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IDENTIFICATION OF DESIGN AND EVALUATION CRITERIA

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*A Technical Note is a working paper that presents the preliminary results of research related to a single phase or factor of a research project. Its purpose is to instigate discussion and criticism, by presenting the concepts, findings, and/or preliminary conclusions of the author. It may be altered, expanded, or withdrawn as further research results are obtained.

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I INTRODUCTION

As part of a recent study of railroad switchyard technology, SRI determined that the design of classification yards significantly influences the effectiveness of yard operations. For example, we found that the number and/or length of the yard tracks are a major problem at more than one-third of all classification yards. The study projected that as many as 200 classification yards will have to be built, rebuilt, reequipped, or otherwise modified between now and the year 2000. In addition, the SRI study and other studies have identified classification yards as the major source of other significant railroad problems, such as delays, delivery time unreliability, and low utilization of freight cars.

Because of these and other factors, the Federal Railroad Administration and the Transportation Systems Center of the Department of Transportation are sponsoring a research project to investigate the design of railroad classification yards. The objective of this project is to establish practical guidelines, procedures, and principles that will facilitate the design and engineering of classification yards. It is intended that the project results will include engineering data and methodology in handbook form. The handbook will be used to make informed choices among alternative capital investments by railroads, suppliers, and public agency personnel.

This research project is divided into three phases:

- Phase I: Development of Design Methodology
- Phase II: Preparation of a Yard Design Case Study
- Phase III: Delineation of Final Methodology.

Phase I of this research entails the formulation of a design methodology that personnel from railroads, railroad supply companies, or public agencies can use in developing and evaluating railroad classification yard designs. This report presents the results of Task 2, "Identification of Techniques and Criteria", performed during Phase I of this research project. The objective of Task 2 is to select or develop a set of functional and operational parameters that are suitable for the functional specification of yard designs and as criteria in the evaluation of yard design alternatives.

Our approach to this task was to review the criteria used by railroads in the design and evaluation of railroad classification yards. In the following, however, we describe some parameters that, to our knowledge, are not used, but that may be useful. Although this technical note describes what are judged to be the most useful parameters, it is anticipated this selection will be modified and expanded in other phases of the project.

One of the first and most important steps in the design of a railroad classification yard is the specification of the goals or objectives of the design effort. The objectives selected will significantly affect the final design and how well it performs. In like manner, the design alternatives must be evaluated in relation to how well the designs meet a given objective. One design can be judged superior to another only to the extent that it achieves the selected objectives to a greater degree. For a given design or evaluation effort, the objectives might include cost (or profit), quantity, flexibility, safety, efficiency, reliability, and quality. These objectives, as stated, are too nebulous to be quantitatively used in either the development or evaluation of a yard design. In order to assess the success of meeting these objectives, the designer or evaluator needs definitive measurement scales for determining how well the objectives will be met by the design alternatives. These measurement scales are also used to compare design alternatives. The variables used to define these measurement scales have at various times been labeled as "performance measures," "criteria," "measures of effectiveness," "figures of merit," and the like. In this report, we will primarily refer to these variables as criteria. In the subsequent discussion we will at times, however, differentiate between two types of criteria: design criteria that are suitable for use in quantitatively describing the objectives of a design project; and evaluation criteria that are used to measure, describe, and compare the performance of different yards or yard designs. Many of the variables described herein can be used either as design or evaluation criteris; however, others are more suited to one or the other application.

The description of these criteria will be organized into three general areas:

- Rail system criteria
- Classification yard criteria
- Yard component criteria.

The rail system criteria are intended to measure the system-wide yard operations. The classification yard criteria identify the effectiveness and capabilities of the total yard complex, whereas the yard component criteria are used in the design and evaluation of individual elements of the total yard design.

II RAIL SYSTEM CRITERIA

The design, construction, and operation of an individual classification yard can often influence the operational performance of the entire railroad system. It is important, therefore, to be able to define system-wide goals that should be achieved through the construction of a class yard and to be able to measure how well these goals are achieved. This section describes rail system criteria that are or can be used during the design or evaluation of classification yards.

A. Rate of Return

Discussions with railroad personnel and a review of existing yard-related literature have indicated that the two most important objectives for a yard design project are the construction cost and the rate of return on the investment in yard construction. The railroads rely heavily on the use of rate of return as the basis of their investment analysis. Generally the rate of return is the ratio between annual net profit and the required capital investment; however, the construction and operation of a railroad classification yard cannot easily be related to increased railroad revenues. Instead, the rate of return on nonrevenue-producing investments, such as classification yards, should be calculated on the basis of annual cost savings as a result of the investment as compared to the costs associated with not making the investment (that is, the do-nothing design alternative).*

The primary benefit of using rate of return in such analyses is that it is an aggregate design criterion that describes and combines many criteria into a single variable based on a common scale: dollars. The main problem with this particular measure is the difficulty of accurately representing all of the relevant factors in terms of dollars. Another problem with the use of rate of return is the difficulty of reliably measuring the actual rate of return after completing the project.

