REPORT NO. FRAIORO 78167 PB80190481 1111111111111111111111111111111 CLASSIFICATION ~ =--.~~ ~ -:.~ .. -:-:-:-.-..... ~ . - .;... •. ;;;.J.. . - . _.--~--YAR-D ;;;;;;;'--:--TE-CH"N"'O-LJ-OG-~ DESIGN METHODOLOGY STUDY P.J. WONG. C.V. ELLIOT. R.L. KIANG. M. SAKASITA. AND W.A. STOCK SRI International Menlo Park, California 94025 SEPTEMBER 1978 PHASE 1 INTERIM REPORT DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161 Prepared for FEDERAL RAILROAD ADMINISTRATION Washington. D.C. 20590 REPRODUCED BY NATIONAL TECHNICAL INFORMATION SERVICE u.s. DEPARTMENT OF COMMERCE SPRINGFiElD, VA 22161

EXECUTIVE SUMMARY Even after bypass and intermodal train operations are fully exploited by railroads, it is clear that the railroad yard will continue to be an important factor in railroad operations because of the wide dispersal of traffic origination and destination points and the low car count of aver age customer release. Furthermore, many recent studies on railroad oper ations indicate that the yard has the largest adverse impact on service reliability, car utilization, an,d damage reliability. Also, it has been estimated that a large percentage of the time a car spends in a yard can be attributed to deficiencies in yard layout, design, and operations. Thus we see that improved yard design and operations can contribute sub stantially to the railroads' ability to recover lost revenues and profits. That the yard design process is a topic of both current and future significance is indicated by the following developments: • In the last decade, over 30 projects involving major yard con struction and/or rehabilitation have been undertaken. • Several new yard projects are planned for the near future (e.g., the westbound yard of Union Pacific's Bailey Yard, Southern Railway's Linwood Yard, and additional class tracks at Southern Pacific's West Colton Yard). • It is estimated that 200 yards will receive new construction and/ or reworking in the next 25 years. • A massive project to rework and consolidate yards in the East St. Louis area is in the planning stages. • The United States Railway Association has recommended that over 20 yards on the CONRAIL system be rehabilitated. The objective of this project is to develop a yard design methodol ogy that will improve significantly the effectiveness of classification yard (hump yard or flat yard) design and engineering and thus, ultimately, the ability of yards to process cars. An output of the project will be a manual of practical guidelines, procedures, and principles of yard design, accompanied by a sufficiency of data, tables, and computer pro grams. The yard design manual will be usable by railroads, railroad suppliers, and public agencies having to make informed choices among a myriad of possible design alternatives. The project will be carried out in three phases; each phase is of approximately one year's duration. Phase 1, documented in this report, is concerned with the development of a preliminary methodology for the basic yard design process. In Phase 2, the preliminary methodology Preceding page blank iii --- --------------------

developed in Phase 1 will be applied to actual CONRAIL yard design prob lems. The intent of Phase 2 is to test, refine, and modify the method ology based on real-world yard design problems. Phase 3 will document the finalized version of the design methodology in the form of a yard design manual. Topics addressed during Phase 1 of the project include: ~ • Site selection--A standardized economic alternatives analysis procedure for yard site selection is critically needed in a form that can be readily used by the railroad industry. A brief description of a preliminary version of such a procedure, based on a rate-of-return calculation, is discussed in Section III.B. The yard design manual will discuss other site-selection vari ables, such as social, political, and environmental considera tions. • Hump grade profile design--As part of the Phase 1 effort, a computer-aided design procedure has been developed that should allow the designer to calculate in a few hours what formerly took weeks of tedious manual calculations. This procedure, described in Section III-C, will be documented in the

yard design manual as will a graphical method for hump grade profile design that has been used by the railroad industry. • Subyard capacity determination--The number and length of rece~vLng, classification, and departure tracks were formerly determined by a process akin to a manual yard simulation. This procedure will be documented in the manual (see Section 111.0). During Phase 1, it was determined that the process of determining yard capacity could be improved by developing a computer-aided design procedure. This procedure is also described in Section III.D. • Trim-end conflict resolution--One of the critical bottlenecks in yard operations,is caused by the conflict between trim engines in the pullout end of the yard. During Phase 1, both a manual and a computer-aided procedure were developed to evaluate design alternatives that minimize conflict in the pullout end of a yard. These procedures are described in Section III.E. • Yard geometry and layout--Depending on the size and shape con straints of a site, a critical yard design decision involves the geometric layout of the yard and subyards. Examples of geometric considerations include in-line versus parallel receiving yards and/or departure yards. Geometric issues are discussed briefly in Section III.F. • Yard hardware systems--To handle heavy rolling stocks, a classi fication yard must be hardware intensive. During Phase 1, major yard hardware systems were identified; these systems are described in Section III.G. The yard hardware portion of the design manual will discuss hardware components from a generic (non-vendor-specific) viewpoint. The manual will not provide a complete self-contained iv

catalogue of yard hardware facts but will enable potential users to become sufficiently knowledgeable about yard hardware so that they can intelligently use the catalogue and specification data provided by the vendors. • Yard computer systems--There are as many philosophies and config urations of yard computer systems as there are railroads and vendors. The yard design manual will provide fundamental facts and information on yard computer systems and guidance in making decisions and compromises regarding yard computer systems from both a performance and cost standpoint. Yard computer systems are discussed in Section III.H. v

