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REVIEW OF CLASSIFICATION YARD DESIGN PRACTICES

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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 It may be altered, expanded, or withdrawn as further research results are obtained.

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PREFACE

The work described in this report was performed by SRI International (formerly Stanford Research Institute), Menlo Park, California, for the Federal Railroad Administration (FRA) and the Transportation Systems Center (TSC) under contract DOT-TSC-1337. Dr. John Hopkins of TSC was the contract monitor. Mr. Albert E. Moon was the project supervisor and Mr. Stephen J. Petracek was the project leader. Carola Elliott, Jerome Johnson, H. Steven Procter, and Peter Wong participated in this study.

This report, written by Stephen J. Petracek, describes the results of the work performed during Task 1, "A Review of Existing Practices," of Phase I of this research project.

I INTRODUCTION

As part of a recent study of railroad switchyard technology, SRI determined that the design of classification yards has a significant impact on the effectiveness of yard operations. For example, it was 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 also 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 a 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 a set of practical guidelines, procedures, and principles that will facilitate the process of classification yard design and engineering. It is intended that the project results include engineering data and methodology in handbook form. The handbook will be used to make informed choices among capital investment alternatives 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.

The objective of Phase I of this research is to formulate a classification yard design methodology that personnel from railroads, railroad supply companies, or public agencies can use to develop and evaluate railroad classification yard designs. To be acceptable to prospective users, such a design methodology must have direct applicability to the problem areas encountered during the yard design process, be oriented to various user groups and be consistent with the resource limitations that are generally associated with the yard design process. Therefore, an essential prerequisite of SRI's development of a yard design methodology was a review of the existing practices used during the design of new or modified railroad classification yard facilities.

To review existing yard design practices within the railroad industry we used two complementary approaches: (1) a search of current, related literature and (2) a series of technical discussions with railroad industry personnel familiar with yard design problems. The literature search was performed using the facilities of the Rail Research Information Service (RRIS), the Stanford University library system, the Institute of Transportation Studies library at the University of California, Berkeley, and the library of the Transportation Center at SRI. Technical discussions were held with individuals representing a number of U.S. Class I railroads that had recently been involved in yard design projects. Representatives of major railroad equipment suppliers were also contacted.

The literature search and technical discussions were oriented toward understanding the basic classification yard design processes that occur within the railroad industry, including the individual design steps that occur up to the actual construction decision, the structure of the yard design teams, the general level of effort associated with the yard design process, and the typical design techniques used. In this report we summarize the information gained during the review process.

II REVIEW OF CLASSIFICATION YARD DESIGN PRACTICES

Generalized Design Process

Before describing the specifics of the classification yard design processes that we have become familiar with, it might be beneficial to discuss the major steps of a generalized engineering design process.

Certain engineering design problems are simple and well defined. For such problems, design techniques have often been developed that allow the designer to formulate his design requirements into a few equations or nomographs and determine an optimum design. For example, in the selection of structural steel beams, a designer who knows the maximum bending moment, allowable deflection and depth, and beam span can rapidly select the most economical wide flange section through the use of the appropriate tables or graphs contained in the American Institute of Steel Construction's Manual of Steel Construction.

However, most design problems are not as simple and well defined as the design of structural steel beams. In such cases, the design process generally involves the steps outlined below.

Step 1: Recognition of the problem--A problem or opportunity for improvement is perceived.

Step 2: Definition of the problem--The problem or opportunity is specified, thereby limiting the scope of directing subsequent activities. (In many cases the problem may be such that steps 1 and 2 occur simultaneously or nearly so and thus cannot be easily segmented.)

Step 3: Selection of the objectives and goals of the design process--At this point a decision has been made, generally about authorizing the development of a design intended to alleviate or eliminate the problem or a portion of the problem. Factors constraining the design process are usually defined at this stage.

Step 4: Development of alternative designs--The problem is broken down into understandable and tractable component parts and analyzed. Possible solutions to the problem(s) are devised.

Step 5: Evaluation of alternative designs--The effects of the various design alternatives are determined and compared with each other and with the original design objectives.

Step 6: Decision to implement a particular design--A decision is made that an acceptable design has been developed. If more than one acceptable design has been developed, a discussion is made about which alternative should be implemented.