Our review of economic studies on various yard projects shows that the major factors contributing to a positive rate of return are the reduction of switch engine and personnel assignments in other yards and the overall system reduction of car detention time in yards. Table 1 shows a range of the estimated net rates of return associated with recent yard design projects. As can be seen, it appears that a major new yard project offers a 20 to 30 percent net rate of return on investment.

B. Construction Cost

As mentioned above, the other major design criteria used in the design and evaluation of yard designs is the size of the required investment.

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*Variations of this approach, using information about the incremental cost savings associated with incremental investments, can be used when evaluating several design alternatives.

Name of Railroad	Year Completed	Name of Yard	Estimated Net Annual Rate of Return	Estimated Cost of Construction
Atchison, Topeka and Santa Fe	1969	Eastbound Argentine Yard	25%	$12 million
Illinois Central Gulf	--*	Fulton Yard	24% - 28%	$44 million
Southern Pacific	1973	West Colton Yard	28%	$39 million
Southern	1973	Sheffield Yard	15%	$15 million
Burlington Northern	1974	Northtown Yard	--†	$42 million
Santa Fe	1976	Barstow Yard	20% - 30%	$50 million
Union Pacific	1977	Hinkle Yard	20% - 25%	$20 million

*Never Built

†Unknown

Table 1. Typical Rates of Return Associated with Various Yard Design Projects

Estimated construction costs for a number of hump yards are shown in Table 1. Table 2 shows a breakdown of the components of the cost of typical new hump yards. The enormous cost of these yards is an important factor in deciding whether to build a yard or not and is a principle criterion to be met by the yard designer.

Cost is complementary to rate of return in that an investment alternative with the highest rate of return will not always be the one selected for implementation. The cost of the alternatives must be examined in relation to the availability of investment capital. It is quite possible that an investment with a lower ROR (rate of return) will be selected if it costs significantly less. In addition, it is generally easier for a railroad to borrow money for investments, such as cars or locomotives, that can be reclaimed and resold in the event of default. A study of Table 2 shows that the average salvage value of a hump yard is, at most, 30 to 40 percent of the initial yard cost. It is highly unlikely that even this amount could be obtained by creditors because government regulations restrain creditors from dismantling a railroad's fixed plant even if the railroad is bankrupt.

C. System-Wide Yard Time

Studies have shown that cars spend a significant amount of their time in railroad yards. An analysis of car cycles indicate that more than 60 percent of the car time is spent in yards and less than 15 percent is spent in line haul operations[1]. A recent SRI study on classification yards estimated that about 40 percent of the car time is spent in 1,229 yards that were identified as classification yards[2]. It would seem that the percentage of car time spent in yards would be a good indication of the efficiency of yard operations on a system-wide basis. However, because of the different types of rail networks and the different demand patterns, such a measure could be used effectively only to compare a given railroad system's performance with its past performance and to set a goal for future performance. Such a measure would be inappropriate for comparing the efficiency of two different systems. It is believed that the difficulty in obtaining this information on an accurate and regular basis is the major reason that this measure is not being used within the railroad industry.

D. Car Speed

The average speed at which freight cars move through a rail system can also be used as a relative indication of the efficiency of a system's yard operations. This figure can be obtained by dividing the system's car miles by the system's car hours. This can be done on a daily, weekly, monthly or annual basis. In 1975 the average freight car speed was 2.2 miles per hour. Again, this measure can vary significantly between individual rail systems and even geographical areas* and is most sppropriately used as a

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*The average freight car speed in the Western District in 1975 was 2.8 miles per hour.[3]

Table 2

COST OF CONSTRUCTION FOR TYPICAL HUMP YARD*

Land, 600 acres @ $10,000	$6,000,000
Clearing, grubbing, general site preparation	1,738,000
Utilities, air, water, sewage	540,000
Class yard tracks	8,640,000
Receiving and departure yards	11,100,000
Lead tracks	7,640,000
Other tracks	1,680,000
Retarders, computers, and related gear	3,390,000
Communications, signals	800,000
Scale	500,000
Switch heaters	1,040,000
Buildings, roads, paving, lighting	3,000,000
Contingencies, 15%	6,910,000
Engineering, 6%	3,179,000
Total	$56,157,000

*Catenary system not included.

Source: "USRA Yard Classification Project: Maximum Throughput and Associated Expenditures and Selected Yards," p. 3, R. L. Hines Associates, Inc., Washington, D. C. (2 January 1975).

measure or design goal of the relative yard efficiency for a particular railroad. The major problem associated with this measure is that it can be significantly influenced by the demand for cars. When the demand for cars is low, there will be more idle car time when cars are in storage, thereby decreasing car speed as calculated above. Changes in shipper's operations can also affect this measure.

