause.\(^{16}\)

If the neglect is serious enough and lasts long enough, the track condition can reach a point where efforts of the track forces become bogged down in a struggle to keep the tracks up to a minimal "standard", able to carry trains only at a greatly reduced speed. Unfortunately, the American railroads have done a less than adequate job of maintenance as shown in Figure 12.

The types of maintenance to be covered in this chapter are: culvert maintenance, roadbed maintenance, ballast cleaning, tie renewal, rail maintenance, and snow removal.

A. CULVERT MAINTENANCE \(^{25}\)

Culvert maintenance involves continual inspection and cleaning. The section foreman should inspect his culverts
at least once a week and after every heavy storm. The best opening can become plugged with debris and be a source of danger in the event of a sudden, heavy storm. Culverts are cleaned every fall and spring and any other time the inspection indicates too much clogging or sedimentation.

Other defects likely to be found include:

1. **Sags and Settlements.** These are not serious unless sufficiently developed to impede the flow of water and cause icing or sedimentation. If the pipe is shallow, it may be dug out and reset. If the pipe is deeply buried, the comparative cost of abandoning it and putting in a new pipe should be considered.

2. **Crushed Pipes.** Usually only timber and concrete pipes are subject to crushing failures. If, as frequently happens, the crushed section is near an end, it may be replaced. If further in, temporary relief can be had by placing supporting struts (With an attendant decrease in flow capacity). Cracks may be filled with mortar or asphalt. In extreme cases, a new culvert must be installed. When the new culvert is installed the cause of crushing should be determined. Usually insufficient overburden under increasing track loads is the cause.

3. **Separate Joints.** Failure of or lack of headwalls, coupled with frost action, too steep a gradient, and insufficient support, results in separation of tile,
concrete, and cast iron sections at the joints. Relief may be had by jacking the pipe together, tying together with tie rods, installing or repairing the headwall, forcing grout under the joints, and filling the joints with asphalt or mortar. Shallow pipes may be dug up and reset.

4. Scouring at Entrance and Exits. Scour results from an abrupt change in gradient between the pipe invert and stream channel and from too rapid a flow velocity. Gradients of pipe and stream channel should be the same. Where this cannot be, an apron or a spillway of stones or concrete should be constructed at each end.

5. Concrete Failure. Large concrete box and arch culverts are subject to all the possible ills of larger concrete structures. These must be watched for the development of cracks, deterioration of concrete surfaces, and failure of wing wall and headwall foundations. Concrete structural repairs are then in order.

B. ROADBED MAINTENANCE

Drainage, stabilization of roadbeds, and prevention and clearing of slips and slides are problems closely related to roadbed maintenance.

Settlement and subsidence, where these occur, are conditions which must be covered by maintenance, especially during the first years following construction. If sufficient
roadbed width has been included in original construction, the track may be brought to established elevation by raising on additional ballast. Where subsidence continues over long periods, it is economical to use an inexpensive ballast (cinders, chat, pit-run gravel) across the area of subsidence until the location becomes stabilized. Some of this material should be spread on the roadbed shoulder to keep the ballast section from excessive height.

If additional subgrade width is required because of subsidence or because of erosion and sloughing of the shoulders, the subgrade can be widened by dumping from side dump cars and leveling with a spreader blade.

In areas of persistent subsidence or instability more innovative measures are required. Among the methods in use today are drainage, grouting, pile driving, sand piles, sand-filled blast holes, and mats.

1. Roadbed Grouting. This method consists of injecting a cement and sand grout slurry into the roadbed. Injection points are driven into the roadbed and connected by flexible hose to the injection machine. Two systems have been developed for forcing grout into the roadbed, pneumatic injection and hydraulic injection.

a. Pneumatic Injection. The equipment required for pneumatic injection consists of a grout mixing tank equipped with power-driven agitator paddles wherein the grout slurry is mixed. An air compressor provides
pneumatic pressure, forcing the grout into the sub-grade through heavy rubberized hose with train line couplings and injection points consisting of pipes or tubes driven by air hammers.

b. Hydraulic Injection. The hydraulic system differs in operation only in the type of force used for injection, a hydraulic pump, and in richness of the mix.

2. Piling. So-called slide piling has given relief in fills up to forty feet high by preventing or retarding slides and settlement. The piling is driven into the shoulders on either side of the track, in some cases tying opposite piles together with steel tie rods or cables through the fill under the ballast sections. Waling strips are sometimes secured to the piles parallel to the track. Timbers and concrete or steel sheet piling are commonly used, but old steel rails have also been driven. To secure good anchorage, the piles must be driven several feet into the subsoil under the fill.

3. Sand Piles. This method involves the driving of a series of holes with a steel or timber spud into the subgrade inside and outside the rails. Water pockets must be located and pierced by the spud. Driving is done by a light on-track driver or off-track caterpillar-mounted driver. Sharp clean sand suitable for engine or concrete use is poured into the holes. A resurfacing
of the track must be planned in conjunction with the spud driving.

4. **Sand-filled Blast Holes.** A modification of the sand pile requires a hole drilled with a two or three inch earth auger and widened at the bottom by a discharge of dynamite. The holes are filled with clean, dry, sharp sand, blown in and compacted by an air compressor.

5. **Mats.** Concrete slab mats, both precast and built in place, have been inserted between the top of subgrade and the ballast section. A more even distribution of load from ballast to subgrade is obtained, and ballast is prevented from being forced into the subgrade to form water pockets. Subgrade material in turn is prevented from working upward into the ballast.

Timber mats have also been used. Planks are laid across the embankment with planks laid lengthwise on top.

An objection to the installation of mats on a finished railroad is the delay to traffic during the operation and disturbance of the track. Timber mats may have a relatively short life due to decay unless treated.

6. **Other Methods.** Methods of obtaining stability are limited only by the ingenuity of the engineer or maintenance officer. When the project is not too extensive, the unstable materials may be excavated from the subgrade
limits and replaced with suitable soil components. Occasionally the old fill has been abandoned and a new line constructed.

A problem just the opposite of subsidence is "heaving" or frost action. Heaving results not only from the direct volumetric increase due to free moisture freezing in the soil but also from a continued swelling caused by the building up of ice layers fed from below by capillarity. Water in a state of high capillary tension tends to resist freezing even at very low temperatures so that channels of supply remain open. Warm-weather thawing provides excess free water which destroys normal internal soil friction and reduces cohesion and stability.

Maintenance men cannot perform the usual track surfacing to maintain proper grades because the ballast is frozen. They must provide a remedy by placing wooden shims between the tie and the rail (or tie plate). Occasionally if the frost heaves are severe, shims as much as six or eight inches thick have been used. Sometimes a second tie is spiked on top of the original tie for this purpose. Such a procedure could never be followed on a high-speed main line. For such a line, the ballast may be "dug down" under the track, a costly and undesirable operation. The better procedure is to reduce the likelihood of heaving by proper drainage and soil selection.
Heavy rainfalls may severely erode unprotected slopes and in some cases wash out low embankments. The eroded areas must be filled and reseeded. The washed out embankments have to be rebuilt. In these areas erosion prevention devices should be placed.

The control of weeds, grasses, and undergrowth is another routine maintenance duty. Hand or machine mowing can be used when the terrain permits. These machines may be either on-track or off-track mounted, depending on the available terrain. Spraying the roadbed with weed-killing chemicals from rail-mounted spray cars or burning the roadway with flames from weed burners also provide effective weed control.

The control of objectionable types of vegetation on the right-of-way outside of the ballasted area, facilitates proper policing, improves the view, facilitates operation and maintenance activities, and reduces the accumulation of snow.

Objectionable types of vegetation should be destroyed at that period in their growth that is most effective in preventing regrowth or reproduction. Generally, this period is in the early part of the seeding stage of the vegetation concerned.

The greatest economy in vegetation control is effected by reducing to the minimum the amount of manual labor through the use of mechanical equipment, burners, chemicals,
or oil, the relative economy of which depends upon the character and density of the vegetation concerned, and on local conditions.

Economy of maintenance may be promoted frequently by smoothing the right-of-way to the extent practicable to permit the use of power-operated mowing machines. Also, it is economical to plant and maintain grass on the right-of-way outside of the roadbed shoulders to retard growth of objectionable types of vegetation and to minimize soil erosion; this grass to be of a variety adapted to the locality.

C. BALLAST CLEANING

Since a principal function of ballast is quick and complete drainage, it follows that anything which decreases drainability is seriously undesirable. Ballast may become foul and impervious from sand and other fine particles blown into it or dropped from cars. Ballast particles crush and form dust which turns to mud when moisture is present. Clay and silt particles work up from the subgrade beneath. Capillary action, always an active agent under the pumping action of track under a moving load, is promoted by dirty ballast. The fouled ballast collects and holds moisture. Weakened joints and general track deterioration follow.

To correct these conditions, prepared ballasts (stone, slag, and sometimes washed gravel) can be cleaned. Other
ballast types must be renewed either through removal of the old ballast or by raising the track on the old material and filling the cribs with new.

Prior to the ballasting operations, all bank widening, drainage, and rail renewal work should be completed.

Frequency of ballast cleaning depends on local conditions. The general rule to follow is that ballast should be cleaned whenever it loses its ability to drain. On heavy coal lines, where coal dust is plentiful and the heavy wheel loads have a deteriorating effect on the ballast material, cleaning may be required every two to five years. Light traffic lines or those with electric operation need to be cleaned less often. An especially rainy season may foul the ballast in much less time than normally required.

Ideally, all the ballast in a section should be cleaned. Practically this is almost impossible. Fortunately, those portions of the section not actually cleaned will drain and leach into the cleaned areas.

Ballast-cleaning machines are of two general types, those that occupy the rails of the track and those that operate on portable auxiliary tracks (in the intertrack space) or on auxiliary tracks and tractor wheels on the shoulder. The latter type, known as a "Mole", is dug into the ballast and clears train movements while in the operating position. Digger arms scoop the ballast onto a conveyor belt which carries the dirty material to vibrating screens where the
dirt is removed. Cleaned ballast is deposited in proper position at the rear of the machine, and the dirt is wasted on the subgrade shoulder from a conveyor belt. On-track machines are usually designed to clean both sides of the track at once. The ballast is raised onto elevating conveyors by means of digging arms similar to those in the "Mole", by clam shell buckets operating in curved guides, or by being forced to the rear of a steel plow box and onto the conveyor by the forward movement of the cleaner. A system of conveyor belts is sometimes used to carry the dirt back to gondola cars for wasting at selected sites. This procedure is especially desirable within city and terminal limits.

A part of the dirt removed by cleaning consists of fine particles resulting from abrasion and powdering of the ballast materials. As a consequence, it is usually necessary to make a light application of new ballast to replace what has been lost through these abrasive and cleaning processes.

The elimination of vegetation within the ballasted area is essential to the economical maintenance of track. Within this area the elimination of vegetation facilitates drainage, increases the life of ties, and reduces the fouling of ballast, thereby decreasing the cost of track maintenance.

D. TIE RENEWAL

There are a number of factors which govern the life of a tie in track:
1. Kind of wood used in the tie.
2. Type of treatment used.
5. Traffic conditions, including speed, axle loadings, and density of traffic.
6. Weather and climatic conditions.

The renewal of ties should be based on a carefully planned and organized program. It is customary to make two major tie inspections per year. One is made in the fall of the year. Each tie that is no longer suitable for one more year of service is marked to come out. This inspection is the basis for preparing a tie-renewal program for the following summer. A second inspection is made in the spring to note how the ties came through the winter and to make any last-minute revisions in the program.

No tie should, in general, be removed unless it will not serve another full year.

Two systems of renewal are possible, out-of-face renewal and spot renewal. When ties are renewed out of face, every tie in a given stretch is renewed regardless of its condition. Serviceable ties may be reassigned to yards and side tracks. For general maintenance, there may be some installation economy in renewing all ties in a stretch. The roadbed is disturbed less frequently and is probably good for two or three years
with little or no attention. Since all ties will not wear equally, there will be wastage of tie life.

The replacement of ties in quantity is largely mechanized. Spike pullers remove spikes from the ties. The ties are cut into small sections and extracted from the ballast. Spaces are prepared in the ballast for the new ties. The new ties are placed, tie plates replaced and respiked. Finally, the track is aligned and the ballast tamped.

In summary, the basic reasons for the failure and deterioration are decay and mechanical wear. Efforts to prolong tie life are directed in these two directions, with much of today's emphasis being laid on the reduction of mechanical wear.