CONTENTS

I INTRODUCTION A. Background It is generally accepted that the best railroad operating policy is to schedule trains so that they bypass as many intermediate switching terminals as possible. However, the wide dispersal of traffic origina tion and destination points and the low car count of the average customer release indicate that most railroad traffic must still undergo consider able switching and consolidation before trains can be formed that bypass terminals. Since the bulk of this switching and consolidation takes place in terminals, the railroad terminal will remain an important factor in railroad operations as long as freight is shipped in carload units by widely distributed shi~pers to widely distributed receivers. Recent studies (MIT 1972) on car utilization and freight service reliability have concluded that the rail terminal has the largest nega tive impact on service reliability, car utilization, and damage liability. Furthermore, it has been estimated that 25% to 40% of the time freight cars spend in classification yards is closely associated with deficien cies related to yard layout and design. This is roughly equivalent to a loss of 55 million to 85 million car-days per year, an underutilization of approximately 210,000 freight cars. Consequently, we see that yard designs can have a substantial impact on the ability of terminals to pro cess cars when better designs are implemented. The procedures for designing classification yards have evolved through trial and error over many decades. Thus, within a conventional framework of basic design principles, many crucial decisions may sometimes be based in part on personal intuition or persuasiveness simply because the required analytical tools are not available, and the price of developing or acquir ing them is not warranted for a particular project. The relative infre quency with which anyone railroad builds a yard makes it difficult to maintain a core group of individuals who specialize in and can improve upon the design process. This will become a more acute problem when many of the most experienced yard designers reach retirement. On the other hand, there is scattered throughout the railroad industry yard design information and knowledge that could be of benefit to the entire industry if it were aggregated and documented. That yard design is a subject of both current and future interest to railroads is exemplified by the fact that in the last decade over 30 yard projects involving major rehabilitation have been undertaken, at a cost of tens of millions of dollars per yard (see Shaffer & Roberts, 1973; Welty, 1978; WABCO, 1976; GRS, 1976). Therefore, designs must be even more efficient for the best return on investment. Table 1 indicates yard proj ects completed or under way in the last decade. 1

Approxima te Year In Service 1979 1978 1978 1977 1976 1976 1976 1976 1974 1974 1974 1974 1973 1973 1973 1972 1971 1971 1971 1971 1970 1970 1970 1970 1970 1969 1969 1969 1969 1969 1968 1968 1968 Table i YARD PROJECTS: 1968-1979 Railroad Southern Chessie Licking River Terminal Co. UP ATSF L&N SCL Southern DTS SLSF BN TRRA SOU SOU SP UP UP MP/TP N&W CN PC NP CP SCL SP PC PC AT&SF CB&Q Bethlehem Steel IC D&TSL New York Central Yard Name and Location Brosnan Yard, Macon, Georgia Queensgate Yard, Cincinnati, Ohio Licking River Yard, Wilder, Kentucky Hinkle Yard, Hinkle, Oregon Barstow Yard, Barstow, California Strench Yard, Louisville, Kentucky Rice Yard, Waycross, Georgia Linwood Yard, Salisbury, North Carolina Lang Yard, Toledo, Ohio Tennessee Yard, MemphiS, Tennessee Northtown Yard, St. Paul, Minnesota Madison Yard, Madison, Illinois Inman Piggyback Yard, Atlanta, Georgia Sheffield Yard, Sheffield, Alabama West Colton Yard, Colton, California NB Potomac Yard, Alex, Virginia East Los Angeles Yard, Los Angeles, California Centennial Yard, Ft. Worth, Texas Roanoke Yard, Roanoke, Virginia Calder Yard, Edmonton, Alberta Buckeye Yard, Columbus, Ohio Pasco Yard, Pasco, 'Washington Alyth Yard, Calgary, Alberta Rock Port Yard, Tampa, Florida Englewood Yard, Houston, Texas Morrisville Yard, Morrisville, New Jersey Sharonville Yard, Sharonville, Ohio EB Argentine Yard, Argentine, Kansas No. Kansas City Yard, Kansas City, Missouri Burns Harbor Yard, Burns Harbor, Indiana Belle Helene Yard, Geismer, Louisiana Lang Yard, Toledo, Ohio Perlman Yard, Selkirk, New York 2

A recent study (Petracek et al., 1976) indicates that over the next 25 years 200 classification yards will receive major reworking. This would include the planned massive project to rework and consolidate ter minals in the East St. Louis area (Lewis et al., 1977) and the original recommendations by the United States Railway Association (USRA) that over 20 yards be rehabilitated on the CONRAIL system (USRA 1975). It is clear that procedures to design new yards and rehabilitate old yards can in fluence the ability of the railroads to recapture lost revenues and prof its well into the twenty-first century. B. Design Methodology Objectives The fundamental objective of this project is to establish a set of practical guidelines, procedures, and principles, accompanied by a suf ficiency of data, tables, computer programs, and other resources, to im prove significantly classification yard design and engineering and to enhance the efficiency of the design process. The design methodology will be applicable to the design of new yards and the rehabilitation of existing yards and to the full range of yard types and sizes, including both flat yards and hump yards, whether manual or highly automated. It is expected that the final result of the project will be a manual of yard design, usable by any railroad, railroad supplier, or government planner who needs to make informed choices among a myriad of possible design alternatives. Although a detailed design study will ultimately be required in any particular case, the product of this research will provide a framework that will greatly facilitate the yard design process. In particular., the design methodology will substantially increase the degree to which alternatives will be considered at the early design stages which will include a wider range of configurational, technical, and economic choices. At the same time, it will make possible greater preci sion than is customary in estimating potential costs and benefits. The yard design methodology will contribute to a reduction of design effort, reduced and/or more efficient expenditure of construction resources, and- most important--yard improvements that significantly enhance productivity and system levels of service. The success of the yard design manual, in terms of both substantive validity and user acceptance, requires close coordination with the indus try. This includes drawing upon the experience and insights of numerous individuals and effectively disseminating research results. Thus, to en sure that the end result is comprehensive, practical, and in a form usable by the railroad industry at large, a substantial amount of industry par ticipation and interaction has been incorporated into the project effort. It is anticipated that CONRAIL will use the design methodology on its current yard projects and the American Railway Engineering Association (AREA) Subcommittee 14 on Yards and Terminals will participate in periodic briefings and critiques. The following members of the railroad industry will participate directly in the project: 3