E. Transit Time

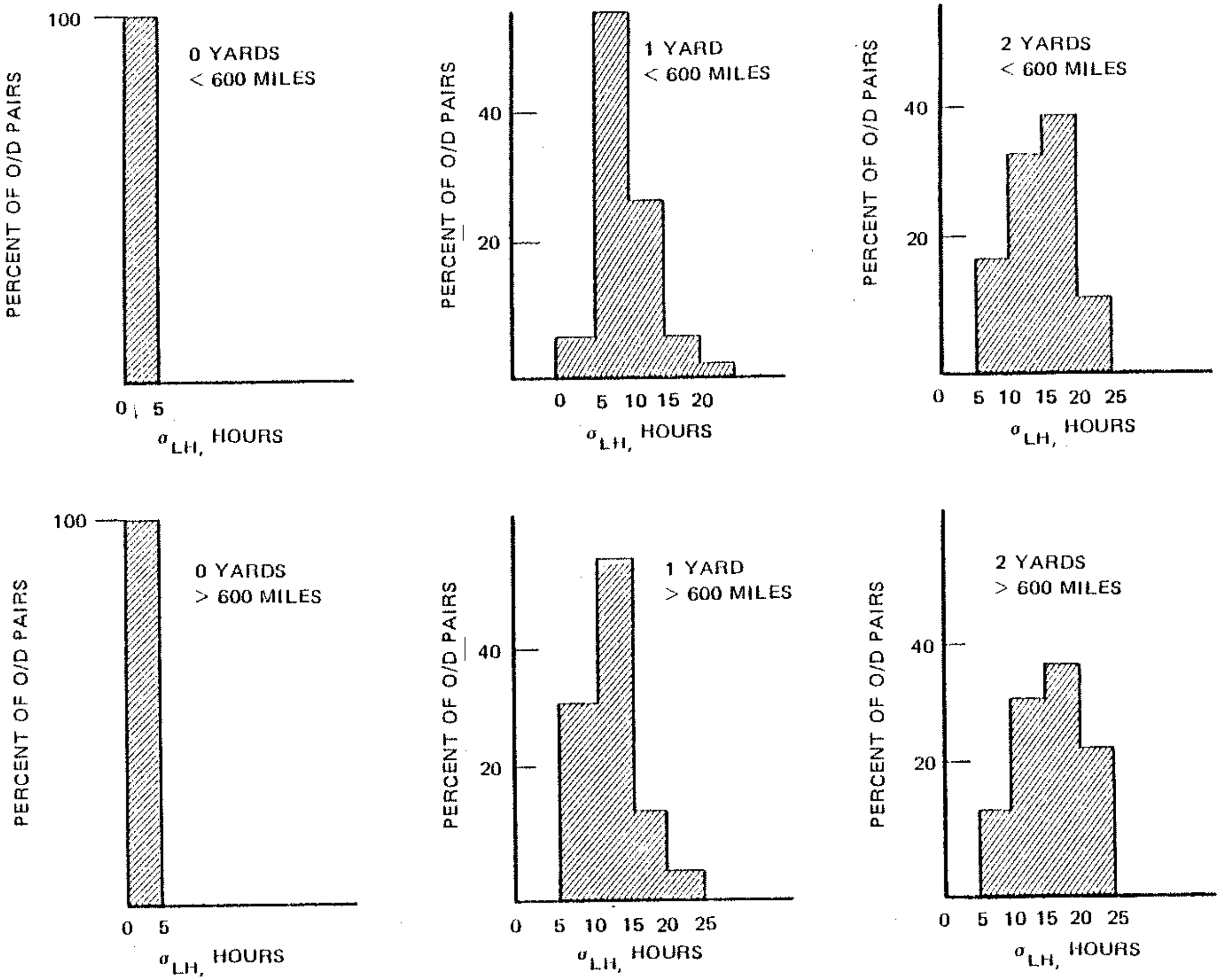
Related to the measure of car speed is the average amount of time required for cars to be moved from a given origin to a specific destination. Average transit time for a movement between a particular origin/destination (O/D) pair is usually measured in terms of average days per trip. Since so much of the time is spent in yards, the transit time through yards can significantly effect the system averages. This is an important measure of the level of service offered to shippers and is a measure that is consistently used by shippers in evaluating railroad performance.

F. Transit Time Reliability

In addition to average transit time, shippers also judge the quality of railroad transportation service by the consistency of transit time between a given origin and destination. This quantity is commonly referred to as transit time reliability, and is a key measure of railroad service since greater unreliability of shipment times will require maintaining higher average inventory levels to minimize inventory stockouts.