Although the generalized design process has been described above as a series of sequential steps, in practice these steps will often overlap and there will be numerous iterations of the work performed in various steps. For example, many iterations typically occur between developing and evaluating alternative designs (steps 4 and 5) and at each iteration the design may be refined and reevaluated. Furthermore, if, during step 6, it is decided that no acceptable design alternatives have been developed, the whole design process may have to be reinitiated, thus forcing a redefinition of the problem, or at least a reassessment of the original definition of the problem.

Classification Yard Design Process

We used the framework of the general design process described above as a guide in developing the structure of a typical railroad classification yard design process.

The yard design process that we conceptually developed was then used as a foundation for discussions with railroad personnel who had been involved in the design or modification of classification yards. Based primarily on our discussions with railroad personnel and secondarily on our literature search, we made several modifications to the basic yard design process. We intend to use this modified yard design process as the basis for developing a comprehensive railroad classification yard design methodology. The steps involved in the basic design process are:

Step 1: Identify need for new or modified classification yard facilities.

Step 2: Determine appropriate yard location(s) on the system.

Step 3: Determine required yard capabilities.

Step 4: Develop general yard characteristics to meet system requirements.

Step 5: Select actual site for yard construction.

Step 6: Recognize and define design constraints and guidelines.

Step 7: Develop classification yard design alternatives.

Step 8: Evaluate economics of design alternatives.

Step 9: Select best yard design alternative.

Step 10: Perform detailed yard design.

These steps can be grouped into three subprocesses of the design process--rail system analysis, site selection, and engineering. The interrelationship of the individual steps are shown in Figure 1.