• J. A. Wetzel, Assistant Director, Yard Projects, CONRAIL. • B. G. Gallacher, Assistant Chief Engineer, Southern Pacific Transportation Co. • A. T. Lewis, Assistant Director, Transportation and Rehabilitation Planning, CONRAIL. • A. V. Dasberg (retired), formerly Manager of Yard and Terminal Development, General Railway Signal. • W. V. Williamson, Manager, Operating and Terminal Systems, Southern Pacific Transportation Co. • J. N. Page (retired), formerly Director of Terminal Operations, Penn-Central Transportation Co. C. Project Plan The project has been divided into three phases; each phase is of approximately one year's duration. During Phase 1, the factors and ele ments to be included in the design methodology and their level of preci sion were identified, and a preliminary methodology for the basic yard design process was developed. In Phase 2, the preliminary methodology developed in Phase 1 will be applied to actual yard design problems. This will be done in cooperation with CONRAIL, which has agreed to use the methodology on at least one actual yard design project. The intent of Phase 2 is to test, refine, and modify the design methodology based on real-world yard design problems. Emphasis will be given to ensuring that the procedures are accurate and effective and can be practically applied by knowledgeable railroad per sonnel. In Phase 3 a final design methodology will be developed as a result of the preliminary form prepared in Phase 1, the modifications made in Phase 2, and industry comment and feedback obtained throughout the project. The end product will be a yard design manual documenting information, data, and procedures applicable to the design of either hump yards or flat yards. Many of the engineering design methods will be detailed in two forms: a manual design procedure* and a computer-aided design procedure. Computer programs will be fully documented, and a user's guide will be prepared for each. Thus, depending on the preference of the user, his particular appli cation, and his familiarity with using computer programs, he may choose to implement a design procedure in either a manual or computer-aided form. It is expected, however, that the computer-aided design procedures will be faster and more accurate than the manual design procedures in most instances. * We use the term manual design procedure to refer to methods based on hand calculations. 4

II THE YARD DESIGN MANUAL A. Perspective The yard design manual will provide facts, guidelines, and proce dures to assist in the yard design process. In some areas, where the procedures are mature (i.e., where the procedures are well known and no improvement can be made), the manual will synthesize and catalogue cur rent practice. In other areas, where advancements to the state of the art are contemplated, the manual will document newly developed practices. To the maximum extent practical, results that are easily codified will be presented in sample worksheets, tables, graphs, and equations; detailed procedures will be given for their use. In those areas where decision rules cannot be precise, design guidelines will be presented in terms of important considerations, facts and information, rules of thumb, and step-by-step design processes (in manual or computer-aided form). Examples of the application of the design methodology will be provided. The needs for computer-aided yard design tools are recognized. A description of the computer programs and their use in the design process will be documented in the manual. A user's manual and detailed program documentation for the computer programs will probably be provided in appendices to the yard design manual. The appendices may be bound separately. The yard design manual will evolve in time. The initial version of the manual will be as complete as possible. However, there will likely remain areas in which more work is appropriate. Subsequent revisions (say, every 8 to 10 years) will be made where appropriate to modify and expand the manual and to incorporate results of industry experience in using the methodology. Although it is impossible to be precise about the exact form of the manual at this stage of the project, topics that are likely to be included in the manual are presented below. (A more detailed discussion of some of these topics is provided in Section III.) B. Site Selection It is clear that one of the most important decisions in building or rehabilitating a yard is determining the site that will produce maximum benefits to the railroad from a total systems viewpoint. Consequently, this section of the manual will be concerned with choosing a specific 5

location for new yard construction from a set of alternative locations, or a specific yard for rehabilitation from a set of alternative yards. Many important site selection factors (e.g., sociopolitical, envi ronmental) are nonquantitative; however, those that can be quantified ultimately can be translated into economic terms. A standardized and easy-to-use procedure for evaluating the total, system-wide, economic impact of each yard alternative is needed by the railroad industry. Such a procedure, based on rate-of-return calculations, was developed in Phase I and will be a major element of the manual. It is expected that this section of the manual will include discus sion of noneconomic factors, economic alternatives analysis, detailed procedures, and data requirements. Equations and tables, worksheets, and examples also will be included. C. Hump Grade Profile Design A poorly designed hump profile can severely restrict yard throughput and penalize yard productivity because of excess number of overs peed impacts between cars, and misswitched cars in the classification tracks. Consequently, this section of the manual will be concerned with the design of hump height, grades, and retarder placements and lengths. Standard methods for designing the hump profile are based on a graphical procedure and simple energy calculations. The procedure is both tedious and time consuming and does not accurately handle cases where cars are assumed to have velocity-dependent rolling resistance. Thus a computer program was developed to assist in the hump profile design. The program monitors the speed and headway of cars rolling down the hump and the user can vary parameters associated with the car's rolling resistance, hump grade, and retarder placement and length. This computer-aided procedure promises to greatly facilitate the hump design process. Both the graph ical and computer-aided procedures will be documented in the manual. This section of the manual will present discussions of rolling resistance, hump height, grades, retarder placement and size, switch placement, maximum speed, and headway for switching. Data requirements, manual design procedures, and a computer-aided design procedure also will be discussed. Examples will be presented. D. Subyard Capacity Determination In order for a yard to make the required number of classifications in a short time and to ef~iciently receive and dispatch trains, a yard must have the proper number and length of tracks in the receiving, clas sification, and departure yard. Consequently, this section of the manual will be concerned with estimating the track and length requirements of the receiving, classification, and departure yards. 6