Transit time reliability has been described in terms of many different measures. One obvious measure is the standard deviation of the distribution of the transit times for car movements between a given O/D pair. Another measure is the percentage of cars whose transit times are within a consecutive N-day period, where N is an acceptable variation in transit time. Still another measure of transit time reliability is the percentage of cars that arrive before some defined cutoff time.

Recent MIT research has shown that transit time reliability is very strongly related to the number of intermediate yardings.[4-7] As can be seen in Figure 1, car movements that do not entail any intermediate yardings were found to be significantly more reliable than trips that require one or two intermediate yardings, irrespective of the length of haul. This conclusion about the relationship between transit time reliability and the number of intermediate yardings is not too surprising when the operations at intermediate yards are analyzed. At each such intermediate yard individual cars and groups of cars called "blocks" arrive on incoming trains, are switched onto various sorting or "classification" tracks, and finally are assembled into an outgoing train bound for another yard. The MIT research indicates that the primary cause of transit time unreliability is when cars miss their outbound train connections at these intermediate yards, and thus have to wait 12 to 24 hours for the next appropriate outbound train. Thus, as the number of intermediate yardings increases for a given car movement, it is reasonable to expect



SOURCE: Sussman[8]

O/D means original destination.

σ_{LH} means standard deviation in line haul reliability.

FIGURE 1 THE PREDOMINANCE OF THE NUMBER OF INTERMEDIATE YARDS OVER DISTANCE AS A FACTOR AFFECTING TOTAL LINE HAUL RELIABILITY the probability of missed connections to increase, thereby increasing the unreliability of transit times. Table 3 shows an MIT-derived relationship between the probability of a missed connection at a yard and the magnitude of transit time delay and transit time variance.

G. Loss and Damage

Successful claims against U.S. railroads for the loss and damage of shipments amounted to 266 million dollars in 1975. (To place this in perspective, this amount is about 1.36 percent of the railroads' gross freight revenues for that year.) The railroad industry commonly accepts the hypothesis that most of this loss and damage occurs in railroad yards. Much of the damage to shipments is felt to be caused by the overspeed impacts of free rolling cars that often occur during the car switching process. It is felt that coupling speed greater than 4 mi/hr have the potential of damaging the shipment. Yet because many other factors, such as commodity type, shipment packing techniques, and type of car cushioning, also influence the amount of damage, there is at present no clearly defined relationship between system-wide damage figures and system-wide yard operations.

In addition, there is general industry-wide agreement that the loss of shipments through theft occurs primarily at railroad yards. Concentrating car switching activities at a large, well-secured yard may decrease the theft levels compared to those occurring when switching is done at several smaller yards. There is no definitive relationship, however, between theft and the design and operation of the yards of a particular railroad.

Table 3

AVERAGE DELAY TIME AND STANDARD DEVIATION OF DELAY TIME AS A FUNCTION OF THE PROBABILITY OF A MISSED CONNECTION

Probability of Missing Connection	Average Delay (Hours)	Standard Deviation of Transit Times (Hours)
.1	2.4	7.2
.2	4.8	9.5
.3	7.2	11.0

Source: Sussman[8]

III OVERALL YARD DESIGN AND PERFORMANCE CRITERIA

A. Yard Throughput

Yard throughput is a term used to describe the daily volume of freight cars that are handled in a classification yard. As such it is a measure of the quantity of work performed in a yard. Unfortunately, definition of the term has not been formally developed and accepted by on an industry-wide basis. At some yards throughput is defined as the number of cars classified during a day and at other yards as the number of cars that are dispatched per day. At other yards throughput even includes the cars on trains that are yarded just for inspection. In general, however, throughput is an aggregate measure of the number of cars that enter a yard, are switched one or more times, and then depart on an outbound train. Most of the yard performance measurement systems with which we are familiar, including those of BN, Frisco, ICG, Southern, and SP, describe yard volume in terms event pairs, matching up individual car arrival events with car departure events. (More detailed events, such as the movement of cars between areas of the same yard, also can be described.)

In whichever way throughput is defined and measured at various yards, it is always the principal measure of the amount of work performed at any given yard. Throughput is also the most dominant element used in describing a yard's capacity. Typically, yard capacity is defined as the maximum daily throughput that can be achieved on a consistant basis without causing excessive delays to car and train movements. However, a general relationship between daily yard throughput and car detention time or delay has not yet been developed; therefore, the value of yard capacity as a design criterion is usually estimated on the basis of experience or intuition unless yard operations are simulated.

B. Yard Detention Time

Recent studies have estimated that most car time is spent in railroad yards. It is, therefore, understandable why yard detention time is a primary criterion used in designing and evaluating classification yards.