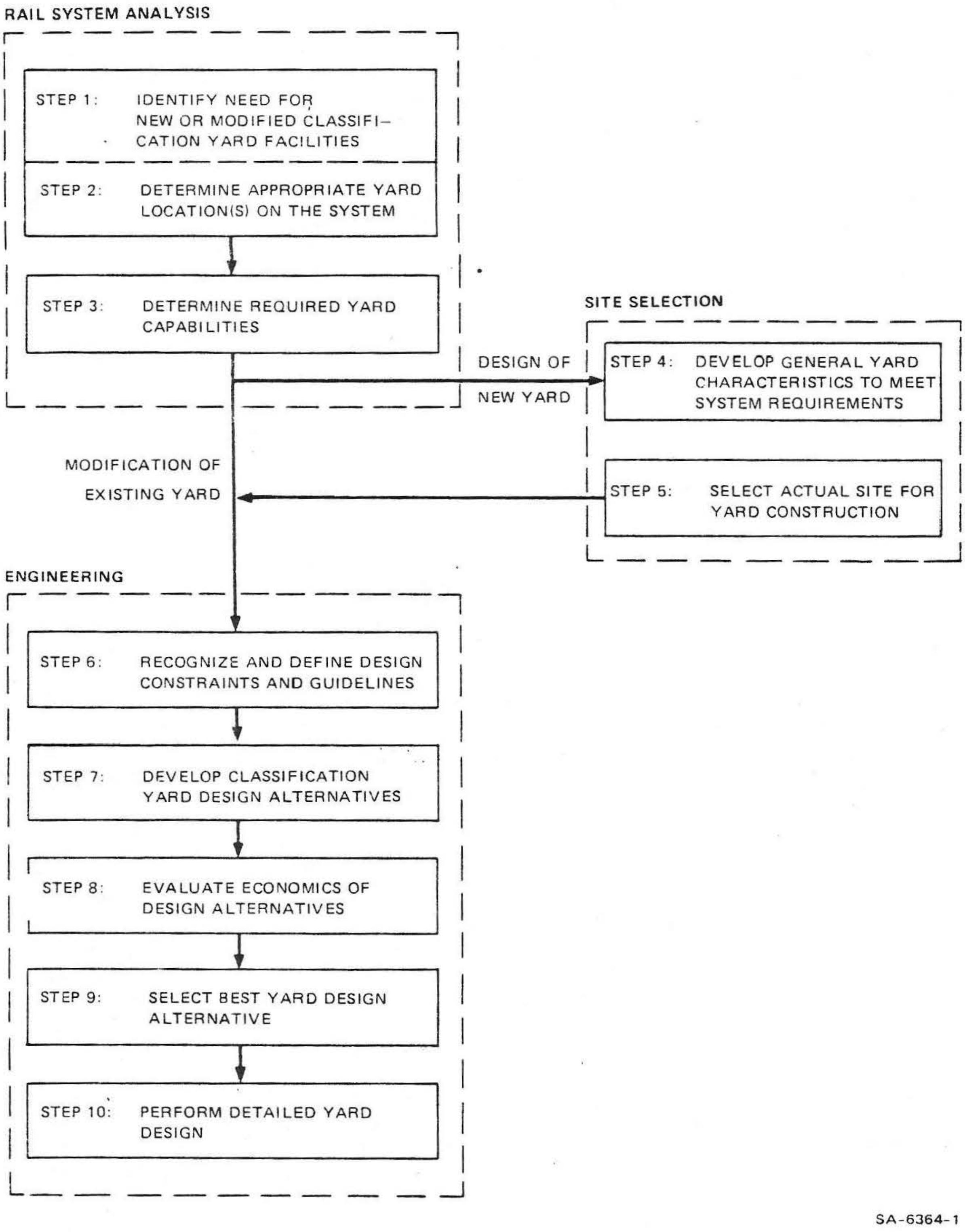

FIGURE 1 CLASSIFICATION YARD DESIGN PROCESS

Although terminology might be used to describe the steps and some designers might describe the process differently, we feel that the design process that we have defined is generally representative of the sequence of activities associated with the design or modification of a railroad classification yard. Once again, there will be iteration and feedback in successive parts of the design process. Although the description is facilitated by describing the steps in sequential order, certain steps may be repeated as a result of the findings of later steps. For example, it is quite usual to iterate between steps 7 and 8. Other situations might arise in the design of particular yards that cause special interrelationships to develop between certain steps. For example, in a complex design situation, the selection of a particular site might be tied to the design alternatives that are under investigation. Thus the site selection step (step 5) would have to consider the alternative designs developed in step 7.

We describe below the individual design steps and briefly discuss how individual railroads may deviate from the typical design process.

Step 1: Identify Need for New or Modified Classification Yard Facilities

The rail system analysis process starts in Step 1 by determining whether there is a need for new or modified classification yard facilities. This step is analogous to step 1 in the general design process, the recognition of a problem or opportunity.

The need to modify an existing yard or to build a new yard can be determined in one of two ways. First, the need may be recognized at a local yard. Local railroad officials, such as terminal superintendents, trainmasters, and yardmasters, at individual yards generally monitor the performance of their particular yard on a continuous basis. (At this level, yard performance is usually assessed in an intuitive manner or by some aggregate measures of effectiveness, such as total daily throughput and average car detention time.) If these rail officials perceive a general decrease in yard performance that cannot be corrected through operational changes at the yard itself, they generally make the problem known to officials concerned with operations at the division or system level.* The system officials will decide whether the decrease in yard performance is tolerable on a systemwide basis; if it is not, they will

*Yard officials may also suggest ways to alleviate the problem, such as doing more work at other yards or modifying the existing yard layout. If the suggestion for modifying the yard is fairly minor, such as the installation of a crossover, the decision may be made at a division level. However, major modifications to an existing yard, such as adding another group of class tracks or even a single additional track, will probably require a review by officials above the division level.

attempt to alleviate the problem by changing system operations. If this option is not feasible or effective, it is then conceded that new or modified yard facilities are required.

The need for yard modification or new construction can also be recognized at the system level. This recognition is generally based on a review of systemwide performance* and on the fact a perceived problem cannot be resolved by changing such operations as blocking strategies, train makeup, or schedules.

This step of the design process is generally performed in an intuitive manner. As one railroad official states, "The need for new or upgraded yard facilities just evolves," as solutions to individual problems through changes in the railroad operational practices become ineffective due to growth in traffic levels and changes in traffic patterns. At this point, a need for capital investment in the construction of new or upgraded yards is recognized as the only alternative.

Railroad officials state that an impending or potential need for a new yard may be perceived many years before the yard is actually constructed. (In fact a number of railroads actually bought the land that was ultimately used for a new yard as much as 15 to 20 years before the final building decision was made.) However, this recognition is primarily subjective, and, with few exceptions, no analytical techniques are used. Although one official we contacted stated that his railroad relies heavily on 5- to 15-year traffic forecasts in determining yard construction needs, most railroad officials we spoke with seemed highly skeptical about the accuracy of such long-range forecasts and preferred their own judgment. In either case, however, the decision to proceed with the design of new or modified yard facilities is invariably based on the recognition of existing problems rather than on problems that are projected to occur in five years.