Manual procedures for estimating capacity requirements involve a "hand" accumulation of cars in the various subyards as a function of inbound and outbound train schedules, and standard processing times for various yard activities. Such procedures are essentially a "manua1- simulation" and require a great deal of time and manpower. Thus a com puter program was developed to assist the yard designer in estimating car accumulation by block in various parts of the yard. This computer aided procedure will greatly improve the accuracy of track capacity estimates and the ease with which they are made. Both manual and computer-aided procedures will be documented. This section of th~ manual will include discussion of receiving, classification, and departure capacity requirements; a manual estimating procedure; and a computer-aided estimating procedure. Examples will be given. E. Pullout Design The main bottleneck to productivity in most hump yards is the pull out end of the yard. An efficiently designed pullout end should allow the maximum number of trim engines to work simultaneously in building trains without interfering with each other. Consequently, in this sec tion of the manual, the pullout end (also called trim end or throat) of a yard will be considered from the viewpoint of minimizing conflict be tween trim-engine movements. Currently a good manual or computer assisted procedure does not exist for designing the pullout end of a yard to minimize conflict between trim engines and to facilitate the makeup of trains. It is generally acknowledged, however, that one of the major bottlenecks to improving throughput in hump yards is the makeup end of the yard. For this reason, in Phase 1 a substantial effort was devoted to developing both a manual and a computer-aided pullout design procedure. Both of these procedures will be documented in the manual. Topics likely to be included in this manual are location of crossing points, parallel routes, and multiple ladders; a manual design procedure; and a computer-aided design procedure •. Examples will be given. F. Yard Geometry and Layout A proper yard layout and geometry is important to m~n~m~ze engine travel, the logistics of supervising and deploying yard crews, and inter ference among various yard activities. Consequently, this section of the manual will consider certain geometric aspects of subyards and their location with respect to each other. One of the most basic considerations in yard design is whether in-line or parallel receiving yards and/or departure yards are appropriate. These decisions may be dictated by the . size and shape of the site. However, when a choice exists, such factors as traffic characteristics, weather, and operating costs are important. Some of these trade-off considerations and rules of thumb will be docu mented in the manual. 7

This section of the manual will include discussion of rece1v1ng and departure yards (in-line versus parallel); classification yards (tear drop, fish tail); and location of repair tracks and yard office. Design guidelines, rules of thumb, and examples will be presented. G. Hardware Systems It is important that the yard designer is aware of the latest state of-the-art options available in yard hardware. Consequently, this sec tion of the manual will describe various yard hardware systems and com ponents from a generic (non-vendor-specific) viewpoint. Currently, knowledge of all hardware items in a yard is generally gained through years of experience by working in and around yards. A document that describes yard hardware and that is easily readable by a novice does not exist. The yard hardware section of the manual will present a tutorial description of hardware items and certain fundamental facts on hardware that will allow the user to search intelligently through vendor catalogues for detailed information. It is expected that this section will include discussion of switches, speed control (e.g., retarders), scales, and wheel detectors. H. Computer Systems The computer is playing an increasingly important role in yard oper ations both from a process control and management information systems (MIS) viewpoint. Consequently, this section of the manual will discuss the process control and MIS requirements of yard computer systems. His torically, each railroad has developed (perhaps in conjunction with a vendor) its own yard computer system. Standard guidelines do not exist on the sophistication of the functions to be included in the computer system, the software design, or the hardware architecture. This section will provide guidance in making decisions and compromises regarding yard computer systems from both a performance and cost standpoint. The section will include a description of current practice and fun damental guidelines on computer main-frames, peripherals, data communica tions, software, and fail-safe techniques. The determination of informa tion and process control requirements--that is, no computer system, minimal computer system, intermediate computer system, large computer system--will be discusssed and trade-off considerations in yard computer configurations--for example, centralized versus decentralized, large computer versus multiple small computers--will be presented. 8

III PHASE 1 METHODOLOGY DEVELOPMENT: DESCRIPTION OF SELECTED TOPICS A. Critical Design Problems The yard design methodology will synthesize and document current yard design procedures and practices. It will also extend the state of the art by placing current procedures and practices on a more systematic and scientific basis and, where possible, by developing improved computer aided design procedures. These computer-aided procedures will be more accurate and less time consuming than current manual procedures, thereby allowing yard designers to focus their attention on the critical deci sions and compromises of yard design. Manual as well as computer-aided design procedures will be detailed so that the design manual will be useful to a wide spectrum of users. In this section, selected aspects of the yard design methodology investigated in Phase 1 are discussed to give the reader an idea of the breadth and depth of the yard design procedures to be included in the design manual. The aspects of the methodology that will be discussed are as follows: • Site selection • Hump grade profile design • Subyard capacity determination • Trim-end conflict resolution • Yard geometry and layout • Yard hardware systems • Yard computer systems. B. Site Selection 1. Problem Description The selection of railroad yard sites for new construction or reha bilitation involves numerous factors, such as railroad company policy, community acceptance, environmental sensitivity, regional compatibility, and economic considerations. Our focus here is on economic considerations. This does not imply that the other factors can be ignored; on the contrary, they must be studied and presented to the decisionmaker along with the economic analysis. 9