For an individual yard, detention time is generally defined as the average amount of time a car spends in the yard. This can be roughly determined by dividing the total car-hours spent in the yard during a given day by the number of cars dispatched that day. At yards that have certain types of information processing systems, average yard detention time is determined by comparing the arrival and departure times for each individual car. Simulation of the operations of various yard design alternatives is the only widely accepted analytical procedure for projecting the average yard detention time associated with new or modified yard designs. Other analytically based estimating procedures have been developed, principally in academic environments, but have not yet been widely used. A brief review of many of these estimating procedures indicates that many, if not most, do not consider many important factors in yard design, yard operations, and system operations that can significantly influence detention time. For example, train schedules can have major effects on detention time since, if connections are such that a group of cars consistently misses a departure train by a few hours, 12 to 24 or more hours can be added to that group's yard detention time. Yet the effects of train schedules are rarely included in the analytical procedures that were reviewed.

The SRI yard survey indicates that the average detention time for the nation's 1229 classification yards is a little over 19 hours.[2] The average detention time is a little less at flatyards (18.6 hours) and a little greater at hump yards (nearly 22 hours).

C. Missed Connections

As discussed in Section II, transit time reliability is an important indicator of the quality of service offered to the shipper. Also mentioned was the fact that the yarding of trains and cars is thought to be the most significant factor in unreliability. It, therefore, seems important to be able to determine how the operations at individual yards influence systemwide transit time reliability. Many railroads have reflected this influence by establishing certain transit time performance standards and measuring how effective various yards are at meeting these standards. These standards are of three types:

- An absolute time standard (for example, 24 or 30 hours)
- A cutoff time standard wherein cars arriving at a yard before a certain time are expected to depart by a given time.
- A train connection standard wherein cars arriving on a certain inbound train and are then moving to another given destination are assigned to connect with a specific outbound train.

It is our feeling that the train connection standard is the most suitable for demonstrating the yard's influence on transit time reliability. An appropriate measure would be the percentage of cars that miss their scheduled connections (that is, the percentage of cars that do not make their standard). This measure does have some significant drawbacks, however. The train connection standards are difficult to routinely define because of the significant daily changes that can occur to train schedules, system blocking strategies, car travel patterns, and so on. In addition, this measure at present can only be used to evaluate the performance of existing yards as there exists no well-accepted relationship between yard design or operations and the percentage of missed connections. Even the simulation techniques currently in use have limited applicability in estimating this measure.

D. Operating Costs

One measure of yard performance that is important both as a design criterion and as an evaluation criterion is operating cost. This is used as a measure of the efficiency of the yard design and operations. In designing a yard it is important to be able to accurately estimate the operating costs associated with the design alternatives so the initial investment costs can be traded off with the projected operational costs and savings, and so that the rate of return can be calculated.

The actual cost measure generally used to evaluate yard performance and efficiency is the average cost per car put through the yard. This is usually called the cost per switch. A major difficulty encountered when using this measure is that different railroad systems calculate costs in different ways, often allocating different unit costs to an identical cost element, such as car time, or, in many cases, not accounting for all of the relevant cost elements. Thus the average cost per switch cannot generally be used for comparing the relative efficiencies of classification yards on different systems. Even on the same railroad the cost-accounting scheme used may not account for all costs and thus may be biased toward certain types of yards. For example, if car time is not included in the cost-accounting algorithm, a classification yard that has a very high average car detention time would seem to be more efficient (that is, would have a much smaller cost per switch) than it would if car costs were accounted for. Thus the measure of cost per switch should be used with some care and should probably be used only to compare the relative performance of two or more yards.

A review of the output summaries from terminal management information systems shows that the cost per switch associated with classification yards varies from about \$4 to \$13. Previous SRI estimates of national classification yard costs indicate that the average cost per car classified in classification yards was about \$9.90 in 1973.[*]

E. Cars Per Switch-engine Hour

Another measure of the efficiency of a yard that can be used as a design or evaluation criterion is cars per switch-engine hour. This measure can be calculated by dividing the number of cars put through a yard during a period of time by the number of switch-engine hours (SEH) worked at that yard during that same time period.[†] This measure can be used as a surrogate for the previous measure of cost per switch, since our previous analysis show that a large percentage of the operating cost of classification yards is directly connected with switch-engine operation. Other yard costs are often allocated in terms of SEH, as shown in Table 4, so that a total cost per SEH can be developed. This cost per SEH will vary among railroads, depending on how costs are allocated. In the period 1973 to 1975 the cost per SEH generally ranged from \$60 to \$90.

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[*] This estimate is only for the 1,229 classification yards identified by SRI. When including the costs for industrial yards, the average cost per switch in 1973 increases to \$10.20.

[†] In this discussion SEH is equal to eight times the number of engine tricks assigned at a yard. SEH therefore includes idle and break time.