E. RAIL MAINTENANCE

Nothing is more worrisome to track men than the implications associated with broken rails. This worry is something that has been almost second nature to the track engineer since the very earliest days of railroading. Doubtless it had its beginnings in the days when rails consisted of strips of metal fastened to timber members. To have a wheel get under one of these strips, causing the rail to be pushed up through the floor of a passenger car, was a fearsome experience. Following a particularly disastrous wreck in October, 1925 caused by a transverse fissure, Dr. Elmer Sperry, who had shown interest in the problem, was commissioned by the American
Railroad Association (now the Association of American Railroads) to develop a device for detecting the hidden defects before failure of the rail occurred.

The result, starting in 1928, was the Sperry system for detecting transverse fissures and other internal defects. In this system an indication is given of the presence of a defect, the Sperry car is stopped and hand devices are used for confirming the presence, location and size of the defect. The magnetic system used in early Sperry cars was ultimately abandoned in favor of the induction method. On the newer cars detection equipment is mounted under the car using both the induction system and ultrasonics for locating internal defects in rails. Dependence is placed on ultrasonics for detecting cracks and other defects in the joint-bar area. Presence of defects is indicated on a tape inside the car in front of the operator's position so the operator can note related track conditions as defects show up. When a defect is indicated, the car is stopped and a hand test is made to determine type, location and size of flaw.

Many roads supplement regular rail-detector testing with ultrasonic testing of bolted joints and frogs and switches. One large mid-western road, for example, has two-man parties who inspect joints, frogs and switches with hand-held ultrasonic devices. These parties inspect frogs and switches once every ninety days and inspect all bolted joints at least once a year.
Rail end batter is a significant problem caused by wheel loads and impacts at the rail joints. This problem may be repaired by building up the battered end by welding. Another repair method is the use of Speno's rail-grinding train. This method is used on track where rail-end batter does not exceed 0.050 inch. Use of the Speno train also removes rail corrugations and many engine burns, thus improving rail conditions generally.

Rail joints not only serve to connect adjacent rails into a continuous string, but also to hold rail ends on an even plane and support the rail rigidly enough to act somewhat like the rail itself. Yet, when the bolts become loose from stretching, broken loosened nuts or corrosion, the deflections of the joint under traffic and tie wear progressively become greater and the rail ends bend permanently, eventually forming a dropped joint. Good maintenance requires periodic inspection of the joint bolts and performing any required tightening.

An interesting and also annoying phenomenon is the longitudinal running or creeping of rails. With few exceptions, creepage is in the preponderant direction of traffic. Local conditions, such as steep grades or a point where trains apply brakes heavily, speed, and type of ballast may increase the amount of creepage.

A similar problem is the thermal expansion of the rail. The use of longer rail lengths increases the expansion
problem in that fewer joints are available to accommodate the expansion.

In some cases of rail creeping or thermal expansion, short lengths of rail may have to be removed or added.

F. SNOW REMOVAL 25

Snow and ice create problems sufficiently serious to warrant special mention. Drifted snow may impede train movements to the point of impassability. Snow and ice on and about the rails can cause derailments, especially when packed into the flangeways of highway and street crossings, frogs, and platforms. Snow and ice on driveways and platforms slow the movement of freight handling vehicles as well as create inconvenience and slipping hazards for employees and patrons. One of the most serious threats to operations is the stoppage of switch, frog, and retarder movements by ice or packed snow.

Snow melting devices are used at isolated switches. These may be either gas or electric heaters. In areas where a large number of switches and frogs are concentrated the snow is generally removed by hand labor using brooms.

Some preventive efforts are helpful in snow problem areas. Trees and shrubbery may be planted to break the force of the wind and control the drifting of snow. Cuts may be widened and slopes are flattened where drifting is bad. Temporary snow fences reduce wind velocities and cause the snow to drift before it reaches the roadway. In
turnouts ballast may be removed from between the ties under the switch points and sometimes under frogs and guard rails to provide a space wherein snow can fall or be swept without fouling the switch points or flangeways.

Various equipment is used for snow removal, depending on amounts to be removed. The flanger is used to clear light snowfalls from the rails and to follow up on heavy plowing. A light plow, grooved to fit over and against the rails, is hung underneath a car, containing the controls, which is pulled or pushed by a locomotive. The plow is raised or lowered from the flanging position by air from the train line. The flanger must be operated or supervised by someone thoroughly familiar with the territory in order to raise the flanging blade at the proper moment to avoid damage to turnouts, track pans, crossings, and other track appurtenances.

For heavier snowfalls and for bucking medium-sized drifts, some form of push plow is used. It may consist of an ordinary wedge plow blade mounted on the front of a weighted gondola car. More elaborate designs mount the plow on a specially built car with heavy steel frame construction capable of withstanding the shocks of hitting heavy drifts. Plows designed for single-track lines throw the snow evenly to both sides of the track. For multiple-track territory, the plow is sloped to throw all snow to one side of the track only to keep from covering an adjacent track. The
spreader used in earth work has proved an aid in snow removal.

For the heaviest drifted areas rotary plows are used. The rotary is equipped in front with a set of giant rotating blades which cut into high and tightly packed snowdrifts and throw the snow out through a directable nozzle placing the snow well clear of the tracks.

G. DIVERSION OF TRAFFIC

Under all but the most intensive traffic, the practice of diverting traffic on multiple track lines to facilitate the work of the maintenance forces is feasible and when employed results in definite savings in the cost of doing the work. In addition to the economies effected, there are added benefits in better production, better work and greater safety to workmen.

The provisions necessary for diverting traffic are comparatively simple and can be varied to meet physical conditions or conform to operating methods. There is little, if any, added interference with train movements while the work is actually under way and operating conditions as a whole are improved, as compared with doing the work under traffic, by reason of the reduction in the time required for its completion.

H. CONCLUSION

There are three basic conditions which must always be present in a track—correct gage, good line, and smooth surface.
These, economically obtained, are the end results of all maintenance.

Failure to keep the track and structures in good condition creates a state of deferred maintenance. The situation may not be immediately serious. Most structures can go a year or two beyond the scheduled time for painting without undue deterioration. For many items deferred maintenance is an accumulative and even dangerous condition. Unsound ties left in track place an extra strain on adjoining ties, causing those to wear out more rapidly. The rail and joint bars then wear more rapidly, and general deterioration sets in. Whatever the reason for deferred maintenance, it must at some time be recouped. Often the final cost to the railroad is greater than if a normal program had been maintained.
CHAPTER VI

RAIL PLANNING

The realization that rail transportation is an interconnected nationwide system has opened the door to the spread of government financing throughout the country. While the Rail Passenger Service Act of 1970 played a role, the key instruments for action have been the Regional Rail Reorganization Act (3R Act), that became law January 2, 1974, and the Railroad Revitalization and Regulatory Reform Act (4R Act), signed February 5, 1976.

Just preceding and concurrent with passage of the 3R and 4R Acts, an unprecedented federal rail planning effort took place. Planning on the part of government for the railroads was unprecedented because private sector rail firms had performed any necessary financial or market development planning for themselves as a general matter of normal business operation.

As a basis for comment on federal planning, and to meet the requirements of the 3R Act for rail subsidy funds, approximately seventeen eastern and midwestern states began their own rail planning efforts in 1973 and 1974. Initial state rail plans were completed in December, 1975, and those plans were revised and updated on August 1, 1976. Since the entry of the original midwest and northeast states into rail planning, these planning activities have spread to virtually every one of the contiguous forty-eight states.
A national effort in rail planning is now well along. The U.S. is moving from its first substantial experience with restructuring the rail sector, to a period of government involvement in railroad management and operations that is unprecedented in this country since the railroads were returned to private operation in 1920, following federal control during World War I.24

A. PLANNING ISSUES24

The Transportation Research Board's executive committee developed a list of the ten issues in transportation it considered to be most critical in 1976 and the near future. These issues and their application to rail planning are:

1. **Energy Efficiency.** Certain rail operations such as ones typified by light-density branch-lines, may be large users of energy compared to a motor carrier alternative. Likewise, railroads are not as energy efficient in moving people as they are in moving freight. A rail planning process can evaluate the relative efficiencies of the various applications in order to achieve optimum use of the railroads inherent energy efficiency.

2. **Transportation and the Environment.** General national and state policy is to minimize the generation of pollution by the transportation modes. A rail planning process can weigh alternatives to determine the relative effects on the physical and social environments of rail movements compared to use of other modes.
3. **Transportation Safety.** Safety can be an issue concerning passenger trains running on poorly maintained track, or in relation to grade crossings. While full grade separation between railroads and highways could be desirable if safety is accorded a high priority, such possibilities as line consolidation and train scheduling to prevent conflict are alternatives for rail planners to investigate.

4. **Intergovernmental Responsibility for Transportation Systems.**

Should states be the primary subnational focus for rail planning? States differ tremendously in area, interests, and other attributes related to rail transportation. Rail systems most commonly traverse state boundaries, thus making regional compacts or close coordination necessary for such significant actions as revising main-line configurations. What division of responsibility between the states and the federal government is best?

5. **Transportation, Land Use Control, and City Forms.**

Railroads shaped the geography of many American cities and greatly influenced the distribution of industry. The present rail system operates in a broad sense to permit regional competition, and on the small scale to divide neighborhoods. Dependent on whether city form is of concern in a particular state, urban rail relocation may be a major study item for rail planners.
6. **Improvement of Existing, Non-urban Transportation Facilities.**

In part the issue is how to use efficiently the present rail system, in lieu of expanding capacity. This raises the question of whether and to what extent rail transport is competitive in goods movement with other forms of transportation. From another standpoint, the issue is measurement of the amount of excess capacity in railroading. If capacity can be reduced by branch-line abandonment, yard consolidation and main-line mergers, lower-cost rail transport might be the result. Of course, the extent of scale economics and economies of utilization need investigation.

7. **Transportation System Performance Criteria and Design Standards.**

Before improving existing facilities or making investments in new railroad track, yards or equipment, it is necessary to use investment analysis methods that measure the effectiveness of the various proposed expenditures. In the foreseeable future the volume of federal, state or local funds that may be spent on the railroads will be quite limited. With a 1.20 per cent rate-of-return in 1975, the railroads are able to generate very little private capital. What level of service or what economic return will come about through the application of these available funds?
8. Financing Requirements and Alternatives for Transportation System and Services.

Are railroads to be treated as public goods, or are rail users still to provide the great majority of rail revenue needs? The pricing of rail services to those users is an issue, and a complicated one, dependent on the allocation of railroad costs and determination of the extent of value-of-service pricing that can continue in the industry. If the public is to finance some or many railroad operations, tax sources need to be found.

9. Effects of Transportation Regulations. Extensive economic regulation of rate and service competition has been cited as a major reason for the poor performance of the rail industry. Regulation takes place at the state level as well as under federal statutes. Should the rail plan analyze the impact of varying regulatory controls? In particular, regulation is said to stifle innovation. How might innovation and change in railroading be encouraged through regulatory revision?

10. Transportation System Maintenance Technology and Management.

The challenge of developing a transportation system, such as the building of the railroads, seems to encourage quick advances in technology needed to put the system in place. Maintenance of that system, however, attracts less interest and encourages less innovation. Making an established rail system work better through joint usage,
support of intermodalism and coordination is difficult. These issues can be addressed by rail planners.

B. STATE RAIL PLANS

Railroad planning at all levels of government, particularly for freight traffic, has been described as virgin territory. Like all planning, it involves the acquisition and analysis of information. Neither the information that is needed nor the method of analyzing it has been developed to the point where a planner can study a state railroad system with proven, readily accessible tools and techniques.

Although the information needed for state railroad planning is not difficult to define, it has frequently been time-consuming and difficult to acquire. States have not until recently attempted to analyze the railroads within their boundaries in system terms. The role of the states, if any, has been regulatory, accepting the systems as given and leaving planning decisions to the railroads themselves. Thus, there has been no sustained effort to acquire the data needed for planning on a statewide basis.

The planning process, under the terms of the Regional Railroad Reorganization Act, requires the state to reach judgments as to which lines or parts of lines should be retained in the public interest and which may be considered unnecessary. These judgments must rest on specific, detailed information about the financial viability of the individual
lines and their various branches or segments, the services they provide, the probable future demand for those services, and the economic and social consequences of eliminating those services. Basic information about individual lines is not readily available in specific, detailed form. Some information about individual railroads, such as that required by the ICC is publicly accessible but does not provide sufficient detail to evaluate separate branches or segments of the roads. Most of the necessary information is held by the railroads themselves; however, they are often reluctant to release it. Even when they make it available, it is not always compiled in the form that is most useful for planning studies. Moreover, the railroads vary somewhat in the kind of information that they keep and the form in which they keep it. In addition, records are often destroyed after a few years, making it difficult to get time-series data for more than three years.