Step 2: Determine Appropriate Yard Location(s) on the System

Step 2 is closely related to step 1. In general, the recognition that a new yard should be built or an old one modified is accompanied by the determination of where the new yard should be located or which existing yard(s) should be changed.

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*At the system level, overall yard performance is generally assessed by monitoring a set of selected measures of effectiveness (MOEs). However, these MOEs are often aggregated and artificially defined. For example, one railroad's systemwide measure of the cost per car switched may include cost elements that are not included by another railroad that also may use this MOE for monitoring overall yard performance on a systemwide basis. For this reason, railroads are capable of comparing their system's overall yard performance over time but are not generally capable of accurately comparing their overall yard performance with that of other railroads.

Individual judgment or the consensus of opinion of a knowledgeable group of persons determine general yard location, which is limited to one, or at most two, divisions. The selection of the appropriate yard location is further narrowed by such factors as crew districts, major interchanges, train operations, and overall traffic volume. Discussions with railroad personnel indicate that the weight given to these factors is quite subjective, depending on the individuals involved and the particular design project. Certain factors are always considered important, however, such as the desirability of locating near a junction of major routes or in an area where the railroad has a good relationship with the community. By the end of this design step, the location of a new yard should be specified to a fairly small area, not more than 50 to 100 route miles. In fact the potential location for a new yard will generally be limited to one or two cities. For a yard modification project the actual yard site will often be identified during this step.

The planning and analysis procedures used for step 2 are usually quite subjective. All railroads perform some type of traffic study to determine the traffic volume past potential locations. Such studies are generally based on current traffic patterns and volumes rather than on forecasts.* The output of these studies, which includes the number and size of individual blocks, the number of carloads, and the number and length of trains that typically pass a given location, is but one element considered when deciding yard location.

Some railroads have used computer programs that simulate railroad system operations to evaluate the effectiveness of locations for new or modified yards. However, it appears that railroads usually use simulation models to verify the location decisions that have already been made rather than as an aid in the actual decision process.

Certain operations research and economic models have been developed in an attempt to determine the optimal locations for classification yards on a railroad system. However, none of the railroads contacted during this task relied on such models.

Step 3: Determine Required Yard Capabilities

This step involves determining the functional and operational capabilities required of a yard to support the rail system's demand for services. These capabilities should include the main yard activities associated with classifying cars and making up trains and the required yard capabilities for ancilliary yard services, such as car and locomotive servicing and repairing, car weighing and cleaning, and so on. These required capabilities are expressed in terms of a set of parameters such as the following:

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*The reluctance to use traffic forecasts is due in large part to a general lack of confidence by railroad personnel in the validity of forecasts beyond five years.

- Number of cars to be classified.
- Yard detention time limits.
- Number and sizes of blocks to be made up.
- Number and sizes of blocks to be set out or picked up by road-haul trains.
- Number, schedule, and length of incoming trains to be classified.
- Number, schedule, and length of departing trains.
- Number of cars to be repaired, weighted, oiled, or cleaned.
- Number of locomotives to be repaired or serviced.
- Number of trailers and containers to be loaded or unloaded.
- Volume of commodities and cars requiring special handling.

The values of these parameters depend, for the most part, on the systemwide operating plan used by the railroad, and they are determined by traffic analysis, which is usually based on current, or sometimes even past, traffic data.

The traffic analysis procedures presently used aggregate or consolidate much of the information into total figures or simple averages, despite the acknowledgment of numerous railroad personnel that it is inappropriate to use daily totals or averages in describing the system demand for a yard's services. Most railroad personnel interviewed agreed that daily fluctuations in traffic levels and traffic patterns should be considered in the yard design process.

Step 4: Develop General Yard Characteristics to Meet System Requirements

This step involves developing a set of first-cut general yard characteristics and resource requirements based on the output of step 3, that is, the required operational and functional capabilities of the yard. Some of the general yard characteristics and resource requirements that need to be defined are yard type (hump or flat), land needs (e.g., the size, shape, and terrain of the required land parcel), manpower requirements, and utilities requirements. The major purpose of this step is to provide general information to be used in selecting a site for new yard construction.

In the course of our research, we discovered that few analytical techniques are used in the performance of this step. Instead, general yard characteristics are subjectively defined on the basis of past experience in yard operations.