Table 4

DETAILS OF SWITCH-ENGINE HOUR COSTS

Cost Element	Allocated Cost
Maintenance of way and structures	$1.49
Locomotive and car expense	
Depreciation and retirements	0.79
Maintenance of equipment	0.38
Rents	0.35
Yard service	
Operating crews	39.96
Clerical	12.78
Switch/signal tenders	4.57
Servicing	3.51
Fuel	1.61
Transportation casualty	
Other transportation expense	4.38
Cost per switch-engine hour	$71.79

Even without associating a cost figure with SEH, the term cars per SEH can be used to give a relative measure of the efficiency of various yards without the ambiguities inherent in allocating costs. For example, the SRI yard survey showed that, nationally, flatyards processed 11.3 cars per SEH, on the average, whereas hump yards processed 13.7 cars per SEH.[*]

$0.8(11.3) + 0.2(13.7) = 11.78$

$9.90 \frac{\text{dollars}}{\text{car}} \cdot \frac{11.78 \text{ cars}}{\text{SEH}} = 116.62 \frac{\text{dollars}}{\text{SEH}}$

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[*] These figures are SRI estimates of national averages and include all switch-engine jobs in classification yards except industrial switching assignments. The statistical significance of the difference in cars per SEH between flatyards and hump yards has not been tested.

IV YARD COMPONENT CRITERIA

A large variety of operational activities typically occur in any railroad classification yard. The main activities are connected with performing certain necessary functions, such as receiving incoming trains, switching cars, and so on. The yards are often designed to accomplish these activities in an efficient manner by segmenting the yard into functional areas. In this section we describe the criteria that may be useful in the design or evaluation of individual components of a railroad classification yard. These components include the receiving tracks, switching area, classification tracks, and departure tracks.

A. Receiving Tracks

The receiving tracks of a classification yard are used to receive inbound trains. If an inbound train is longer than the available receiving tracks, the train must be split up before yarding, an action that requires perhaps an additional 15 to 20 minutes. If receiving tracks are not available for yarding an inbound train, it might wait outside the yard until an acceptable track becomes available. While on the receiving tracks the cars generally will be given an inbound mechanical inspection. Some of the criteria that can be used in evaluating yard design alternatives for receiving tracks are described below.

1. Yarding Delay

This is the average amount of time that an inbound train has to wait for an acceptable receiving track. An average yarding delay of more than 10 or 15 minutes generally indicates an operational bottleneck in the yard. However, such a bottleneck could exist at many different points in the yard. This measure does not identify the location of the bottleneck.

2. Transit Time

This term refers to the average amount of time spent between yarding and when the train is switched. As such it is a component of the yard's total transit time. In general, it appears that, if the transit time through the receiving yard is more than 25 to 30 percent of the total yard transit time, an operational bottleneck exists somewhere in the yard, but this measure provides little information on the location of the bottleneck. However, if this time is broken down into the average time spent in the receiving yard before inspection and after inspection, it should be possible to determine if the bottleneck occurs in the receiving yard.

3. Receiving Track Availability

One measure of the utilization of the receiving yard is the percentage of time that at least one receiving track is empty, and thus available for incoming trains. It is expected that this criterion should show a close inverse relationship with the measure of yarding delay. That is, as receiving track availability decreases, average yarding delay should increase. To the author's knowledge, this measure has not been used in either the development or evaluation of yard designs.

4. Receiving Yard Occupancy

This criterion is related to the average number of cars in the receiving yard. It would seem that a good measure of the utilization of the receiving yard would be to calculate the ratio between the average number of cars in the receiving yard and the standing capacity of the yard. In one hump yard the utilization of the receiving yard was 60 percent, although this may not be a typical figure.

5. Inbound Inspection

The mechanical department personnel at most yards generally perform a Class A mechanical inspection of all cars that move through the receiving yard. The rate at which these cars are inspected can be significantly influenced by the geometric design of the yard. For example, greater distances between tracks can facilitate faster inspection through the use of mechanized crew transport between the tracks. In addition, it has been found that locating the receiving yard close to the departure yard facilitates the interchange of the inbound and outbound inspection crews to meet sudden peak demands. A possible measure of the performance of the inspection process is the time between the arrival of a train and when it is inspected. However, it would be more useful to measure the average time between the completion of the inbound inspection and when the train is humped or switched. Other potentially useful measures are the percentage of trains that are delayed from being switched because the inbound inspection has not been completed, and the average or total amount of such delays.

B. Switching Area

The switching area is a critical element of a classification yard design because virtually all cars that are switched at a yard must travel over these tracks. It is, therefore, important to be capable of describing how effectively these key elements of a yard design should be used or of measuring how efficiently these resources are being used.