When the state railroad planner acquires the necessary information, he must find the means to analyze it. Although a wide variety of appropriate analytical techniques exists, few of them have been fully adapted to statewide railroad planning. Network simulations, for example, have been used for some years in the analysis of urban transportation systems, but they have only begun to be applied to statewide railroad systems. Similarly, economic forecasting techniques have long been applied to a wide range of commodities and industries, but they have only begun to be adapted to the
discrete limits of a particular branch of an individual rail-
road.

Basically, state rail planning activities are divided into two parts, each leading to the preparation of a document that meets one of the eligibility requirements of the Federal Railroad Administration. The first document is the Planning Work Statement and the second is the State Rail Plan.

The Planning Work Statement which a state must file with its application for federal funds for planning assistance is a description of the process by which the state intends to develop the State Rail Plan. Most simply, it is a work program with six principal components:

1. **Framework Guiding Development of Rail Plan.** This statement (the regulations call it a "philosophical framework) should set forth initial state policies regarding such matters as:

   a. previous commitments regarding rail services
   b. expected degree or type of state involvement respecting light density lines
   c. role of the state regarding other rail services
   d. role of the certified program of projects in the state's programming and budgeting system.
   e. role of the rail plan in any multi-modal statewide transportation planning.
   f. policy of state regarding methods or limitations in working with private transportation companies.
g. plan for subsidized rail services upon expiration of federal assistance.

h. policy regarding proportionate share of costs to be borne by local governments.

It is recognized that such policies may be changed, but it will help a state's own rail planners if these issues are faced early, even if the report states, regarding some issues, that policies will only be developed after the facts and costs are known.

2. Methods for Involving Regional/Local Governments and the Public.

This component will describe (a) organization and (b) procedures for obtaining adequate involvement of non-government agencies and groups in the planning process.

3. Criteria and Goals. This is a preliminary statement of goals relating primarily to local rail services assistance. It should be consistent with the policy framework described previously. To the extent possible, it should emphasize the development of criteria to guide key investment decisions such as subsidization, acquisition and rehabilitation. Consideration should be given to development of criteria for selection of projects for investment and for establishing priorities.

4. Data Requirements. Most of the detailed data needed is for threatened light density lines. However, information giving an accurate overview of all rail services
is needed, and the need for such data will grow in the future.

5. **Analytical Methodology.** Proven methods are available for estimating costs and revenues attributable to light density lines, for evaluating economic, social, energy and environmental impacts, and for ranking lines in priority order. An initial selection of methods should be made by each state.

6. **Management Plan.** The Planning Work Statement should be concluded with certain administrative details: an organizational chart giving the titles and numbers of professional and supporting personnel assigned to rail planning, major tasks assigned to them, a task budget, and a chart of tasks showing anticipated timing of accomplishment.

The State Rail Plan has several required components but may contain additional elements if a state desires. Most of the required components relate primarily to local rail service assistance, but others are at least partially related to comprehensive planning for all modes.

Each of the elements required to meet the provisions of the RRRRA is discussed below.

1. **Description of the Rail Planning Process.** Using text and diagrams, the process by which the rail plan was developed should be described so that any reader, whether in government or an interested citizen or
businessman, can understand the background and reasoning of the process by which decisions have been reached.

2. **Report on State Rail System.** The minimum requirements for this report are a map or maps showing the rail system of the state indicating operating carrier(s), freight traffic density (expressed in tons or ton-miles per year on each link), and the location of passenger service. In addition, a written statement is required dealing with commodities carried and with rail services provided on each line.

3. **Classification of the State Rail System.** All rail lines in the state must be classified according to a system specified in the Federal Register of August 9, 1976.

   The classification must be reported on maps, with a written description accompanying it. It is suggested that a tabular summary of the lines in each class be maintained, summed to the total length of all rail lines in the state.

4. **Detailed Data on Selected Lines.** For selected lines (those now eligible under Section 803-K of the RRRRA, those "potentially subject to abandonment", and those for which abandonment petitions are pending) extensive and detailed data must be assembled and analyses made.

5. **Describing Present Situation.** This is primarily a reporting activity, and will produce the following materials:
a. Present freight traffic, in carloads, by type and by station of origination or destination on the line.
b. Characteristics of shippers/receivers (type of industry, unemployment level, annual wages paid, and freight transportation requirements).
c. Revenues received by the railroad for freight service on the line and costs of providing service.
d. The present condition of the rail line, equipment and facilities.
e. An economic and operational analysis of present and future rail service needs.

a. Impacts. If a rail line is abandoned, a variety of impacts will result, some being harmful and others beneficial. Using methods of calculation that have been tested in practice, it is possible to estimate impacts on the following:

   (1) other transportation systems of the state
   (2) local and state economies
   (3) social impacts
   (4) the environment
   (5) energy usage
   (6) other profitable railroads

b. Alternatives. The evaluation of each line must compare abandonment against the costs and benefits
of alternative solutions to transportation needs. These alternatives include a wide variety of options:

1. substitution of other transportation
2. construction of new terminal, storage, or trans-shipment facilities at nearby railroad
3. state, shipper, or short-line acquisition and operation
4. negotiated solutions with shippers and railroads
5. rail service assistance

Based upon the comparison of costs and benefits, the state must reach a decision as to whether the project should be selected for federal and/or state assistance. The report on this concluding decision should show how the decision was reached, in terms of the criteria used, and grouping projects in accordance with other state criteria.

7. Group Projects. This task is a summary of all projects for which detailed analyses were made, with the result being a grouping of all projects in order of compliance with the state's criteria for assistance. The tabular presentation should indicate location, type of action proposed and estimated amount and duration of financial assistance.

8. Description of Participation. The methods and instrumentalities used to provide agencies and groups outside
state government with an opportunity to participate in
the planning process should be described completely.

9. Description of Overall Planning Process. The clear
intent of the RRRRA is to make rail planning a coordi­
nate part of the multi-mode transportation planning at
the state level. Therefore, a description of the pro­
cesses and steps used in planning highway, aviation,
waterway, pipeline and other systems should be prepared,
indicating to the extent practicable the ways in which
these processes link together and where common technical
activities (e.g., population and economic forecasting)
can lead to better coordinated products at lower cost.

10. Inclusion of Additional Information. This is
optional if a state undertakes other rail planning activ­
ities beyond those required such as main line studies,
urban rail rationalization, or passenger studies. Then
the results of such work should be incorporated in the
State Rail Plan, at least in summary form.

To provide those public and private agencies or groups
that have an interest in railroad transportation with an oppor­
tunity to participate in the planning process, the creation
of a "public participation advisory committee" may be con­
sidered. Such a body can meet at regular intervals as needed,
and can provide information, reviews, and ideas on the various
elements of the plan as they are being prepared and updated.
This advisory committee can serve as an advisory body to both
the planning and implementation functions.

Representation of interest groups on the public participation advisory committee will have to be determined by each state, reflecting local issues and the ability and willingness of the interest groups to contribute to the process.

C. ABANDONMENT

Estimates have been developed of the extent of potentially uneconomic light density railroad lines in thirty-one states outside the Northeast and of the amount and type of traffic on these lines. The analysis utilized the FRA Network Model, the One-Percent Waybill Sample, and a decision rule, derived from USRA planning, of seventy carloads per mile of line.

It was estimated that approximately 25,500 miles of line in the thirty-one states are uneconomic. This represents 18 per cent of the route length in these states, although only 2.4 per cent of total traffic originates or terminates on these lines.

Most light density lines were constructed in an era when alternative modes could not compete. Most were built for land access purposes, that is, to transport agricultural and mineral products to the cities and manufactured products in return. Overbuilding of light density lines occurred in many portions of the country. Since 1920, new modes of
transportation (predominately trucks) have successfully competed for the more lucrative traffic, leaving the light density lines with only low-rated bulk commodities such as grain, fertilizer, lumber, and extractive products. The fact that a line has little originating or terminating traffic does not necessarily mean that it will have to be abandoned, as profitability depends strongly on the type of traffic being served and the length of haul. Even so, the lower the traffic density, the more likely the line will be marginal or uneconomic.

Many light density lines have experienced a downward cycle of declining traffic and revenues, followed by the carrier-initiated response of decreasing service and deferring maintenance, which in turn has led to further traffic erosion. Eventually the point is reached where the light density line ceases to be profitable to the owning carrier. Further operation either requires cross-subsidization from other portions of the system or leads to a formal request for debilitated track, and changing distributive technology often results in gradually-increasing light density line unprofitability even with stable demand. Under free market conditions, a firm will seek to disinvest in those capital goods whose marginal cost exceeds the marginal revenue. Abandonment then is the rational process of adjusting to changed market conditions.
State interest in abandonment stems from the potentially severe impact that affected communities may experience from cessation of rail service. Figure 13 shows a chain of potential events initiated when a light density line is abandoned. A shipper essentially faces three immediate options. He can close down his operation, initiating a series of events including primary and secondary job losses, increased governmental unemployment and welfare payments, and reduced state and local taxes. He can cut back operations that are affected by loss of rail service, while changing suppliers or market areas or taking other steps to absorb the effects of direct rail service termination. Or, he can continue his operations and shift his freight traffic to trucks, possibly incurring higher shipping and materials handling costs as a consequence of mode substitution or transfer at a nearby team track.

One of the main tasks of state rail planning is to determine objectively what these impacts are likely to be on a line-by-line basis. This requires a careful probing of the current economic situation and short-to-medium term expectations for each major rail service user located on the light density line. Such analysis must recognize the uncertainties involved in projecting rail service user effects of light-density line abandonment. Such analysis also requires careful consideration of the impacts of change upon local communities—their employment, their transportation network, and their ability to adapt to change.
FIGURE 134

IMPACTS OF LIGHT DENSITY LINE ABANDONMENT
The actions and roles that can be taken regarding light density lines are most readily understood when seen in relationship to the amended abandonment process of the ICC. The RRRRA has carefully linked state rail planning, which is now supported by federal funds, with the basic steps of the ICC abandonment process, not just in a reactive way, but with provision for anticipating abandonment and taking preventative actions wherever possible.

The formal ICC abandonment process, which had its beginning with the Transportation Act of 1920, has been amended by the RRRRA to read as follows:

"No carrier by railroad subject to this part shall abandon all or any portion of any of its lines of railroad (hereafter in this section referred to as 'abandonment') and no such carrier shall discontinue the operations of all rail service over all or any portion of any such line (hereafter referred to as 'discontinuance'), unless such abandonment or discontinuance is described in and covered by a certificate which is issued by the Commission and which declares that the present or future public convenience and necessity require or permit such abandonment or discontinuance--"

Over the years, the Commission has interpreted this authority by balancing the desire of carriers to avoid further operating losses against the desires of local users for continued service. In rendering abandonment decisions, the
Commission seeks to determine the "public interest" on a case-by-case basis, sifting between the conflicting facts and claims within an adversary proceeding framework. In the end, the Commission must decide whether to overrule a managerial conclusion that a particular disinvestment in fixed plant is necessary in order to eliminate an operating loss or whether all shippers and receivers of freight should pay increased shipping charges to cross-subsidize continued operation of the light density line in question. Decisions that lead to higher rates have become increasingly untenable. Carriers cannot raise rates and maintain their competitive position relative to other modes. At the same time local communities cannot accept the locally perceived economic loss stemming from light density line abandonment.

To meet this dilemma, the RRRRA has taken two actions. First, the Commission's abandonment process has been streamlined by establishing tight time limits. Second, the RRRRA has provided a new mechanism whereby a state or a local community can elect to support continued service on a light density line which would otherwise be abandoned. In addition, the Act greatly expands and changes the type of public notice to be given by railroads proposing abandonment.