Step 5: Select Actual Site for Yard Construction

This step is applicable only to the construction of a new yard, since the selection of a yard to be modified is generally performed in step 2. Prior to step 5 in the design process, the location of a new yard is selected almost solely on the basis of the rail system operational requirements. This criterion often allows a large amount of flexibility in the selection of the actual yard construction site. For example, even though Southern Pacific's West Colton yard and Santa Fe's Barstow yard perform essentially analogous roles in their respective systems and are in fact located within 100 miles of each other, the characteristics of their immediate locations are quite different. Other factors usually considered in the selection of a specific yard construction site include;

- Railroad main line accessibility.
- Land use compatibility.
- Land availability and cost.
- Availability of supplies, utilities, and highway access.
- Manpower availability.
- Community values and attitudes toward the railroad.
- Suitability of physical site conditions (including soil characteristics, terrain, climatic conditions, etc.).
- Local tax level and structure.

These factors range from quite quantifiable, such as soil characteristics, to quite qualitative, such as community values.

We have included step 5 in our formulation of a typical yard design process because it has been an important element in a number of recent yard design efforts where, in fact, the site was selected and the necessary land was purchased within five years of the actual start of construction. In these efforts, at least a rough idea of yard size and shape was required before the acquisition of the land was finalized. For example, Southern Pacific acquired land at West Colton based on the concept of an in-line or tandem hump yard, as well as on other design factors such as those described in step 4. Other railroads have also used a design process that closely parallels our typical yard design process. In most cases, however, it appears that railroads tend to buy land much in advance (10-25 years) of the actual yard design or construction and then limit the site selection decision to those land parcels that are already owned. Generally, these land parcels are purchased in advance to insure land availability if the need arises and as a speculation against large increases in land costs. A major drawback of this approach, however, is the fact that traffic levels and patterns can change dramatically over time and thereby make the preselected land parcels only marginally acceptable for their intended uses. The designs of a number of recently built yards were influenced considerably by the size and shape of the available land parcel.

<u>Step 6: Recognize and Define Design Constraints and Guidelines</u>

This step involves the identification and definition of those factors that may act as constraints during the subsequent steps in the yard design process. These will include rail system constraints, such as main-line capacity, project budget and schedule, system operations, and the like, and location constraints, such as incompatible land uses; the size, shape, and profile of the land parcel; climatic conditions; location of the main-line and support yards; location and availability of utilities, zoning regulations, and other local laws.

In addition, this step will refine the guidelines of the design process and will finalize the functional and operational objectives that were determined in step 3. These will typically include design goals for such performance factors as average car detention time, frequency of overspeed impacts or stop-shorts, and average and maximum daily throughput.

Step 7: Develop Classification Yard Design Alternatives

Step 7 involves developing one or more basic yard designs. We use the term "basic yard design" to refer primarily to a general plan of the layout of the yard that would include profile and plan views showing all grades, track placement and separation, switch size and placement, retarder placement and sizing, and so on. Such a design would typically be related to a certain operational usage and to staffing levels and may include the general design of parts of the yard communication system (e.g., the number and location of closed circuit television cameras, or the location of a pneumatic message tube system). The basic design would not include a detailed design of bridges, buildings, or other structures; the process control system; the information processing system; and so on; nor would it specify the actual brands of hardware or equipment.

Step 7 is itself an interactive process that synthesizes the information gained from all of the previous steps into a limited number of feasible design alternatives and analyzes the effectiveness of these designs. The interaction between the synthesis and analysis is strong.

The methods used to carry out step 7 vary from railroad to railroad. Some railroads develop three or four radically different basic design alternatives during this step. For example, the design term of one railroad started out with 10 to 15 trial designs that were subsequently merged into 3 different basic designs. Other railroads develop only one basic design to be reviewed by upper management.

The synthesis segment of this step (i.e., the development of design alternatives) seems to be performed by railroad personnel who rely predominantly on intuitive judgment and previous experience rather than on analytical or engineering design methodologies. There are many commonly accepted rules of thumb that are used by designers as guidelines, and engineering techniques have been developed for certain aspects of yard design [e.g., the American Railway Engineering Association (AREA) Manual for Railway Engineering has a fairly detailed section describing grade design practices].

The evaluation of design alternatives is often performed in a qualitative manner. However, a number of railroads have used simulation techniques (either manual or computer based) to evaluate the effectiveness of the various design alternatives.