2. Rate-of-Return Calculation Methodology The method of economic analysis is to formulate alternatives, define the costs of each alternative, compare and evaluate the alter natives, and select one alternative. Each step of the analysis is briefly described below. a. Formulate Alternatives The formulation of new alternatives includes the designation of alternative sites and the rough design of

the alternative yards. The designation of alternative sites is often obvious because the number of candidate yard locations that can alleviate existing operational problems is limited. The rough design of an alternative yard is done along with the network flow analysis for each alternative plan. The capital and operations and maintenance (O&M) costs for each yard (and the system wide cost change for each alternative) are estimated based on the work in this step. b. Define Costs and Other Gains or Losses of Each Alternative The yard costs and other cost factors to be considered in the analysis are given in Table 2. The items listed under systemwide costs are the costs that may change as a result of building a yard. The direct revenue of the railroad is assumed to be unaffected by the con struction of a yard. c. Compare and Evaluate Alternatives; Select One Alternative The capital budgeting technique used in selecting yard sites is the rate-of-return method, the budgeting technique most commonly used in the railroad industry. The rate-of-return is defined as "the rate of discount which reduces a stream of cash flow to zero" (Lorie & :Savage, 1964), or as "the rate of interest at which the present value of expected capital outlays is ex actly equal to the present value of expected cash earning on that project" (Solomon, 1964). The rate of return can be computed in two ways: (1) the equivalent annual benefit and cost procedure, and (2) the discount benefit and cost procedure. In method (2), which is used here, the rate of return is the interest rate at which the present value of both present and future costs is equal to the present value of both present and future systemwide cost reduction due to the construction of a yard. 10

Table 2 YARD AND SYSTEMWIDE COSTS Yard Costs Capital Costs Land and site preparation Track and switches Signal system Electrical power Corrnnunications Miscellaneous hardware (e.g., retarder, hump scale, switch machines) Building and structure Yard computers (process control and MIS function) Salvage Operations and Maintenance Costs Operations Switch engine crew Clerks Car men Supervisors Freight cars Per diem Ownership Locomotives Ownership or rental Fuel and supplies Maintenance Utili ties Maintenance Track and switches Signals systems Retarders Miscellaneous hardware Yard computers Communications Buildings Property taxes Systemwide Costs Costs for switching done by foreign railroads Line-haul operating costs (crew) Locomotive costs Car costs Track and plant costs 11

Here, all yard costs and the systemwide cost change for each year are assumed to be known. These costs and the cost change are given in present dollars. Then, the rate of return r is given as the interest rate which satisfies Equation 1 (Wohl & Marton, 1967): n k n k L (CCk + COk) / (1 + r) - L Bk / (1 + r) = 0 k=O k=O where CCk = capital cost for facility, land acquisition, etc. in year k COk = continuing costs for facility opera tions and maintenance in year k Bk = cost reduction received in year k n = the period of analysis or planning horizon. (1) The decisionmaking criteria for the rate-of-return method are given by Lorie and Savage (1964) as: Compute the rate of return for that investment proposal, among the set of mutually exclusive proposals, requiring the least initial net outlay. If the rate of return on the investment requiring the smallest outlay exceeds the firm's cost of capital (or other cutoff rate), tentatively accept that investment. Next compute the rate of return on the incremental outlay needed for the investment re quiring the se~ond lowest outlay. If that rate exceeds the firm's cutoff rate, accept the investment requiring the greater outlay in preference to that requiring the lesser. Proceed by such paired comparisons (based on rates of return on incremental out lay) to eliminate all but one investment. 3. Application of Rate-of-Return Method To apply the rate-of-return method to the process of site selection, six worksheets to guide the process will be developed: • Worksheet l--includes all data related to capital investments. • Worksheet 2--includes the O&M costs of the alternative yard and other yards in the railroad system that are affected by the new yard. 12

• Worksheet 3--presents the systemwide O&M costs under existing conditions and with the new yard in operation. • Worksheet 4--presents the difference between the O&M costs under existing conditions and the O&M costs under an alternative yard operation. • Worksheet 5--presents the time schedule of investment and cost reduction. • Worksheet 6--used to calculate the rate of return (see Figure 1). To obtain the rate of return, the ratio of the present value of the total costs and the present value of the total cost reduction is calcu lated. Then, the rate of return is given as the interest rate at which this ratio becomes 1. Using Worksheet 6 (Figure 1), the cost/cost reduction ratio for interest rates of 10%, 15%, 25%, and 40% can be cal culated, and the rate of return can be obtained by the interpolation method (see Grant, Ireson, and Leavenworth, 1976). C. Hump Grade Profile Design 1. Problem Description The procedures for the hump grade profile design are based on a worst-case design philosophy.* The assumption is that if a design can satisfactorily handle a worst-case situation, it can certainly handle less severe situations, which occur much more frequently. The worst-case situation in the design of a hump yard occurs when a hard rolling car is followed by an easy rolling car, which in turn is followed by another hard rolling car (HEH). The grade must be designed (perhaps with a small amount of retardation) so that the hard rolling car observes all speed constraints at various points between the hump and tangent point. This results in the easy rolling car quickly catching the hard rolling car, unless a large amount of retardation is applied to the easy rolling car. In some cases, the easy rolling car is retarded so much that a second catch-up problem can occur when a second hard rolling car is following the easy rolling car unretarded. In this situa tion if too much retardation is given to the second rolling car, it may not enter the classification tracks with sufficient velocity for proper coupling. The objective of the calculations will be to design the hump yard so that the hard rolling car is delivered to the clearance point (or some other point specified by the user) with a specified velocity, while meeting all speed and headway constraints for an HEH group of cars. In most cases, this will require iteration to a final design. * Although a worst-case situation may occur relatively infrequently, the consequences of, say, overspeed impacts between cars or misswitched cars may be severe from an operational and cost standpoint. 13