Under the revised process (diagrammed in Figure 14), when the Commission makes a finding that the public convenience and necessity permits the abandonment or discontinuance of a railroad line, it is required to publish the finding in the
STABILIZATION AND VIABILITY PLANNING
- negotiated solutions among shippers, labor, railroads
- track rehabilitation
- expanding traffic potential
- promotion
- monitoring

LINE RETENTION AND SUBSTITUTE SERVICE PLANNING
- traffic studies
- impact studies
- cost studies - line retention
- cost studies - substitute service
- acquire line
- rehabilitation line
- provide substitute service
- do nothing

SUBSIDIZATION OR ACQUISITION DECISION
State has 30 days to offer financial assistance to operate or acquire all or part of line; 6 months to reach a binding agreement with carrier

IMPLEMENTATION
- continued operation
- maintenance/rehabilitation
- extend/renegotiate agreement
- financial status reports
- audits

FIGURE 1434
ICC ABANDONMENT PROCEDURES
Federal Register. If within thirty days, the Commission finds that a responsible person (including a governmental entity) has offered financial assistance which would likely cover (1) the difference between the revenues attributable to the line and the avoidable cost of providing rail freight service plus a reasonable return on the value of the line, or (2) the acquisition cost of all or a portion of the line, then the Commission is required to postpone the issuance of an effective certificate authorizing abandonment or discontinuance for a reasonable time (not to exceed six months) to permit the carrier seek to such abandonment. Upon notification of the execution of such an agreement, the Commission will then postpone the issuance of a final and effective certificate for the length of the agreement, including any extensions or modifications. In theory, this does not change the basic abandonment process since the Commission must first decide whether to permit the abandonment or not. However, it allows for an accommodation to be worked out between the carrier and those individuals or firms dependent upon continued rail service, with financial assistance from the state. This is a third course of action, previously unavailable.

D. MERGERS

Mergers are generally viewed as mechanisms for creating solutions to perceived problems or for tapping new opportunities. Many unsuccessful attempts to solve railroad
difficulties have resulted from an inability to correctly define railroad problems.

The studies mandated by the 3R and 4R Acts highlight three areas of structural problems in the rail network:
1. There are significant amounts of redundant mainline tracks.
2. There are infrequently used and uneconomic branch lines.
3. There are uncoordinated and duplicative yards and terminal areas.

The reports issued to date continue to indicate that the current rail network exists as a result of the demands for rail service in the last part of the 19th Century and the early part of this century and that the rail industry has only partially adjusted to the economic and social changes of the last fifty years. As a result, the current rail network is inefficient and impedes the development of a modern, financially healthy railroad industry. The key factors cited are:

1. The expenses necessary to maintain the excess physical plant of the current rail network to the standard necessary for safe and efficient operations are not justified by the traffic these facilities serve;
2. Each railroad company undertakes to maintain its part of the rail network without considering the impact on the efficiency of the entire system; and
3. There has been no previous framework for resolving these structural problems on a network rather than a system basis because of economic, managerial and regulatory factors.

Due to the importance of structural considerations, all DOT and USRA reports to date have made a major effort to identify the facilities which contributed most to the viability of the rail industry. The main-line system has been highlighted in these reports. It has been found that significant savings to the industry and the government are possible by downgrading or eliminating redundant mainlines. The studies show that consolidating mainline networks would eliminate the need to rehabilitate duplicative lines, resulting in rehabilitation savings of up to $250,000 per mile for a line in poor condition. Consolidating mainline networks would also lead to a decrease in maintenance of way costs, either through complete elimination of track maintenance costs, or through the considerable savings which would be realized by the lower costs of maintaining some track to secondary standards. The reports conclude that the identification of essential mainline networks is essential if government funds are to be utilized in a cost-efficient fashion.

From the point of view of the carriers involved, the major advantages of railroad consolidations may be summarized
as follows: (1) reduction in operating costs; (2) increased opportunities for additional revenue; (3) corporate reorganizing and strengthening; and (4) the prospect of being in a position to offer improved services. The underlying motivations in most cases are the regaining or the maintaining of sufficient net income to enable the carriers to attract capital and to compete successfully with other railroads and with other modes of transportation.

Underlying all railroad unifications is one basic motivation--maximization of profit. To achieve this, a unification must result in either (1) penetration of new markets; (2) greater efficiencies through cost-saving reductions of duplicate facilities, employment, and operations; or (3) a combination of items (1) and (2).

Penetration of new markets is usually accomplished through end-to-end unifications while cost savings are more easily obtainable through parallel unifications. Obviously, some unifications have both end-to-end and parallel characteristics. Market penetration through end-to-end unifications invites protests from the applicant's former connecting carriers ("invasion of territory"), while parallel unification proposals usually raise the issue of monopoly power or, at least, of the elimination of competition.

The foregoing observations are generally true regardless of the form of the proposed transaction. There are three principal means by which carrier operations may be unified:
(1) by leases, which cover only a limited period; (2) by acquisition of stock control; and (3) by unifying actual ownership of the properties in a single corporation through a purchase or a statutory merger or consolidation.

Four criteria for Interstate Commerce Commission consideration in rail merger cases are spelled out in section 5 (2) (c) of the Interstate Commerce Act: effect on adequate transport service to the public; effect on public interest of including or failing to include other railroads in merger; total fixed charges; and interest of carrier employees.

E. FREIGHT PLANNING

The difficulties many railroads experience in attempting to effectively utilize their freight cars has far reaching impacts on the financial and competitive structure of the rail industry. Twofold increases in the cost of rolling stock combined with the difficulties of capital formation within the rail industry makes equipment utilization, which ultimately determines the fleet size and required car acquisitions, an essential ingredient to railroad success.

One particularly vexing component of this utilization problem involves the distribution of empty cars on the network. Since cars only generate revenue when loaded, a car sitting idle incurs an opportunity cost equivalent to the revenue which might accrue to it from immediate use. Such costs are difficult to calculate, however; thus decision-
makers are seldom held responsible for the true costs of empty car time.

Empty car distribution also has a dual relationship with the service reliability provided by railroads. An effective car distribution system requires predictions of car supply and demand, but uncertainty and natural variability in both supply and demand makes forecasting at any point difficult.

Unreliability in the network and changes in the quantity of goods moved are the principal causes of car supply variability, and in addition it is perceived by the shipper as a correlary form of unreliability in his supply of empty cars for loading.

The oft quoted 1972 Reebie study suggests that a typical freight car is empty more than 40 per cent of the time, of which only 7 per cent is recorded as empty movement. One explanation for this excessive idle time, and one that is related to service reliability, is premised on the notion that a local decision-maker who is sensitive to shipper demands for empty cars will attempt to minimize his risk of shortage by maintaining an inventory of empty cars as a buffer against the inherent system unreliability. A review of actual empty car distribution practices on several railroads reveals that inventories of cars are held for precisely this reason by local decision makers.

As real time data systems have been introduced into railroad operating environments, a trend towards centralized empty
car control has taken place. Such a policy can circumvent the local agent who is likely to maximize his own, rather than the system's objectives, but even with this change, the problem of optimizing the allocation process under uncertainty at a network level remains.

Car distribution systems are typically composed of the following subsystems:

1. identification or prediction of car supply
2. identification or prediction of car demand
3. allocation and/or control of car movements from surplus to deficit areas.

The least sophisticated systems can be classified as "reactionary". They make no attempt to forecast supply and demand; rather, when a car is made empty, it is allocated to a known customer order for an empty car. Various levels of centralization characterize systems employing this operating philosophy.

Other systems forecast supply and demand either on a weekly or monthly basis. These forecasts are then used to determine "flow rules" which route cars from surplus to deficit areas. Again the degree of centralization can vary significantly.

The actual allocation procedures are straightforward, and in most cases rely on standard optimization techniques. The principal short-comings of all the systems can be found in their inability to accurately estimate supply and demand.
These quantities are inherently variable and causing two problems:

1. Any allocation based on the forecast values of supply and demand will only be as good as the forecast values.

2. Uncertainty in the levels of supply and demand, introduces additional costs into the allocation decision-making process, specifically, the costs incurred when empty cars aren't available when needed, and the costs to maintain an excess supply of empty cars to protect against such an occurrence.

Interest in the latter problem has been the principal motivation for the simulation model described as follows.

The model developed is capable of simulating both surplus and deficit terminal areas, but the optimization routine is slightly different in the two cases.

In the surplus terminal situation, where supply exceeds demand, the model determines the optimal "target" inventory. Each day, consignor demand for empties are satisfied, then the inventory is brought up to the target level, and finally any additional cars are sent away as system empties (see Figure 15).
In a deficit terminal area demand is greater than the number of loads terminated, requiring that additional empties be trans-shipped to the terminal area so that in the long run, empty demand and supply are in balance (see Figure 16).
In this case, there is little likelihood that the inventory could be replenished by the incoming empties, since supply just equals demand on average. An initial inventory of cars, $E^0$, is therefore provided at the beginning of the simulation period, and the model determines the optimal value for this initial inventory level. The theoretical results are derived from the deficit terminal structure, described graphically below:

\[
L_i^N = \sum_{j} L_i^j
\]

\[
E_i^m = \sum_{j} E_i^j
\]

**FIGURE 17**

SIMULATED DEFICIT STRUCTURE

On each simulation day, $n$ groups of loaded cars, $L_i^j$, are generated. While the number of cars in an individual group may vary from day to day, the average value of the total daily loaded cars, $L^N_i$, is constant over the simulation period. Likewise $m$ groups of empty cars are generated daily, and the average value of the total over the simulation period, $E^M_i$, is also constant.
Each individual group of loaded or empty cars travels to
the terminal according to trip time distributions (denoted
here by \( R_L^j \) and \( R_E^j \)) which can be different for each group.
Each day, the actual travel time for each group of cars is
selected randomly from the appropriate trip time distribution.

All empty cars arriving on a particular day, \( i \), are used
to satisfy that day's demand for empties, \( E_i^d \), but all loaded
cars arriving on day \( i \), \( L_i^T \), must first be emptied and returned
to the terminal. The "time to empty" distribution, \( R_s \), may be
constant or variable, and determines the number of empties,
\( E_i^T \), that are returned to the terminal on day \( i \). These empties
can also be used to satisfy \( E_i^d \).

The model is "warmed up" for a period equivalent to the
maximum, \( q \), possible trip time specified by the trip time
distributions. The model then simulates "\( z \)" additional days
(the simulation period) and for each day, the cumulative sur-
plus or deficit, \( W_i \), is calculated:

\[
W_i = W_{i-1} + E_i^M + E_i^T - E_i^d
\]

Thus, the cumulative surplus or deficit for day \( i \) is
equal to the cumulative surplus or deficit from day \( i-1 \) plus
the net balance of empty cars at the end of day \( i \). As
described, an inventory of cars, \( E^0 \), is provided at the begin-
ning of the simulation period and cannot be replenished. The
model determines the optimum \( E^0 \) which minimizes the terminal
operator's disutility:
\[
\text{Min} \quad - \quad \sum_{i=q+1}^{q+z} U_i (E^o)
\]

where:

\[
U_i (E^o) = \begin{cases} 
(W_i + E^o) (C_u) & \text{if } (W_i + E^o) \leq 0 \\
(W_i + E^o) (-C_h) & \text{if } (W_i + E^o) > 0 
\end{cases}
\]

For short simulation time periods, this structure seems reasonable. Empty car allocation decisions are seldom made instantaneously, and are not generally responsive to daily fluctuations in demand or supply. In general, cars are allocated some weeks in advance so the use of an unreplenishable initial inventory over the simulation period appears to be consistent with actual railroad operations.

The foregoing model is presented as a typical example. Its application may or may not be appropriate, but is an example of the current state of the art.

F. PASSENGER FLEET SIZING

1. Background. The Regional Railroad Reorganization Act of 1973 mandated the Department of Transportation to undertake engineering and planning studies in support of improved passenger rail service in the Northeast Corridor (NEC). In order to obtain estimates of the
fleet required to provide the improved service and to analyze the effect of fleet management strategies, a study was undertaken to calculate the optimal number of cars required for design day service in the NEC. A linear programming model was formulated for determining fleet requirements for a variety of scenarios, including several different formulations of the objective function. Using a demand forecast based on the service standards prescribed in the Railroad Revitalization and Regulatory Reform Act of 1976, the minimum fleet size was calculated. Minimum car-miles per day and maximum load factor were also found.

Proper fleet management results in a reduced fleet size, lower operating costs, and an increase in ridership. Fleet management includes both the scheduling of trains and the scheduling of the units that make up these trains.

2. System Description. Eleven cities along the NEC rail line are assumed to be served by improved rail service. Seven of these cities receive half-hourly service and the remaining four, hourly service. The accompanying map identifies the eleven cities and the level of service at each. In addition, it is assumed that train length modification can occur at Philadelphia and New York as well as the two end points, Washington
and Boston. The switching points are referred to as terminals in Figure 18.