Step 8: Evaluate Economics of Design Alternatives

At this stage of the design process each surviving design alternative has been technically defined through the delineation of various design elements, such as grade, track placement, and so on. In addition, the effectiveness of the design alternatives, in terms of a selected set of operational performance MOEs, has been estimated either subjectively or by simulation techniques. Closely related to this effort is the economic analysis of the design alternatives. It is somewhat misleading to describe this activity as a single step because it in fact occurs throughout the entire yard design process. During the early stages of the design process, however, the lack of design information forces the economic analysis to be performed with varying levels of precision. At the conclusion of the basic design step, however, a quite detailed economic evaluation of the design alternatives can be made. Moreover, before the actual selection and implementation of any one of the design alternatives commits a railroad to potentially large financial expenditures, it is important that a detailed economic or investment analysis be performed.

Economic analysis involves the use of a conceptual framework to investigate systematically problems requiring decisions related to economic or investment activities. A number of methods for performing an economic analysis have been developed, such as the rate-of-return, annual cost, payout, present-worth-cost, receipts-versus-disbursements, and capitalized cost methods. Our discussions with railroad officials and our review of railroad economic studies indicate, however, that railroads use the rate-of-return method almost exclusively in their investment analyses.

Generally, the rate-of-return method involves the calculation of the ratio between annual net profit and required capital investment, where annual net profit is annual revenue minus annual expense. However, the construction and operation of a railroad classification yard cannot easily be related to increased railroad revenues. Instead, the rate of return on non-revenue-producing investments, such as classification yards, should be calculated on the basis of annual cost savings as a result of the investment as compared with the costs associated with not making the investment (i.e., the do-nothing design alternative).* Our review of the economic studies on various yard projects shows that two major cost-avoidance factors are the reduction of switch engine assignments in other yards and the overall system reduction of car detention time in yards.

Step 9: Select Best Yard Design Alternative

In this step a decision is made on which design alternative, if any, should be implemented. This selection is based on the results of the economic analysis, which ranks the design alternatives in terms of return on investment. However, the alternative with the highest rate of return on investment will not always be selected. Many other factors influence the decision, such as company financial policy and resources, company competitive position, operational flexibility, labor agreements, legal and regulatory policies, and community values and relations.

The influence of some of these factors on design selection is the result of a formalized decision process that can be easily discerned and understood. The factor of company financial policy and resources is a good example. This decision process generally involves a comparison of the

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

return on investment and investment requirements of the design alternatives with the company's basic criteria of acceptability in these areas. These criteria would be based on such factors as the return on investment of alternative investments and the available means of financing various types of investments.

The influence of other factors is more qualitative and thus cannot be formally characterized. These intangible factors may often have the most significant impact on the design selection process, however.

Typically, a decision on which yard design alternative to implement is made at a high management level, such as by the company president or the vice-president of operations. When the decision maker(s) is presented with a number of design alternatives, he may select one for implementation or perhaps suggest modifications that might make a design more acceptable. When the decision maker(s) reviews a single design, he may also suggest modifications or even a reorientation of the design effort. In one case, the decision maker was presented with a design for a new yard that was projected to cost nearly $40 million. A reorientation of the design objectives led to a design costing $30 million, and after further management review and comments, to a design costing $20 million.

Step 10: Perform Detailed Yard Design

After a decision has been made to implement a certain yard design, the detailed design efforts are performed. These include the development of specifications for the subcontractors and equipment suppliers as well as the detailed design work on structures, communications systems, information processing systems, and so on.

Structure of Design Team

Our discussions with officials of different railroads indicate that the structure and organization of a design team varies significantly among railroads and even among design projects of the same railroad, depending whether or not the project involves a major design effort.

At least two large railroads have formed permanent terminal planning departments whose personnel are dedicated solely to terminal planning and design. These departments generally constitute the nucleus of a formal design team for major yard design projects. The design team is supplemented by other individuals with experience and expertise in particular technical areas and by persons representing other organizations within the railroad that may be affected by the yard design. The head of the terminal planning department usually has direct responsibility for the work of the design team. However, someone from another department, such as engineering, or another upper-level manager may lead the basic design effort.

The majority of railroads contacted have not established a special department for terminal planning. At these railroads, a minor yard design effort would typically be handled by a small group of individuals from the engineering and operating departments. For a major design effort, however, a special design team will be organized. The head of the design team is usually a person in middle- to upper-level management who has direct access to the president and vice-presidents and a great deal of autonomy in his conduct of the design effort.

The head of the design team usually has a background in rail operations management, industrial engineering, or civil engineering. The composition of the rest of the design team may vary among railroads. However, the basic design team usually includes those individuals in Table 1.