1. Switch or Hump Rate

A primary design criterion of a classification yard is the rate at which cars can be switched. At hump yards cars are generally pushed over the hump crest by a hump engine moving at a standard speed. Therefore, the hump rate can be directly related to the speed of the hump engine. This speed can be significantly influenced by design features, such as the grades in the switching area; the size of the groups; and the sizing, placement, and control of the retarders. (The major factors influencing hump speed are described by Wong[9]). A recent SRI survey of more than 45 hump yards showed that the average hump speed at hump yards is about 2.4 mi/hr. However, this survey revealed considerable variation in the hump speeds of various yards. One hump yard reported a hump speed of 1.0 mi/hr whereas Southern Pacific's West Colton hump yard is capable of humping at speeds of 4.5 mi/hr.

Although it is technically more correct to discuss hump speed in terms of velocity, it is generally more common to describe it in terms of the average number of cars humped per minute. This figure can therefore be biased by the average length of the cars being humped in a particular yard. Assuming an average car length of 55 feet, the humping rate may be as fast as nearly eight cars per minute. The average is between three and four cars per minute.

The switching action at a flat yard consists of a switch engine pushing a cut of cars up to a certain speed at which point the engine decelerates and cars are uncoupled and allowed to roll freely into the correct classification track. It is therefore inappropriate to describe the speed of the switching activity in terms of velocity. In addition, it also seems inappropriate to describe the switching rate in terms of cars per minute because this rate will depend not only upon the design of the yard but also on how the cars are sequenced in the cut to be switched. Thus a cut of 20 cars may require 10 minutes to switch if it contains five ordered groups of cars but may require more than 15 minutes to switch the cars have to be uncoupled and kicked individually into the classification tracks. It is common, however, to speak about a flat yard switching rate in terms of cars per minute. Our limited observations have indicated that this switching rate varies from about 0.6 to 1.0 cars per minute.

2. Switch Lead Utilization

A measure of the utilization of the hump crest and the hump lead gives an indication of the efficiency of the humping operation and complements the measure of hump speed. Hump utilization can be expressed as the percentage of time that the hump is being used for humping operations. This percentage is less than unity even when working at maximum throughput due to the need to perform activities that interfere with the humping. Some of these activities include trimming the bowl tracks, pulling cars back over the hump, and repairing critical yard elements, such as the master retarders, the scale, or the process control system. The maximum hump utilization possible at most yards is between 60 to 70 percent. It has been claimed that a correctly designed yard could achieve a hump utilization of as much as 90 percent; however, this degree of hump utilization is not achieved at existing yards.

Hump utilization is also measured in terms of minutes per hour (typically 35 to 40), and minutes per day (typically 800 to 1000). It is believed that the utilization of the switching lead in flat yards could be measured in the same terms as those used in hump yards; however, we are not familiar with any railroads that use such measures.

3. Catchups

Catchup is a term used to describe when a car or cuts of cars rolls so much faster than a preceeding cut that the headway between the two cuts in the switching area is insufficient to allow a switch to be thrown to separate the cuts. If the following car hits the switch point before the switch is fully thrown a derailment can occur. In order to prevent derailments, provisions are made to cause the second car to be misclassified (follow the slower preceeding car's route). The misswitched car must then be reclassified.

The occurrence of catchups is significantly influenced by the design of switching area and the process control system. The percentage of cars that catch up with preceeding cars is, therefore, a very appropriate criterion in the design and evaluation of classification yards. If the percentage of catchups exceeds one or two percent, the design of the switching area and the process control system should be reviewed and possibly modified.

C. Classification Tracks

1. Number of Blocks Built

When a new yard is designed or an existing yard is modified, a basic consideration is the number of locations for which the yard can sort cars. The goal is to increase the number of blocks that can be made. The ideal situation, from an operational viewpoint, is one in which each block is sorted onto a single classification track. However, often the number of tracks is limited and cars must be mixed for several destinations on one track. The mixed blocks are sometimes reswitched but are sometimes sorted again in satellite yards or secondary sorting operations. When the cars are reswitched, class tracks often must time share between the blocks previously switched and the reswitched cars. This is called "swinging" the classification track. Reswitching measures and their relation to the number of blocks that can be made will be discussed in more detail later in this section. Swinging can also improve the total classification track capacity, which is discussed next.

Elements of design that affect the number of blocks that can be made are thus number and length of classification tracks, secondary sorting schemes, and tools that improve the yardmaster's ability to swing class tracks.

2. Class Track Capacity

The total capacity of the classification tracks dictates the number of cars that can be held in the yard. Receiving and departure yard capacities also influence the holding capabilities. A highly cyclical operation (having peaked arrival patterns followed by peaked departure patterns will require predictably greater classification track capacity (as well as receiving and departure yard capacity). There is a trade-off between operational schedule, and relative capacities of the receiving, classification, and departure yards.

The class track capacity itself is usually restricted. For this reason swinging is used to increase the usable capacity. For example, cars in a particular block sometimes tend to arrive at about the same time of day. Often most of the cars for a particular destination will arrive in the yard during a limited time period (for example, 8 hours). During this time there will be a high demand for a long classification track to accommodate the cars. At other times of the day the yard might be better utilized by placing the few cars that arrive at odd times on a slough track.