The trip times shown in Figure 18 which include intermediate stopping times, correspond to the requirements set forth in the Railroad Revitalization and Regulatory Reform Act of 1976. Since the time gained by not stopping at a station is negligible (estimated to be one and one-fourth minutes by the Engineering Division, Northeast Corridor Project Office), it is assumed that the skip-stop service has the same running time as the local service trains. There is a twenty minute time requirement for reversing the direction of a car. (Reversing direction of equipment may occur at any of the four switching points).

A uniform fleet with an average car capacity of seventy-five passengers is assumed. This corresponds to the Amfleet equipment and allows one snack bar car for every four cars. Parlor car service is not considered.

All equipment is locomotive hauled with a maximum train length of fourteen cars, not including the locomotive. The maximum train length is determined by the platform lengths planned for the improved rail system. If more than fourteen cars are required to satisfy the projected demand, a second section is added to the
FIGURE 18-23

NORTHEAST CORRIDOR TERMINAL SPACING
schedule. All deadheading is accommodated through the existing schedule.

3. **Model Formulation.** The system described above can be modeled by a transshipment network whose unit of flow is one car. In its simplest form, the network has a node for each potential arrival or departure time at each city. These nodes are connected by two types of directed arcs. Storage arcs connect each time node for each city to the immediately following time node; flow along one of these arcs represents storage of cars at a city in the interval between two times. Train arcs connect a time node in one city to a subsequent time node in a different city; flows along these arcs represent movement of cars from one city to another in scheduled trains. Network flows must satisfy constraints of several sorts: flow must be conserved at every node (cars do not enter or leave the system); flows along the train arcs must be great enough to meet demands; and all flows must be integer and nonnegative.

This network system may be transformed to an equivalent set of linear programming (LP) constraints. (Linear programming represents the most efficient technique for computing an optimal solution.) In more precise terms, this is done as follows. First, define the relevant sets:
The set of cities

The set of time intervals into which the day (or other schedule-period) is divided

The schedule: each element represents a train that leaves city \( c \) at time \( t \) and arrives at city \( c' \) at \( t' \)

Represent the demands by:

\[ d_{cc',[t,t']} > 0 \]

the smallest (integral) number of cars required to meet demand for train \((c,t,c',t')\) \( \in S \)

Express the nodes of the network as:

\[ A_c[t] \]

for all \( c \in C \), \( t \in T \)

The directed arcs representing storage of unused cars are then:

\[ U_c[t]: A_c[t] \rightarrow A_c[(t+1)\mod r'] \] for all \( c \in C \), \( t \in T \)

The arcs representing movement of cars in trains are:

\[ X_{cc',[t,t']}: A_c[t] \rightarrow A_{c'}[t'] \]

for all \((c,t,c',t')\) \( \in S \)

Define an LP structural variable corresponding to each arc, and representing the flow over the arc:

\[ u_c[t] \]

flow over \( U_c[t] \), for all \( c \in C \), \( t \in T \)

\[ x_{cc',[t,t']} \]

flow over \( X_{cc',[t,t']} \), for all \((c,t,c',t')\) \( \in S \)
The constraints on network flow are then expressed as follows:

**Conservation of flow:**

\[ u_c [(t-1) \mod T] + \sum_{(c_1, t_1, c, t) \in S} x_{c_1 c} [t_1, t] \]

\[ = u_c [t] + \sum_{(c, t, c_2 t_2) \in S} x_{c c_2} [t_1 t] \quad \text{for all } c \in C, t \in T \]

**Satisfaction of demand:**

\[ x_{c c_1} [t, t'] \geq d_{c c_1} [t, t'] \quad \text{for all } (c, t, c', t') \in S \]

**Nonnegativity:**

\[ u_c [t] \geq 0 \quad \text{for all } c \in C, t \in T \]

**Integrality:**

\[ u_c [t] \text{ integral } \quad \text{for all } c \in C, t \in T \]

\[ x_{c c_1} [t, t'] \text{ integral } \quad \text{for all } (c, t, c', t') \in S \]

Nonnegativity of the \( x \) variables is insured by satisfaction of demand.

Given that all \( d_{c c_1} [t, t'] \) are integral, a fundamental property of transshipment problems guarantees that every basic solution to the above LP is an integral solution. Consequently, a feasible solution to the above problem (and hence a feasible allocation of cars to trains) may be determined directly by application of the (phase 1) simplex method. Given any linear objective function, the simplex method will also find an optimal feasible allocation.
Objectives of special interest include the following:

a. Capital cost. The daily cost of amortizing
the passenger-car fleet, here referred to as the
"capital cost", may be considered proportional to
the number of cars in the fleet. Hence, minimizing
fleet size serves to minimize capital cost. A
linear expression for this objective is:

\[ Z_{\text{CAR}} + \sum_{c \in C} u_c (\gamma - 1) + \sum_{(c, t, c', t') \in S \quad t' < t} x_{cc'} [t, t'] \]

This expression counts the number of cars in the
system during the last interval of the day. The
first sum represents the number of cars in storage
during the interval, while the second represents the
number in trains that are running at that time.

b. Operating cost. Costs proportional to the number
of car-miles run in a day, here called "operating
costs", are another logical candidate for minimization. Letting the distance from c to c' be \( m_{cc'} \),
total car-miles per day is equal to the linear form:

\[ Z_{\text{MILE}} = \sum_{(c, t, c', t') \in S} m_{cc'} \cdot x_{cc'} [t, t'] \]

c. Load factor. Given fixed demands, it is reason-
able to try to maximize system load factor in order
to minimize cost of providing service. By definition,
system load factor is:

$$Z_{LF} = \frac{\text{passenger-miles / day}}{\text{seat-miles / day}}$$

$$= \frac{(\text{passenger-miles / day})}{(\text{seats / car})} \times \frac{\text{car miles / day}}{\text{day}}$$

Since both passenger-miles/day and seats/car are fixed by the problem, $Z_{LF}$ is inversely proportional to car-miles/day $= Z_{MILE}$. Hence, minimizing operating cost is equivalent to maximizing the system load factor.

Many desirable extensions and refinements of this model are presented in full detail in "Models of Railroad Passenger-Car Requirements in the Northeast Corridor" by Robert Fourer. Variations on the network permit the number of nodes to be greatly reduced and make possible a distinction between northbound and southbound trains. Techniques for optimizing two or more objectives sequentially or in combination are also developed.

4. Applications. Using an expanded version of the model that distinguished northbound and southbound trains, it was possible to minimize turnaround, the changing of cars' directions at terminal stations. Analysis of the optimal solution suggested that many cars are needed only for the Philadelphia-New York segment to satisfy peak demand northbound in the morning and southbound in
the afternoon. This suggests a revised schedule in which New York-Philadelphia shuttle trains are run at peak hours, in addition to the usual through trains.

Under simple assumptions, the model may be adapted to analyze requirements for locomotives as well as for cars. In the Northeast Corridor application, it was determined that a single solution minimized both the number of locomotives required and the number of locomotive-miles run.

Many more sophisticated sensitivity analyses are conceivable if one allows patronage between different station-pairs to vary at different rates. Other parametric studies include changing car capacity, altering turnaround time, and modifying train-size limit rules. Also, the schedule can be modified.

In addition, other fleet management strategies (several have been mentioned above) should be investigated in similar fashion and comparisons drawn. The present linear programming formulation is not capable of handling the more sophisticated express/feeder arrangement. However, it is likely that there is a suitable integer programming formulation which would require different optimization techniques.

Finally, it should be noted that although the model has been formulated for Northeast Corridor operations, the same technique could be applied to other portions of the Amtrak system.
RAIL TRANSIT

Rail transit, including streetcar, light rail, rapid transit, and regional rail, is a family of transportation modes with a broad range of service, operational, and cost characteristics. Consequently, these modes may be used efficiently for various conditions. As a result of numerous technological and operational innovations of rail systems during the last two decades, rail transit can be highly automated, reliable, and comfortable and can operate with minimal environmental intrusion. Although several U.S. systems (e.g., Lindenwold Line and Bay Area Rapid Transit) have some advanced features, general knowledge and understanding of rail systems in this country lag behind those of some western European countries and Japan. Based on a comparison of the population characteristics of selected European and U.S. cities with similar population size and density, European cities generally have a much greater application of rail transit. Despite extensive research into new technologies, no new mode has emerged with performance and cost characteristics superior or comparable to rail technology. Thus, to achieve more efficient and economical transit systems, information about rail modes must be increased and these modes must be included among the alternatives considered in transit planning.
The United States was the leader in rail technology and operation for a number of years several decades ago. However, while many foreign systems have been vigorously improved and modernized, U.S. systems have suffered from underinvestment and a decrease in technical and managerial expertise. The leading role of the United States was consequently lost after World War II.

Although the Lindenwold Line in Philadelphia and the New York, Chicago, and San Francisco rapid transit systems have some unique features and innovations that do not exist elsewhere, U.S. rail systems are generally obsolete in their technology and type of operation. Several observations confirm this condition:

1. There are few systems in the world that have less attractive, less safe transit stations than those, for example, along the Broad Street Line in Philadelphia or along many routes in New York City.
2. A survey of noise levels of rail rapid transit systems in eleven U.S. and European cities undertaken by Operations Research, Inc., in 1964 showed that all four U.S. systems included in the survey were on the top of the list ranking levels of noise.
3. The condition of track on many commuter railroads in U.S. cities is probably worse than the condition of any corresponding facilities in Europe or Japan.
4. Labor practices in railroad companies are more obsolete than in any corresponding operations in Europe. Many regional rail systems are operated by crews of up to nine persons although two or three would suffice for modernized operation.

5. The newest streetcar vehicles operating in the U.S. cities are twenty-two years old; some regional rail vehicles are over sixty years old.

6. Many systems have limited speed because of unsafe track conditions, and some cities require every streetcar to make a safety stop before every diverging switch, a practice abandoned in Europe decades ago.

7. Numerous technical innovations, such as the above mentioned switches with elastic points, constant-tension overhead catenary, and fare collection machines, are not known to exist even by most persons in the rail industry and operating agencies.

The neglect of rail technology and operations in the United States is also reflected in the extremely expensive and yet unreliable rolling stock and train controls for our most recent systems. Several of them have suffered from rather elementary mechanical and electric failures that result in excessively frequent service slowdowns and interruptions. Low reliability is not a typical problem of rapid transit systems. For example, the newly opened rapid transit system in Munich was built by using extensive experience from other
cities so that, although the system was entirely new, it had only two major delays in its service during the first eighteen months of operation; both were caused by factors out of control of the operating agency. 

This lagging expertise and lack of information about many modern technological developments in rail systems and policies are a serious problem in the United States. Frequent justification for ignorance of foreign developments is given by claims that U.S. cities are different or that Americans are unique in their love for the automobile. Although it is true that conditions are not identical in any two cities of the world, the claim that solutions from other countries do not apply to U.S. cities is incorrect.

Most frequent is the simplistic argument that rail transit is justified only in large cities that are densely populated; European cities use rail systems because their population density is greater than that of U.S. cities. Neither of these two arguments is correct. First, population size and density are not sufficient factors to determine feasibility of rail systems: A medium-size city with low average density may have either topography or high-density corridors that require rail transit. Second, European cities that use rail modes extensively do not have more people or more dense populations than many U.S. cities that have no rail systems.

The belief that Americans are unique in their love for the automobile is also highly questionable because in most
West European countries automobile registrations increased several times during the 1960's (in Italy more than six times from 1960 to 1970). However, although this automobile ownership increase in European countries did divert some passengers away from transit, transit patronage trends differ considerably from those in the United States. Although there are many physical, economic, and social differences between the United States and some European countries, it is quite clear that the basic policy toward urban transportation, improving both public and private modes in a coordinated manner, has already shown distinct positive results and is leading toward a stable situation in urban transportation.

The lack of knowledge about rail modes among transportation planners and engineers results in a misinterpretation of their proper application in urban transportation. U.S. cities that could efficiently use light rail systems have been planning systems similar to BART or the Lindenwold Line and, therefore, incur much higher costs than are rationally justified. Further buses and busways are planned for many corridors that would clearly be more efficiently served by rail transit.68

A. STREETCAR SYSTEMS 68

Streetcar systems consist of one, two, and occasionally three rail vehicles operating mostly on streets in mixed traffic, sometimes with limited separation from street traffic
on private rights-of-way. Although their comfort and dynamic characteristics are good, when they operate in mixed traffic their service quality is often unsatisfactory. Street conditions generally keep operating speeds below twelve mph. The comfort, schedule reliability, speed, and passenger attraction of streetcars are consequently similar to those offered by surface buses and are inferior to those of other rail modes.