Calendar Annual Capital Investment O&M Cost for Systemwide Year Period for the New Yard the New Yard Cost Change (present worth) (present worth) (present w01:th) -4 -3 -2 -1 0 r---. 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 .- 28 29 I 30 A+B)/C Totals (A) (B) (C) FIGURE 1 CALCULATION OF THE COST/COST-REDUCTION RATIO 14

Two alternative procedures have been developed for the calculation of the motion of cars rolling under gravity from the hump into the classi fication tracks. The first is a manual procedure that requires the con struction of scale drawings and calculations in a tabular format. The advantages of the manual procedure are that it: • Does not require the availability of or familiarity with a digital computer. • Follows on the well-known classical procedure for the calculation of the motion of cars. • Gives the user, as a part of the graphical process, a "feel" for the behavior of individual cars. The second procedure is a computer simulation model called PROFYL. This program simulates the motion of a sequence of up to three cars in their roll from the hump into the classification tracks. The advantages of the computer-aided procedure are that it is: • Fast and easy to use. • More accurate in its ability to conform more closely to the theoretical model. • Less likely to have user errors; it is relatively easy and inexpensive to recover should such errors occur. 2. Manual Procedure The basic equation of the manual procedure relates energy head at two points 1 and 2 of a section of track: h = h + 6y + m6L e, 2 e, 1 (2) where h = energy head at a downstream point (ft) e,2 h = energy head at an upstream point (ft) e,l 6y = drop between points 1 and 2 (ft) m = sum of energy losses (ft of head per ft) 6L = distance between points 1 and 2 (ft) . 15

The energy loss term m is the sum of individual energy losses: where / a s' VI s w c r w r e r = static car resistance (lb of resistance per lb of car) = velocity-dependent car resistance (lb per lb/ft per sec) = velocity at point 1 (ft per sec) = switch loss (ft of head per ft) (applies only if the section is a swi tch)

= curve loss (ft of head per ft) (applies only if the section is a curve) = wind loss (ft of head per ft) = retarder extraction (ft of head per ft) (applies only if the section is a retarder). (3) Except for VI' the individual terms and coefficients of Equation (3) are specified by the user. This equation is plotted graphically by the user in a point-to-point representation on a profile drawing as shown in Figure 2. The energy head over the entire profile is represented as a series of such sections. It is at the user's discretion to determine the number and location of sections needed to represent a car's roll from hump crest to a point of coupling on the classification track. Usually, new sections begin where there is a major change in track characteristics, such as grade or horizontal curvature. Sections are also required for the representation of switches and retarders. The velocity at any point can then be directly converted from the energy head at that point using the relation where V. ~ g k = = = V. = ...J2gh . k ~ l' e, ~ speed (ft/sec) gravitational acceleration constant (32.2 ft/sec2) rotational head correction factor for energy stored in rotating wheels and axles. 16 (4)

0.0% MAL Ay I· ·1 FIGURE 2 ENERGY HEAD PROFILE PLOT 17

The velocities thus computed are then integrated to yield distances from which time-distance diagrams of the motion of each car are drawn. Dis tance headways are scaled directly from these diagrams. If there are a large number of sections (say, 40 or more), these manual calculations can be both tedious and time consuming, thereby impeding experimentation with alternative designs. Furthermore, the cal culations become even more cumbersome if there is a velocity-dependent rolling resistance term. 3. Computer-Aided Procedure: PROFYL This model is a continuous time simulation of up to three consecu tive cars rolling over the hump into the classification tracks. The trajectory of these cars in the time-distance plane is calculated. From this trajectory, nearly any variable of interest can be obtained. The model allows a user to specify parameters associated with hump height, grades of track sections, and for each track section, the rolling resistance for various types of cars traveling in sequence over the hump. Provisions to add extra resistance for curved sections of track, wind, and switches are included in the model. At switches, switch resistance is assumed to be in the form of feet of velocity-head drop at the point of the switch location. The simulation assumes that the rolling behavior of a car is governed by the following differential equation: v = (5) where v = velocity of the car e = grade of the track section g = acceleration of gravity M = mass of the car I = equivalent rotational mass of the wheels of the car Rl = sum of all static rolling resistance terms RZ = sum of all velocity-dependent rolling resistance terms. The simulation also assumes that at retarder sections the length of the section is given and that the maximum and actual retardation forces in feet of velocity-head drop per foot of retarder length are also given. 18

The outputs of the simulation are speed of cars versus distance (or time) and headway of trailing cars versus distance (or time). These are given in both tabular and graphical formats. Sample graphical out puts are shown in Figures 3 and 4. A computer-aided hump design process using this program will be more accurate and less time consuming than the manual procedure. This will allow more experimentation with and evaluation of alternative hump designs and thus will ensure the most optimum design. D. Subyard Capacity Determination 1. Problem Description The number of receiving, classification, and departure tracks and their required lengths can be estimated in a variety of ways. A yard operations simulation model is one approach to the problem, queueing theory is another. In the former case, the model usually requires pre cise input data, which frequently are not available at the yard planning stage. In the latter case, it is not obvious whether an accurate repre sentation of block movements in the yard can be easily determined. Thus, in the planning stage of yard design, a design tool is needed that re quires simple input and produces sufficiently realistic output. Both a manual and a computer-aided procedure were developed for use in determiningcsubyard capacity requirements. Both procedures use a deterministic accounting-type approach and represent block movements in the yard following a given set of rules. To illustrate the rules followed in the procedures, yard operational functions are initially described. Although there are numerous types of classification yards, a series of operational procedures common to most yards can be applied to represent yard functions. The major functions of a yard are as follows: • Receive inbound train on the receiving track. • Inspect and bleed brakes of cars on inbound trains standing on the receiving tracks. • Hump cars standing on the receiving tracks onto the classification tracks. • Make up the outgoing trains by pulling blocks from classi fication tracks to departure tracks. • Inspect and charge air brakes of cars on outgoing trains standing on the departure tracks. • Depart outgoing trains. 19