3. Percentage of Cars Reswitched

As discussed earlier, the need to reswitch cars can result from misswitches due to catchups in the switching area. Reswitching can also be caused by erroneous inventory information and operational errors. However, the primary cause of reswitching is that there are often not enough classification tracks to permanently assign a class track to each block or classification of cars. Thus many cars of various classifications are first switched to a general slough track and then later reclassified when more class tracks become available for use. Other significant causes of reswitching are the need to initially classify for such purposes as repairing, cleaning, or weighing cars.

According to our SRI survey, flat yard operations typically require more reswitching than hump yards.[2] The results of this survey indicate that hump yards generally reswitch 10 to 15 percent of all cars while flat yards reswitch between 20 and 30 percent of all cars.

4. Coupling Speeds

As mentioned Section II-G, it is widely believed that a coupling speed greater than 4 miles/hr may result in damage to certain types of lading. It is, therefore, logical to specify certain design and evaluation criteria related to coupling speeds on the class tracks. The most frequently used criterion is the specification of a certain desired maximum percentage of couplings over a given speed. The design criteria for Southern Pacific's West Colton yard specified that 90 percent of all couplings were to occur at less than 4 miles/hr and all of the remaining couplings at less than 6 miles/hr. If this goal was achieved it certainly is an improvement over the national averages of coupling speeds for 1969 and 1970 shown in Table 5.

5. Percentage of Stalls

Related to the specification of allowable coupling speeds is the factor of cars that stop rolling before coupling. When a car stalls on the class tracks, a switch engine must travel into the class track and push the cars together. This activity is called "trimming", and it generally requires interrupting the yard's switching activities. Thus trimming stalled cars can significantly affect the performance of a yard whose switching lead is already highly utilized. At West Colton the design criteria specified that car stalls short of coupling should not exceed 4 percent. However, in other yards, stalls have been observed at about 10 percent of the time.

Table 5

NATIONAL CAREFUL CAR HANDLING OBSERVATION DAY RESULTS

Coupling Speed in Miles per Hour	Retarder/Hump Yards Percent of Total		Flat Switching Yard Percent of Total	
	1969	1970	1969	1970
4 or less	51.6%	65.6%	71.2%	80.0%
4.1 to 4.9	23.1	12.7	20.7	11.0
5.0 to 5.9	13.1	12.6	5.7	5.6
6.0 to 6.9	5.0	3.6	1.3	2.0
7.0 to 7.9	4.7	3.7	0.7	0.9
8.0 to 8.9	1.1	1.1	0.2	0.3
9.0 to 9.9	0.9	0.5	0.2	0.1
Over 10	0.5	0.2	0.1	0.1
Sample Size	3,949	10,493	14,642	26,933

Source: Association of American Railroads, October 1969 and 1970

D. Departure Tracks

The departure tracks of a classification yard are used to make up outbound trains. The required number and capacity of these departure tracks therefore depends on the number and length of the scheduled outbound trains. This section describes criteria that can be used in the design and evaluation of a departure yard. Many of the criteria described below are analogous to the criteria described in the section on receiving tracks.

1. Transit Time

This term refers to the average amount of time spent by cars in the departure yard and is a component of the total yard transit time. It is generally between 3 and 5 hours.

2. Departure Track Availability

One measure of the utilization of the departure yard is the percentage of time that at least one departure track is empty, and thus available for marshalling an outbound train.

3. Departure Yard Occupancy

This criterion is related to the average number of cars in the departure yard. One measure of the utilization of the departure yard would be the ratio between the average number of cars in the receiving yard and the standing capacity of the yard. In one hump yard with which we are familiar the average occupancy of the departure yard was 70 percent. Occupancy levels higher than 75 to 80 percent are likely to cause significant delays to the train makeup activities, which in turn will be an operational bottleneck and cause congestion to propagate back through the yard.

4. Pull Rates

Pull rates measured in average time per pull, are affected by the distance that must be traveled, the number of cars pulled, the amount of doubling, the interference with other pull engines, and the productivity of the pull crew. The amount of doubling that can be accomplished is to some extent the result of good design, and the distances traveled by the pull engines is definitely affected by the design.

Pull engine interference increases pull time as engines are held idle while other engines complete their pulls. From our experience, interference at the pull end is one of the most critical bottlenecks in the operation of switch yards (particularly medium to large hump yards). Methods for alleviating interference almost exclusively entail proper physical layout of the pull engine leads.

5. Air Charge and Inspection Rate

Air charge rates and outbound inspection rates are measured in units of cars per minute. These two measures are closely related in that air hose hook-up and inspection are performed simultaneously by the same crew. The charging rate is also dependent upon whether the train is charged by using locomotive or yard air. Yard air installations provide faster and more consistent charging.

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