The positive qualities of streetcars include a higher capacity and a more distinct image than that of buses, and a lower cost for right-of-way than for other rail modes. Selective application of traffic priority measures including reserved lanes and provision of some private rights-of-way (both of which are inexpensive improvements) can greatly enhance the attractiveness of the streetcar mode. Yet, the greater facility with which buses serve low-density areas and the trend to upgrade heavily traveled streetcar lines into higher quality rail systems have resulted in the conversion of most streetcar lines to either bus or light rail; consequently, this mode has experienced a general decline in ridership and a diminishing role in urban transportation.

B. LIGHT RAIL TRANSIT

Light rail transit is an urban electric railway having a largely segregated but not necessarily grade-separated right-of-way. Speeds, capacity, and overall performance are generally lower for light rail transit than they are for
fully grade-separated rapid transit, yet LRT is substantially superior in capacity and performance to any form of transit operating on public streets or roadways in mixed traffic. Because it is not fully grade separated and because it is not designed to have as high an overall performance and capacity as rapid transit does, LRT generally costs much less to construct per route mile. This lower cost allows LRT to be economically justified in urban areas or in specific corridors where conventional rail rapid transit is not feasible either because of cost or demand considerations.

Light rail transit is a medium cost mode that provides a medium speed service for a medium volume of passengers. It therefore falls into that cost-service region between conventional rail rapid transit and motor bus, yet there is considerable overlap upward into the traditional cost-service domain of rail rapid transit and downward into the domain for which motor buses have been considered most appropriate.

During the past two decades, there have been a number of novel modes proposed to fill various medium speed and capacity needs. It has been evident to planners and researchers, as well as to inventors and promoters, that medium demand corridors exist in many medium and larger sized metropolitan areas constituting a significant market for these novel modes. However, any new technological innovation needs considerable research and development before it can be used in the marketplace. Highly publicized difficulties of the
first operating prototypes of some new modes give cause for caution before such modes are adopted widely. Yet the need to service medium density corridors is clear to many planners and political leaders.

Light rail transit is suitable to fill this role today. Light rail transit is an evolutionary development of the street railway and full-scale rapid transit and has some features of both. Its subsystems have been fully developed and proved, and there is no need for costly, time consuming research and development.

Light rail lines in the early days used just what the name says: light rail. It would be difficult to find any sixty pound per yard rail remaining, but at one time it was very common. Many interurban lines were built with seventy pound rail. The minimum weight T-rail now in common use on light rail lines is eighty pound.

A desirable standard for light rail operations is one-hundred pound rail. A fairly heavy rail, because it is more rigid, can help to overcome a poor roadbed. The eighty pound rail in wide use is just too light, and ninety pound rail is becoming difficult to obtain. One-hundred pound rail, particularly in the ARA-A cross section, will probably remain common for many years.

Some rebuilding of existing light rail lines has been done with much heavier rail. Anything larger than the popular
115 pound AREA rail may be a waste of money, unless a larger section is wanted for greater electrical return and it proves more economical than supplementary negative cable. The trade-off must take into consideration that the rail will have to be replaced eventually and that the cable should last indefinitely.

Rail gauges for light rail applications have ranged from meter gauge common in Europe to as wide as five feet four and one-half inches in the Baltimore street railway system. The narrower gauges originally were adopted for economy; ties could be shorter, and the ballast cross section was narrower. These gauges generally are inadequate for U.S. practice. To avoid poor riding of cars, narrow gauge rail lines must have better maintenance than standard gauge lines, particularly for cross level. The meter gauge light rail lines of Europe usually are maintained superbly.

The nonstandard wide gauges once fairly common in the United States and still surviving in Toronto were imposed by city councils who wished to physically prohibit the operation of interchange railroad cars in city streets. So-called wagon gauge, which is about five feet two and one-half inches survives in Pennsylvania, in both Philadelphia and Pittsburgh.

Although the wide gauges are better than narrow gauges for controlling sway, they have no particular riding merit and have cost disadvantages in light railways, for which four feet eight inches is just about right for the usual
light rail car. Wide gauges of five feet six inches, which are used in Spain and on Bay Area Rapid Transit in San Francisco, are better than standard gauge for today's giant railroad operations that have very high cars and fast unit trains, but a general change probably will never be economically justified.

For ease of availability, special work (frogs, switches, crossings) ought to be standard railroad or heavy rapid transit types except when tracks are in pavement. When using the street types of special work intended for paved surfaces, one must take care that the rail contour and flangeways will accommodate the wheels of any equipment to be used on that part of the line. Deep flanges can readily smash street railway switches; again, any new project should use full-depth railroad types of paved area special work.

Special elastic switch points and improved frogs have been developed in Europe and are used widely in light railways. In the United States, use of the spring frog, which requires conscientious maintenance, has declined. One special work item that should be considered more often is expansion points. Expansion points minimize problems with continuous welded rail (CWR), especially on sharp curves. If CWR with all its advantages is not installed correctly and is not maintained to the best standards, it can be terrible for a light rail line whose cars are sensitive to misalignment. At the speeds proposed for most new light rail projects, this
alignment matter can be very important. In other words, CWR must be done right or be avoided. Field welding is not as suitable as shop welding because the latter generally gives better accuracy of alignment.

Slab track, on which the ties or a substitute method of support and gauge holding are completely enclosed in one or more concrete pours, has proved satisfactory in preserving excellent alignment and minimizing maintenance costs. Pittsburgh has several examples, some of which have been in use a long time. Indeed, joint use of private right-of-way by buses requires this method and pavement up to top of the rail. The line thus becomes a restricted-use street for public transit vehicles only. A law enforcement problem is created in keeping automobiles out. Disadvantages of slab track include a far higher installation cost than ballasted track and the difficulty of using track actuated signal systems, which require special rail-to-rail electrical insulation. Noise transfer ought to be studied carefully before a decision is made to install slab track at a particular location. Major railroads are studying the entire question of track structure because it is believed that the present standard practices are inadequate for heavy loads at high speeds. Open types of slab track with rail and fasteners fully exposed show promise, and considerable advanced testing is going on in both Europe and Japan. However, the conventional standards have served light rail very well.
The time proved support for all types of railroad still is treated hardwood ties on crushed rock ballast. For light rail, the ties can be smaller than standard railroad practice. Cross section of six by eight inches is adequate. A length of eight feet is suitable, but eight feet six inches is more common. Tie centers can be twenty-four inches; this requires 2,640 ties per mile versus 3,000 ties per mile or more for heavy-duty railroads. In a light rail application in which properly selected hardwood ties are used on a well drained and adequate ballast and in which tie plates are used and good maintenance practices are observed, the ties should last an average of forty years.

Stations for light rail facilities can vary all the way from a mere patch of cleared ground to elaborate enclosed facilities in a subway or terminal building. The type of station to be provided is a function of several variables: passenger volume, train frequency, climate conditions, method of fare collection, immediate surroundings, and civic requirements.

One thing to keep foremost in mind when one plans stations for a light rail facility is that most sites should be able to be upgraded later if conditions warrant. When possible, it is important to obtain control over enough land at the station locations at the beginning to allow for later elaboration. Space for parking requirements ought to be a major consideration in locating some of the stations.
Grades of 6 per cent or more both ascending and descending are common with light rail vehicles. Short grades of up to 14 per cent are the extreme limit.

Because of low vehicle weight and high power-to-weight ratio, LRT can handle grades at a faster speed than the usually heavy trains. The desire to operate long trains in conventional rapid transit work precludes doing some of the things that have been done with LRT. The controlling factor is braking capacity, a feature that easily can be made higher than standard on light rail vehicles.

Vertical curvature can be rather extreme on LRT compared to that of conventional rapid transit. Having no requirement for riders to pass between vehicles, light rail vehicle design can provide great freedom in vertical curve limits, both sag and crest. Single vehicles made to the rather short Presidents' Conference Committee (PCC) truck centers can do amazing things in this respect. When light rail vehicles (LRV's) are operated in multiple units, the couplers with their drawgear and radial carriage requirements can tend to restrict the vertical curves that can be taken. However, this limit is not reached on any active North American operations.

Articulation can place fairly restrictive limits on vertical curves, though the new standard light rail vehicle seems rather liberal in that respect with a limit of 310 feet crest radius and 460 feet sag radius. Passenger apprehension of the change in curvature might be greater with articulation.
Just about anything reasonable can be done. The decision involves how much seating capacity to sacrifice to make the connecting drum larger.

Horizontal curve capability is what sets LRT apart from conventional rapid transit. Light rail transit was originally conceived to have a track that could accommodate the right-angle intersections on city streets.

Light rail cars usually have been designed with rounded ends. This has been done not so much for aerodynamic design as for clearance on turning, particularly when they are run in multiple units. Couplers are radial; they swing in a semi-circle rather than ride in a striker box as they do on a railroad car. When knuckle couplers are used, the capability of going around curves becomes very high.

Today's light rail vehicles are designed to negotiate curves of forty-two feet inside rail radius. Anything tighter than that would place limits on features other than the coupling or articulation. Car width, location of trucks, and wheelbase might have to be restricted unduly.

Usually, the most extreme horizontal curves in a light rail system are in the non-revenue tracks required for reversing single-end vehicles at the end of a route. The single-end design is highly desired in markets that demand maximum seating, and the relative inflexibility and need for turning trackage of the single-end car can be a favorable trade-off for its lower first cost and greater number of seats than
double-end cars. Loops and Y's can be placed in a relatively small space because of the forty-two foot radius.

The size and weight of the LRV are usually less than that of rapid transit vehicles. The Boeing Vertol-UMTA standard LRV currently being built for Boston and San Francisco is seventy-two feet long and eight and one-half feet wide; it rests on three trucks; the center unpowered truck is under an articulated joint. The distance between truck centers is about the same as it is on the existing single-unit PCC streetcars being used on the same routes. These measure forty-six feet long and 8.33 feet wide; there is 22.75 feet between truck centers. This results in a rather long overhang on the front and rear of the car, the effect of which is minimized by some tapering of the car ends. Height is typically about ten feet over the roof, plus one or two feet more for whatever current collecting device is installed (trolley pole or pantograph). Some PCC cars were built to lengths of fifty feet and widths of nine feet. In Europe, cars are usually narrower and shorter than they are in North America. The spaciousness of LRV's permits a wide variety of interior arrangements. They can be equipped with spartan seating allowing extensive standing room for high density, short-haul travel, or they can emphasize comfortable seating for long-haul suburban traffic. Nearly all new transit equipment is air-conditioned.
Light rail systems typically have articulated six or eight axle vehicles of multiple unit trains of up to three four-axle cars. Light rail maximum speeds are in the range of forty to sixty miles per hour. The obsolescent but still used PCC streetcar has a maximum speed of forty-two miles per hour. The top speed of the new standard light rail vehicle (SLRV) is fifty-five miles per hour. Certain suburban light rail equipment can attain speeds in excess of seventy miles per hour, but this is unusual.

Overall schedule speeds for light rail lines on fully segregated right-of-way generally fall in the fifteen to thirty-five miles per hour range depending on station spacing and degree of segregation. If the track is in the street, schedule speeds will be much lower; they will range generally from ten to fifteen miles per hour. Maximum speeds will be limited to whatever the allowable speed is for traffic in the street.

Acceleration of three miles per hour per second (mph/s) is a generally accepted industry standard based on what a typical standing passenger can tolerate. The PCC streetcar was designed and built to attain a rate of 4.75 mph/s in the lower speed ranges; some operating properties reduced this somewhat, however. For instance, San Francisco's PCC cars are set for 4.25 mph/s.

Acceleration of the Boeing LRV has been found to be 2.6 mph/s, but it holds this rate to a higher speed. Therefore,
its overall performance is expected to be quite attractive when station spacing allows the vehicle to attain its fifty-five miles per hour running speed.

Past accomplishments indicate that it is technically possible to attain whatever rate of acceleration is desired within the limitations of adhesion. The tolerance of standing passengers and the various costs related to installing the desired power are the controlling factors.

The simplest traffic control for light rail systems is on-sight control, which means that the operator of a train or car merely operates the vehicle an estimated safe breaking distance behind the preceding vehicle. This type of control will be retained on the street portions of both Boston and Muni routes, and is also commonly used on street or surface sections of European light rail lines.