120.000I-------------Y-------------I-------------I-------------I-------------I: 1 • , I I I I I I I I I I I I I I I I I 21 I I I I I I 22 2 1 2 I 2 I I I I I I I I I 1 I I I I I I I I I I I I 1 I 16.0001-----------2-I2----2------2I-------------l-------------I---~----------I I 2 I 2 11 III I \ I I I I 2 I C j 1 III I 1 I I 2 I 221 I III 1 1 1 I 11 2 111 222 1 I I 2 111 I 22222 I 1 I I 11 I I 22222 111 I I 1 2 1 I 12 1211 1 I I 1 I I I 1111 I 22 J I 2 1 I I I lll1 I 21222 I 12.000I-----il------J-------------I-------------I-2--------1122222----------1 ____ I~_ r ' 1 222211111 I I . 21 I I I 2222 I 1111' 1 I 1 I I I i222 I 1111 I I 2 I I I I 11 II I I I I I I 21 I I I I I 121 I I 1 I I r I I I 1 I 21 I I I I 1 8 000t-l-----------1------------- -------------1-------------1-------------1 121 lIt I III I I I 1 12 I I I I ---L- 1 I I I I 1 12 T I I I I 1 I I I I I 2 I I I I I 2 r I I I I I I I I I I 4;0001------·----·-I-------------I-------------I-------------I--------~----I r I I I I I I I X I I L- I I I I J I I I I I J I ___ L I I I I I I T I I I I I I I I I I _____ .-1 __ . J I I I ----L._ r I I I I 1 O.OCOI-------------t-------------I-------------I-------------1-------------1: .-~ --.- -():Oo 00 0 -~J o:-:o~!-o -0 O.,....O-:O---b--:n:-:o .... ~-::-o 0~O::-:O:-:0~---:9:-::0:-:-0 .... ! -::"0 O::-:O:-:O:-:O---:l:-::Z;"":O-c-O ..... !-::"0 O~o-n-:o- .~ 1500.: j FIGURE 3 SAMPLE PROFYL SIMULATION: SPEED VERSUS DISTANCE DISTANCE (FT.) 20 ,.

,..... . ~ r.:.. '-' >< :i ~ < : r:a ::r:: I . 1100.OOOI.-----------·I-------------I--~----------I-------------1-------------1 I I J I J I I I 1 I I I I I I I I -L I r I I I I I I I I 1 I I t I I I I I I I I 1 I I T I 1 I I I I I I I 80.0001-------------I-------------I-------------I-------------I------------~l 222 I I I I I I -_. I 22 22 r 2 I 1 I 1 I 21 22 ~2 I \ I I I I Z I22 2 I J I I 1 2 T 2 I I 2222.21 I I I I I 2 22 I I 2 I 2 I I Z2 I Z I I I J i22?2? I 2 I 2 I I 2 I 2 I 22 22 I Z I 2 I 60.0~or-------------J------------212---------2--1---2---------1---'---------1 I I 2 C I &. I 2 I I 2 I I CI I 2 I I I I 2Ui I 2 I I 2 I I I I I I I 1 I I 2 I r T I I I C 1 I 2 I 1 I I I I I I I I i I I r I I I I .. .----------- ------------- ---------.--- .------------ ------------~f- -- .. - I I I I I I J I I I 12 I I I I I I J I I t I I J I I. I I 2 T I I T r J T I I I 1 2 1 I I I I T J I I I I 20.0001-------------7------------1------------1------------1-------------1 I J I I I I I T I I I I I I I I I I 1 I J 1 I I I ----.-~ I I I I I I I 1 I I I I 1 I I I I I I I I I r T ! I I I O.OOOJ-------------I-------------L-------------I-------------1-------------1 --._- 'O"!-ooo 0 o---}0~o:-'!L...O-O- ::O-:O-:O----6~O::-:O-:-"!'-:O-::O-::O-=O-=-O---::9:-::0:-::0~!'"=o-=o-=o-=-o -=-0 ----=1:-;;2:-:0-::0 ..... !-=070 -0 -0 O---;1-='5-:0-=-O ..... !- .PL~} LEG~_N~O~-~~~ ____ _ HEACW~Y PLOTTEC BT. C~RS ! liC. ~I At.[)2--- e FIGURE 4 SAMPLE PROFYL SIMULATION: HEADWAY VERSUS DISTANCE DISTANCE (FT.) 21