Table 1

COMPOSITION OF A TYPICAL DESIGN TEAM
(Major Yard Design Project)

Traffic analyst - Marketing Department

Financial analyst - Finance Department

Civil design engineer - Engineering Department

Track maintenance engineer - Engineering Department

Operations analyst - Operating Department

Industrial engineer - Operating Department

Signal engineer - Communications and Signal Department

Management information systems representative - Information Services

Locomotive and equipment maintenance representative - Mechanical Department

Design Schedule

The amount of time and effort required for a given yard design project of course depends on project size and scope. A major new hump yard design project requires between 9 and 16 months to develop the basic design, depending on the level of detailed design performed. The development of a detailed design requires an additional 6 to 12 months, although construction can start before the detailed design is complete. The overall design process therefore takes between one and one-half to two years.

Relationship Between Railroad and Outside Firms

The design of railroad classification yards requires specialized knowledge and experience that all railroads do not have to the same degree, if at all. Therefore, small railroads that do not have recent, direct experience in the design and construction of classification yards may contract this work out to larger, more experienced railroads, or a railroad may contract for assistance in specific areas.

In the design of a new hump yard, outside assistance is sought primarily for the design of the process control system, which can have a significant effect on the operation of a yard and influences the design of yard gradients, hump height, retarder placement, the management information system, the communication system, and the signal system. Only one of the railroads whose design activities we are familiar with designed its own process control system. Generally the design work for the process control system is contracted out to the company that supplies the process control equipment (i.e., the retarders and switches).

The relationship between a railroad and the company that designs the process control system can vary widely, depending on the railroad. For the railroad that designed its own process control system, the process control equipment supplier did little more than sell the process control hardware. However, in other cases, various process control equipment suppliers can become informally involved in the early stages of the design process and can significantly influence the development of the basic yard design. In fact, process control equipment suppliers often have helped perform traffic studies for railroads and have played the role of the devil's advocate in questioning a railroad's estimates of required yard capabilities or of particular design features.

On a more formal basis, process control equipment suppliers will often develop an estimate of the cost associated with the design and installation of a process control system for a particular yard based on gross or aggregate yard capabilities and characteristics, such as the number of cars humped per day, number of tracks, number of blocks, and so on. This cost estimate is used by the railroad in preparing a project budget for a basic design.

The formal relationship between a railroad and the process control equipment suppliers also involves the development of bidding specifications. Prior to the letting of a bid, a railroad generally invites prospective bidders to discuss the development of the specifications. [These prospective bidders are generally the suppliers of process control equipment, such as ABEX, General Railway Signal Company (GRS), and Westinghouse Air Brake Company (WABCO). Other non-railroad-oriented companies, such as IBM, have also been invited to bid on the development of the process control system in various yards.] The winning bidder develops a detailed design of the yard's process control system. This includes the development of control algorithms and computer software, the selection of the required process control equipment, and the recommendation of the yard's process control computer (a recommendation that has frequently been overruled by the railroad). In the past, the design and implementation of the process control system has generally been a turn-key operation. However, there appears to be a recent trend toward more active railroad involvement in this phase of the design effort.

We have described the selection of the process control system designer as an open competitive process, and this kind of selection does in fact occur with great frequency. However, many railroads seem to rely on either

GRS or WABCO, the two suppliers that dominate the market. This reliance on a particular supplier is not based solely on cost competitiveness but rather on a railroad's past experience with the supplier. Thus, certain railroads sometimes have been referred to as a "GRS railroad" or a "WABCO railroad." This tendency to rely almost exclusively on a single supplier has diminished somewhat in recent years.

Techniques Used in the Classification Yard Design Process

Because a design methodology must include a set of techniques and procedures to be used at appropriate stages throughout the yard design process, we have reviewed the design techniques that are currently being used in the design of railroad classification yards. These techniques are discussed below.

Subjective Techniques

Early in our review of existing railroad practices it became apparent that the design of railroad classification yards has been primarily a subjective process, that is, based on the intuition and past experience of the designers. The fact that so much of the yard design process is based on subjective judgment strongly suggests that either the design process is so complex that a synthesis of all the relevant factors defies analytical representation or that the analytical representation will not develop substantially "better" yard designs. Both viewpoints were voiced during our discussions with railroad personnel. Another viewpoint that was strongly advocated, however, was that good analytical yard design techniques have not been developed.