A higher type of traffic control is provided by block signals that provide a visual indication to the train operator of the condition of the block ahead or speed at which to run or both. Block signals are commonly used on private rights-of-way (including elevated and subway sections) of many present light rail lines. These depend on the operator's observing and responding to visual indications on wayside signals.

Several European light rail lines using wayside signals have an intermittent inductive train stop that triggers an emergency brake application if a train attempts to pass a red signal. This type of stop enforcement is unaffected
by encounters with other vehicles or debris in the street.

Cab signals may be readily adapted to the light rail mode; in fact, this is being done for the Market Street Subway portion of Muni. The cab signal concept has been used for many years by certain railroads and has been applied to a number of rapid transit lines during the last decade. Normally a cab signal system will indicate visually to the train operator the speed at which to operate. The system also will apply the brake to slow or stop the train if it is operated in excess of the indicated allowable speed. The cab-signal concept provides all-weather capability because the train operator does not need to see wayside signals. This allows full speed operation in snow, rain, or fog.

The primary virtue of cab signals is that they improve performance. A train (or vehicle) need not proceed at restricted speed from, say, a yellow signal to the next signal if the signal should clear to green. With a cab signal, the operator immediately knows the condition of the block ahead and can accelerate or decelerate accordingly. In addition, where visibility is impaired, as in a subway section with curves, cab signals provide the operator with a continuous indication of the block or blocks ahead. Cab signal systems therefore provide somewhat higher capacity and safety over wayside signal systems.

It is natural in a cab signal system to progress to fully automatic train operation. This would add the capability of
automatic station stops in which deceleration to a stop and positioning at a platform would be programmed as has been done on several recently implemented rail rapid transit lines. No light rail system yet implemented or proposed has opted for a fully automatic train operation.

A light rail route can be designed to economically handle up to 12,000 or 18,000 passengers per track per hour. Higher numbers are attained by using multiple-unit trains. For instance, the seventy-two foot long Boeing LRV would have a rush-hour capacity of about 150 to 180 passengers, depending on seating arrangements and assumed space per standee. A three vehicle train thus would accommodate easily 450 passengers. At a two minute headway, thirty such trains could pass a given point in one hour. This results in an offered capacity of 13,500 passenger spaces per hour. A four vehicle train would handle 18,000 passengers per hour, although at this volume of traffic, fully grade-separated rail rapid transit may be a better choice.

Several existing light rail systems carry 10,000 to 15,000 passengers per day on a given route. Such volumes require that only 2,000 to 4,000 passengers be carried during a rush hour, which is attained easily with one and two car trains on three to five minute headways. Yet these passengers enjoy a speedy ride not attainable by transit vehicles in mixed traffic. This is what generates higher per capita LRT ridership in a given corridor.
A light rail system can be designed for modest traffic and can be upgraded from time to time as demand increases. It is not necessary to invest large amounts of money in an initial system. Investment can be distributed over a long period of time and grow in increments as the need arises. Several options in vehicle and station characteristics give a designer numerous investment choices and combinations.

A system can be designed for moderate headways of, say, five minutes. As traffic increases, train length can be increased from one to two or even three or more vehicles. Concurrently, stations must be lengthened (which may require substantial investment) and substation capacity increased to provide power for longer trains. On the other hand, it is sometimes easier to decrease headways from, say, five minutes to two minutes with one or two vehicle trains before additional capital is invested in lengthening stations and increasing substation capacity. It also might be necessary to alter significantly a signal system when changing from a five to a two minute headway. Short trains on short headways and longer trains on longer headways have their place. Both may be needed.

C. REGIONAL RAIL

Regional (commuter) rail systems consist of large, high-speed rail vehicles operated individually or in trains, usually by railroad companies. The service is characterized
by long average trip lengths, large interstation spacing, and very comfortable riding. Passenger volumes are heavily peaked, highly directional, and predominantly suburb-to-CBD. Most regional rail networks in our cities consist of a number of radial lines from the CBD and have stations located at suburban town centers. Kiss-and-ride, park-and-ride, bus feeders and walking are used as access modes. Central city stations are often combined with intercity rail stations, but they are limited in number and provide little downtown coverage.

In recent years another kind of regional rail system has emerged. When there are alignments, station spacings, and speeds similar to those for commuter rail, these systems have frequencies of service and CBD distribution similar to those for rapid transit. Examples include Germany's S-Bahn, Paris' R.E.R., Philadelphia's Lindenwold Line, and San Francisco's BART. These modern regional rail systems give metropolitan regions with many distinct satellite communities an excellent regional transportation network.

Because regional rail service is usually provided by railroad companies, the cars are usually larger and heavier than rapid transit cars and have very high seating capacity (in double decker cars, up to 160 passengers/car). The tendency in new cars is to use two or three vehicle married units in trains of up to ten vehicles. The service quality of regional rail is generally high for European systems, but
it is quite variable among American systems that have been severely hurt by inadequate financing, lack of modernization, disinterested management, and obsolete labor practices.

The capital investment required for regional rail depends heavily on whether modernization of an existing railroad line or an entirely new regional rapid transit system is considered. The former usually involves very low costs (track renovation, electrification, and station construction); the latter, because of high alignment standards, requires an investment cost higher than that for rapid transit. Recent vehicle costs have been about $400,000. Operating costs vary greatly with labor practices, i.e., size of crew, which is typically much larger than the operation actually requires, particularly on U.S. systems.

D. RAIL RAPID TRANSIT

Rapid transit consists of long four axle rail vehicles operating in trains on completely private rights-of-way that allow high speed, high reliability, high capacity, rapid boarding, and fail-safe operation.

Rapid transit has the highest service quality of all transit modes. Recorded capacities of lines with stations have been as high as 45,000 passengers per hour. Some of the recently opened systems (in Sao Paolo and in Paris) have been designed for a capacity of 80,000 passengers per hour. Capacity volume, however, results in low comfort. The maximum
seated capacity is approximately 30,000 passengers per hour, but most systems are designed for volumes from 8,000 to 25,000 passengers per hour.

Most rail transit lines in U.S. cities are basically radial with limited coverage of city centers (except in Manhattan). Modern European rapid transit systems, however, have been designed with networks covering large central areas, thus, also offering service for the medium and short trip and the longer urban commuter trip. Area coverage in the suburbs is often helped by park-and-ride or kiss-and-ride transfer facilities or by bus feeders. In part, these supplementary services are required because of low population densities and rapid transit's longer station spacings in these areas. Generally, average trip lengths on rapid transit systems are longer than those on surface transit, ranging from three to seven miles.

The well known drawback of rapid transit is its high capital cost, brought about mostly by the need to provide fully private rights-of-way. Furthermore, costs of automated vehicles are high. However, because of its high service quality, rapid transit has a greater capability to attract passengers when compared to other modes. This is the major goal for any transit service.

With respect to operations, rapid transit systems are rather diversified. Modern systems operate trains of any length that the station platform can accommodate without
full automation and with one-person crews (e.g., eight car trains in Hamburg since 1957, six car trains in Philadelphia since 1969). Stations may be operated without personnel by using remote closed circuit TV surveillance (Lindenwold Line). Most U.S. rapid transit systems, however, still use trains that have two-person crews (up to four persons in Boston) plus station personnel. When there is a modern type of operation and efficient management, however, rapid transit can be highly labor productive; the Lindenwold Line carries 171 daily passengers per employee (including administrative personnel and police).

The latest systems have extensive train automation that also allows some operational improvements and savings in energy and vehicle maintenance. These are significant in high capacity systems, but for other systems the benefits from automation often do not outweigh the increased cost and reduced reliability at least as long as the train crew is retained. Elimination of the last crew member on rapid transit systems is probably achievable with relatively minor innovations of control and operations. There is presently, however, no serious work in that direction, although unproven automated technologies are being investigated. Consequently, the highly automated rapid transit systems in operation today (e.g., Bay Area Rapid Transit) require a considerably higher investment cost than do nonautomated systems. But, they do not have the reduced operating cost and higher frequency that
full automation could bring.

Most rapid transit system cars are driven by electric traction motors that are contained on each car. The source of energy is wayside electric power distributed through a third rail or overhead catenary wire. Contact shoes or pantographs, as appropriate, function as the power pickups for the car. The traction motors are generally mounted within the vehicle truck. There may be one or two motors per truck, or two to four per car. Four motors up to 150 horsepower each, per car are possible. Motors may be alternating or direct current, although most transit systems use direct current. The motor sizes are determined as a function of car weight, design speed criteria, and design acceleration rate requirements.

The consist (number of cars) varies as a function of system operating requirements and will generally vary from two to ten cars. These requirements are usually influenced by peak versus off-peak traffic demands. Often, cars are semi-permanently coupled in married pairs, which consist of two cars that share certain auxiliaries such as air compressors and communication systems. Although this provides certain economies in car construction and maintenance, the two cars may only be operated as a pair. Some systems, such as the MUCTC in Montreal, operate a three car consist. Large transit systems may operate trains 600 feet long or longer and use ten to twelve cars during peak traffic periods.
Weight will vary with the size of the vehicle; however, it will also vary as a function of construction materials. Cars with aluminum bodies, for example, are generally regarded as lightweight when compared with stainless steel bodies. Vehicle tare weights for rapid transit service will generally range from 50,000 to 80,000 pounds.

The most common type of vehicle truck is a two axle, four wheel type. The wheels are steel flanged for operation on steel rails. Because of the steel wheel-steel rail noise problem in the older portions of the Paris Metro, which contains short radius curves, the French developed a pneumatic rubber tired truck. This design concept is now in use in some parts of the Paris Metro and in the new Metros in Montreal and Mexico City. Two rubber tired wheels are mounted on each of the two axles per truck. The wheels ride on a concrete or steel track. The trucks include horizontally mounted, rubber tired wheels operating against sidewalls of the guideway to steer the vehicles.

Advantages claimed for the rubber tired systems are reduced noise on short radius turns and the ability to operate on steeper grades than with flanged steel wheels. Because of the construction features and number of components of the pneumatic rubber tired trucks, their weight and rotational inertia are significantly higher than for flanged steel wheel trucks. In addition, the limitations of load-bearing capacity of the rubber tires result in significantly
shorter car lengths than the allowable maximum for steel wheeled cars. Another disadvantage of rubber tired trucks is the higher rolling friction and hysteresis losses common to any rubber tired vehicle. Collectively, these losses, together with a greater car weight per passenger, result in total system traction power requirements that may be more than 50 per cent greater than for steel wheeled vehicles on systems with similar track profiles.

For safety considerations, most rapid transit cars have multiple braking systems. These include friction shoe or disc brakes and usually some form of electric braking. In electric braking (dynamic or regenerative), the traction motors are switched to function as generators during the braking mode. Where dynamic brakes are used, the electric energy generated by the conversion of the train's kinetic energy in bringing the vehicle to a stop is discharged to on-board resistor grids.

One of the more recent advances in transit vehicle propulsion-braking systems is the use of a regenerative braking system. Although this system is similar to a dynamic braking system insofar as the switching of the traction motors to operate as generators is concerned, part of the generated energy is then used by on-board auxiliaries. An alternative system permits return of the electrical energy to the contact rail for possible use by other trains. Regeneration can reuse 25 per cent or more of the available braking energy of
trains. Since, on the average, the braking energy accounts for almost 50 percent of the total energy lost in a rapid transit system, reuse of some of that energy and resultant reductions in heat dissipation can be effected. Therefore, a regenerative braking concept is highly desirable for energy conservation. The effective use of a regenerative braking system is limited only by present technology. Further advances in compatible electrification and power control systems are necessary before the full benefits of regeneration can be realized.

E. BART

In spite of operational difficulties, the BART (Bay Area Rapid Transit) system in San Francisco is worth describing as an example of a system with features common to both commuter rail and rail rapid transit.

The BART system is seventy-one miles long, serving four major corridors radiating from the central cities of San Francisco and Oakland on the opposite sides of San Francisco Bay. Oakland and San Francisco are connected by the underwater Transbay Tube. From Oakland, service is provided north to the cities of Berkeley and Richmond, east to the rapidly growing suburban areas of Contra Costa County beyond the Berkeley Hills, and south to suburban Alameda County. The remaining line runs southwest from San Francisco to Daly City on the border of San Francisco and San Mateo County.
In 1975, the population of the three counties (San Francisco, Alameda, and Contra Costa) making up the BART District was approximately 2.4 million persons. Roughly 1.4 million persons lived within one mile of a BART line.