Regardless of the reasons for relying on subjective design techniques, they do have a major failing. Since judgment and intuition are based on experience, new yard designs are heavily based on the successes and mistakes perceived in previous yard designs and thereby inhibit major innovations. It is not surprising, therefore, that the geometric design of new yards usually does not vary significantly from the design of other recently constructed yards. This concept was often unconsciously supported by such statements of railroad officials as "Our railroad almost always uses a side-by departure yard"; "Oh, that person always designs his switch leads and switch connections like that"; and so on.

Engineering Design Guidelines and Procedures

In many areas of engineering design, specific design guidelines and procedures have been developed that are widely accepted and used. In the area of classification yard design, the only such guidelines and procedures that we are familiar with are those developed by the AREA. The AREA Manual for Railway Engineering contains many guidelines for use in the design of classification yards, but these are, for the most part, highly qualitative. The manual does describe a detailed procedure for use in designing track gradients and track curvature and in determining retarder placement in hump yards. Although the AREA design guidelines and procedures are recommended and generally well-accepted design practices, they are not required industry standards.

Detailed Design Standards

There are many design standards that must be followed. For the most part, however, these standards affect only the detailed design of the yard and have only a minor influence on the design of the basic yard layout.

Simulation Techniques

A number of railroads, railroad suppliers, universities, and research organizations have attempted to simulate yard and rail system operations. Simulation is a particularly attractive general approach to the synthesis and analysis of systems or operations that are so complex that an accurate mathematical representation would be impractical.

Railroads have primarily used simulation techniques to evaluate performance that cannot easily be measured or otherwise predicted. Simulation is therefore useful in evaluating the effects of changes to system operations or yard designs before actual implementation. The structuring of a simulation model also provides an organizational framework that is often beneficial in the synthesis of the various factors influencing yard design. However, simulation models are often limited by their design or structure.

A number of railroads have developed and used rail network simulation models. Generally these models are used to simulate the movement of cars and trains throughout a defined railroad system in order to help recognize the need for changes in systemwide operations, modification of existing yards, or construction of new yards. Changes in any of these factors can then be evaluated through additional simulation. Generally the simulation of even a small rail network involves so many calculations and so much data manipulation that a computer program must be developed.

Some railroads have also simulated the operations of individual classification yards to evaluate changes in yard operations as well as design changes for an existing or proposed yard. Although a number of computer simulation models have been developed and used, two of the railroads whose personnel we spoke with showed a strong preference for using manual simulation techniques when evaluating yard designs. Manual simulation techniques offer more flexibility for human input and control during the simulation, they can be used to develop greater insight into the effectiveness of a particular yard design, and they are considered to be of significant assistance in synthesizing yard design alternative. However, manual simulation techniques require large amounts of time and effort. On one railroad yard design project, more than 20 persons working for a full work week were required to simulate one day of detailed yard operations for a major hump yard. By the third week the simulation team had improved to the point where they could simulate three to five days of operations in a week. This is an extreme case, however; less detailed manual simulations have been accomplished with much less effort.

III CONCLUSIONS

This report documents our review of current classification yard design practices within the railroad industry. We conclude that the classification yard design process is closely related to the basic design process used in solving most engineering and systems problems, and that there are few major differences among the various railroads in the structure of these yard design processes.

A major finding of our review is that few analytic design techniques or methodologies are used during the design process. Most railroad yard designs are intuitively formulated, based on the experience of the individual members of the design team and on some rudimentary design guidelines, which, for the most part, are based on subjective judgment. A lack of quantitative techniques for use in the synthesis and evaluation of alternative yard designs and a consequent reliance on the designers' subjective judgment have tended to inhibit the development of innovative yard designs. In addition, the industrywide tendency of railroad personnel to remain with an individual railroad has contributed to the isolation of yard design practices and knowledge to such an extent that railroads are often characterized by particular yard design concepts and characteristics.

Another finding of our review is that a major new design or modification of a railroad classification yard does not occur frequently enough on a single railroad to assign railroad personnel exclusively to this task. Instead, on most railroads, the yard design process is undertaken by a team of individuals representing different departments and having different skills and expertise. However, only a few members of this team may have significant experience in yard design, and thus a significant amount of time may be required for the experienced team members to pass on their understanding of yard design concepts and practices to the less experienced team members.

Our review of current classification yard design practices underscores the need for an accurate understanding of the influence of yard design on yard and rail system operations. This understanding can then be used as the basis developing quantitative yard design techniques.