Approximately twenty miles of the system are located underground, twenty-four miles on elevated structure and twenty-seven miles at grade or on earth embankments. There are a total of thirty-four stations, fourteen of which are located below ground.

BART was designed explicitly to provide fast, comfortable, high-quality transit service which would be competitive with the automobile for relatively long distance commuter trips. Its design calls for high speed operation under automated control. Station spacings in suburban areas average between two and four miles, with somewhat closer intervals in downtown Oakland and San Francisco. These spacings, which are somewhat longer than on most conventional rail transit systems, permit a maximum design speed of eighty miles per hour, with an average operating speed (including stops) of thirty-eight miles per hour. Minimum design headways through the Transbay Tube during peak periods were set at two minutes, with provision for direct, "no-transfer" service to downtown Oakland and San Francisco on all four lines.

BART's designers placed considerable stress on creating a pleasant environment for the traveling public. The stations are constructed to extremely high standards, and reflect
a variety of architectural styles. Each station includes elevators for use by the handicapped.

BART cars are attractive and comfortable. They are air-conditioned, carpeted, and have upholstered seats, tinted windows and a public address system for announcements of stations and transfer points. Each car seats seventy-two persons. Individual trains may vary in length from two to ten cars. It was originally intended that service would be sufficiently frequent to permit all passengers to be seated.

Fares on BART range from twenty-five cents to $1.45, based on the distance traveled. This fare schedule represents an average increase of approximately 21 per cent over the original fare levels adopted when BART first began operations in 1972. The revised fare structure was instituted in November 1975, with fares generally being increased for long trips and decreased for short trips.

BART is equipped with an automated fare collection system, involving the use of magnetically encoded tickets based on the concept of a "stored fare". Passengers may buy tickets in any amount from twenty-five cents up to twenty dollars, and use the same ticket for one or more journeys on the system until its total value is used up.

Parking lots are provided at twenty-three BART stations, primarily in suburban areas. The capacity of these lots ranges from 240 to 1,400 cars. Their combined capacity is approximately 19,000 spaces. All suburban stations have
reasonably good highway access.

The area served by BART is also served by two major bus companies: the San Francisco Municipal Railway (MUNI) in San Francisco itself, and the Alameda-Contra Costa Transit District (AC Transit) on the east side of San Francisco Bay. Both MUNI and AC Transit provide feeder bus service to BART stations as part of their regular operations. In addition, AC Transit provides specialized feeder service contracted by BART to several stations in the outlying suburbs on the east side of the Bay.

One of the major objectives underlying the design of BART was the relief of peak period highway congestion. Each of the four BART lines roughly parallels a major freeway corridor, although often at some distance from the freeway itself. Two of the most congested sections of highway are the San Francisco-Oakland Bay Bridge, paralleling the BART Transbay Tube, and the Caldecott Tunnel, carrying California Highway 24 under the Berkeley Hills parallel to the BART Concord Line.

Throughout the approximately four year period which has elapsed since the opening of the Fremont Line in September 1972, BART has experienced continuing problems with the reliability of its equipment. These have seriously constrained the level of service which could be provided, particularly with respect to the reliability of service and the provision of adequate peak period capacity.
The technical issues involved are extremely complex. No attempt will be made here to discuss them in detail. They fall into two general categories: problems with the BART cars themselves and the as yet inadequate reliability of the automatic train control system.

Significantly higher than anticipated failure rates have been encountered with the train equipment, leading to unscheduled maintenance problems, service disruption, and a shortage of BART cars. In March 1976, for example, the average percentage of BART cars available for service at any given time was approximately 50 per cent; BART operations were designed on the assumption that car availability would be at least 80 per cent.

The most common failures involved the car's propulsion and braking systems, the on-board automatic train control equipment, auxiliary electrical and communications equipment, vehicle suspension and door equipment.

BART's policy is to "recall" to a repair yard any train that contains a car with a serious malfunction. Where feasible, the train is returned to service after the defective car has been removed; in other cases a new train is dispatched to replace the one that was recalled. During the first three months of 1976, an average of fourteen trains a day were recalled. BART's service schedule at that time required thirty operating trains. Thus, on an average day slightly less than half of the total number of trains required
for service had to be recalled for some form of emergency maintenance.

To date, the California Public Utilities Commission has found that the BART automatic train control system, essential to low headway operations, is insufficiently reliable. Until an adequate level of reliability is achieved, the Commission is requiring that BART maintain a full station separation between trains. That is, it is not permissible for one train to leave a station until the immediately preceding train has left the next station down the line. With the relatively long station spacing on the system, this effectively limits minimum headways under current operations to approximately twelve minutes on each line and six minutes through the Transbay Tube.

BART currently carries approximately 132,000 passengers per day. This is equivalent to between 2 per cent and 3 per cent of the total person trips made within the BART service area during the hours of BART operations.

BART's current ridership is roughly half that which was originally projected for the full system assuming that it was completely operational by the year 1975. It must be borne in mind, however, that this ridership has been attained over a period when the system was able to provide only a significantly lower level of service than that originally projected.
Major increases in ridership have occurred following each successive increase in service. The most significant increase occurred with the opening of Transbay service in September 1974. It is interesting to note that, following each such immediate increase, patronage has tended to remain relatively stable or to decline slightly. There has not been any significant, sustained growth in ridership for a given service level. Introduction of evening service resulted in a total increase in patronage of approximately 4.2 per cent over the preceding month. The average increase in fares of 21 per cent implemented in November 1975 resulted in a decrease in patronage of approximately 3 per cent.

The only significant exceptions to this general pattern are associated with two major transit strikes affecting the AC Transit and MUNI bus services in August 1974 and April 1976, respectively, and the severe gasoline shortages in early 1974. During each of these periods, there was a sharp but short-lived increase in BART ridership.

BART patronage is dominated by commuting to and from work. Such travel accounts for over two-thirds of the total trips made on the system, with the predominant direction of this movement being into downtown San Francisco.

Consistent with this pattern, ridership tends to be heavily concentrated in the morning and evening peak periods: in May 1975, ridership in the four hours making up the morning and evening peak-periods averaged approximately
60 per cent of total daily patronage.

Ridership varies considerably between different segments of the system. Slightly less than half of all BART trips are made by the Transbay Tube. Patronage is highest between stations on the Concord Line and San Francisco, and lowest for travel among the five central Oakland stations. In general, the system is used more for long rather than short trips. The average total travel time for a journey involving the use of BART is forty-six minutes; less than 6 per cent of all trips are under sixteen minutes. This pattern reflects strongly BART's geographic orientation and its emphasis on improving service to the outlying portions of the region.

F. SUMMARY

Table III gives some important characteristics for each of the four rail mode categories. These features define the modes and distinguish between them. In summarizing, two points are reemphasized.

1. Rail transit is a family of modes, ranging from the operating and service characteristics of the streetcar to those typical of rapid transit and regional rail systems. Depending on local conditions, individual rail modes can be efficiently used for many conditions in medium and large cities.
<table>
<thead>
<tr>
<th>Item</th>
<th>Streetcar</th>
<th>Light Rail</th>
<th>Rapid Transit</th>
<th>Regional Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Facilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exclusive right-of-way, percent</td>
<td>40</td>
<td>40 to 90</td>
<td>100</td>
<td>90 to 100</td>
</tr>
<tr>
<td>Way control</td>
<td>Visual</td>
<td>Visual/signal</td>
<td>Signal</td>
<td></td>
</tr>
<tr>
<td>Fare collection</td>
<td>On vehicle</td>
<td>On vehicle or at station</td>
<td>At station or on vehicle</td>
<td></td>
</tr>
<tr>
<td>Power supply</td>
<td>Overhead</td>
<td>Overhead or rail; Any type; low or high, fully controlled</td>
<td>Third rail or overhead</td>
<td>Overhead or third rail</td>
</tr>
<tr>
<td>Station Platform</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height and access control</td>
<td>Low</td>
<td>Any type; low or high; fully controlled</td>
<td>Fully controlled; low or high level</td>
<td>Any type; high level</td>
</tr>
<tr>
<td>Vehicle Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum operational unit</td>
<td>1</td>
<td>1 to 3</td>
<td>1 to 3</td>
<td>1 to 3</td>
</tr>
<tr>
<td>Maximum train composition</td>
<td>3</td>
<td>2 to 4 (6-axle)</td>
<td>6 to 10</td>
<td>6 to 10</td>
</tr>
<tr>
<td>Vehicle length, m</td>
<td>14 to 20</td>
<td>20 to 33</td>
<td>15 to 23</td>
<td>20 to 26</td>
</tr>
<tr>
<td>Vehicle capacity, seats/vehicle</td>
<td>16 to 40</td>
<td>16 to 80</td>
<td>36 to 84</td>
<td>80 to 125</td>
</tr>
<tr>
<td>Vehicle capacity, total/vehicle</td>
<td>80 to 180</td>
<td>80 to 335</td>
<td>100 to 250</td>
<td>100 to 290</td>
</tr>
<tr>
<td>Operational Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum speed, km/h</td>
<td>60 to 70</td>
<td>60 to 125</td>
<td>90 to 130</td>
<td>90 to 160</td>
</tr>
<tr>
<td>Operating speed, km/h</td>
<td>10 to 25</td>
<td>20 to 45</td>
<td>25 to 60</td>
<td>30 to 70</td>
</tr>
</tbody>
</table>
### TABLE V (continued)

<table>
<thead>
<tr>
<th>Item</th>
<th>Streetcar</th>
<th>Light Rail</th>
<th>Rapid Transit</th>
<th>Regional Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum frequency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak hour, joint section/h</td>
<td>140</td>
<td>40 to 120</td>
<td>20 to 40</td>
<td>6 to 30</td>
</tr>
<tr>
<td>Off-peak, single line/h</td>
<td>5 to 12</td>
<td>5 to 12</td>
<td>5 to 12</td>
<td>1 to 4</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td>10,000</td>
<td>3,000 to 18,000</td>
<td>6,000 to 30,000</td>
<td>10,000 to 40,000</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td><strong>System Aspects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network and area coverage</td>
<td>Dispersed, good area coverage; good area branching is common</td>
<td>Good CBD</td>
<td>Predominantly radial; some CBD coverage</td>
<td>Radial, limited CBD coverage</td>
</tr>
<tr>
<td>Station spacing, m</td>
<td>250 to 500</td>
<td>350 to 800</td>
<td>500 to 2000</td>
<td>1200 to 4500</td>
</tr>
<tr>
<td>Average trip length</td>
<td>Short-to-medium</td>
<td>Medium-to-long</td>
<td>Medium-to-long</td>
<td>Long</td>
</tr>
</tbody>
</table>
2. The combination of service and cost characteristics offered by different rail modes overlaps, as shown in Figure 19. There is no boundary, for instance, between the streetcar and light rail categories. Similarly, light rail can be designed to function much like rapid transit and to be gradually converted to it. When its scale is magnified, rapid transit can become a regional rail system.

For these reasons, generalizations regarding rail systems with respect to both cost and service characteristics (e.g., rail systems are expensive) are in most cases incorrect, and they should not be used.
Investment Cost

Service Quality*

*Represents a set of mode features including speed, availability, comfort, convenience, safety, user cost and security

FIGURE 1968
RAIL TRANSIT MODE COMPARISONS
BIBLIOGRAPHY
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1. American Railway Engineering Association Manual of 
   Recommended Practice For Railway Engineering 
   Construction and Maintenance. Volume I and 
   Volume II. Chicago: American Railway Engineering 
   Association, 1972.

2. American Railway Signaling Principles and Practices, 
   Chapters 1-6, 15, 21. Chicago: Signal Section, 

3. Armstrong, John. Track Planning for Realistic 

   New Illustrated History of the United States. 

   Use of STOP Signs at Railroad Crossings," Traffic 

6. "Optimum Hazard Index Formula for Railroad 
   Crossing Protection for Lincoln, Nebraska." 
   February, 1967. (Mimeographed.)


   First Big Business. New York: Harcourt, Brace, 
   and World, 1965.

   ting Division, Association of American Railroads, 
   August, 1960.

    Circular No. OT-10-E. Washington, D.C.: Associa-

11. Code of Trailer and Container Service Rules - Per 
    Diem Rules. Circular No. OT-36-C. Washington, 
    D.C.: Association of American Railroads, February, 
    1974.