The exact operational procedure for each function may differ from yard to yard. Both the manual and computer-aided procedures deal with this problem by accepting variable time lengths for each function. Es sentially, the procedures represent car movements in the yard by follow ing the above sequence of operational functions. The major difference between the two procedures is that the manu~l procedure is simpler in concept but more time consuming in terms of man-hours than the computer aided procedure. 2. Manual Procedure The objective of the manual procedure is to provide a method of estimating yard capacity requirements other than the computer-aided procedure, which is described in Section 111.0.3. The manual procedure requires manual calculation and use of diagrams and tables. The major tasks of the manual procedure are as follows: • Task I: Estimate the key activity time periods of .the functions performed in the yard. • Task 2: Construct a queueing diagram and estimate yard requirements based on the diagram. • Task 3: Estimate arrival and departure train block assign ments and classification track buildups. A sample queueing diagram of the receiving yard is shown in Figure 5. The inbound inspection time is indicated by TI, the travel time to the hump is indicated by TT, and the hump time is indicated by TH. The time intervals obtained in Task I are used to build the queueing diagram. Based on this queueing diagram, the required number of receiving-yard tracks and their lengths are obtained. In the real world, the arrival times of trains are not necessarily exactly as scheduled, and the inbound inspection may not finish at the scheduled time. In designing a yard, early arrivals, late inspection endings, and allowances for longer trains may be desired. These allow ances can be considered. The number of offsets from the schedule and the extra number of cars to be considered should be determined based on the experience of the individual railroad. The departure yard capacity requirements are estimated in a manner similar to that used to estimate receiving yard capacity requirements. To obtain the required number of classification tracks and their lengths, a block buildup history table is constructed. This table shows the cumulative number of cars in each block along with the number of cars brought in by each incoming train. If one block is assigned to each track, then the required number of tracks is identical to the number of blocks dealt with in the yard. The minimum track length requirement 22

0 a: j:: ::I: « I- > (!) z > I: w u W ::I: a: I- ~ « I- a: i= (!) I- « ::I: 0 I- (!) Z w ::::> w I: ::::> 0 i= w ...J CL ~ i= « en It) w a: ::::> (!) u.. M 23

of each track is the maximum number of cars carried in a block by a de parture train. A dynamic track assignment can also be designed utilizing the block buildup history table. The table is designed in such a manner that the usage of a class track by a block can be identified. Although the exact time during which cars occupy the classification tracks is not known, a rough class track utilization status can be recognized from the table. When two or more blocks occupy class tracks at different times of the day, they are good candidates for sharing a class track. This manual process is both tedious and time consuming, thereby inhibiting experimentation with many traffic scenarios for the yard and thus reducing the accuracy of estimating capacity requirements for the real-world environment. 3. Computer-Aided Procedure: CAPACY The computer model CAPACY is capable of analyzing yard capacity requirements with more accuracy than the manual procedure. For example, the manual procedure assumes that each block on a departing train is made up by the same engine. The computer-aided procedure, however, can simulate not only the train makeup scheme used by the manual procedure but also a train makeup scheme where each block on a departing train is made up by the engine that can start coupling that block soonest. CAPACY also enables the user to designate certain blocks as preclassified bypass blocks. These blocks go directly from the receiving yard to the departure yard, bypassing the hump and storage in the receiving and classification yards. The use of bypass blocks requires special treatment in the manual procedure. An overall flow chart of CAPACY is given in Figure 6. The inputs to CAPACY are: • General yard parameters • Arriving train specifications • Consist mix specifications of arriving trains • Block assignments • Departing train specifications. The outputs of the model are: • An "echo back".of user input • A prehump scenario of the processing of all arriving trains • Receiving yard occupancy diagrams and track requirements • A departure train makeup scenario • Departure yard occupancy diagrams and track requirements • Classification yard block buildup histories. 24

SET PROGRAM CONSTANTS READ INPUT DATA SET DEFAULT VALUES PRINT "ECHO BACK" SIMULATE THE FRONT END OF THE YARD (RECEIVING THRU HUMPING) AND PRINT SUMMARY PRINT RECEIVING YARD UTILIZATION AND TRACK REQUIREMENTS SIMULATE THE BACK END OF THE YARD (PULLS FROM CLASS TRACKS THRU TRAIN

DEPARTURE) AND PRINT SUMMARY PRINT DEPARTURE YARD UTILIZATION AND TRACK REQUIREMENTS PRINT THE BLOCK BUILDUP IN THE CLASS YARD AS A FUNCTION OF TIME FIGURE 6 FLOW CHART OF CAPACY 25

A computer-aided yard capacity estimating procedure using this pro gram will be more accurate and less time consuming than the manual pro cedure. This will allow more experimentation with and evaluation of alternative traffic demand patterns and will ensure the most optimum yard design. E. Trim-End Conflict Resolution 1. Problem Description One of the most important functions of a classification yard is to make up departing trains by coupling cars in the classification yard and pulling them to the departure yard. This necessitates many back and forth trips by the trim engines between the classification and departure yards. The engines travel with a string of cars from the classification yard to the departure yard and travel light on the return movement. These trim engine movements conflict at the throat, creating a bottleneck in the yard operations. The conflicts of engine movements may be caused by several factors, such as geometric conditions, yard traffic characteris tics, and the trim-engine operations. These factors are interrelated; often it is not clear which factor contributes most to the engine move ment conflicts. The problem can be alleviated by a careful analysis of engine movement conflicts realized under given conditions. Both a manual and a computer-aided procedure were developed for evaluating engine movement conflicts. Yard geometry, traffic at the throat, and the engine operational policy are given as the inputs to both procedures. The procedures merely identify the conflict locations and times. In the envisioned design process, the yard designer will evaluate his trial designs using either the manual or the computer-aided procedure. 2. Manual Procedure The manual procedure was developed as an alternative to the computer aided procedure, which is described in Section III.E.3. The manual pro cedure is not necessarily simple; it requires time-consuming, tedious work. It is essentially a simulation procedure using pencil and paper. First, all links and major routes are identified. A link is a seg ment of track that only one engine can occupy at a time. For example, a classification track can be defined as a link, a pUllout lead can be defined as a link, and so forth. A route is an ordered set of links that connect the classification track lead and the departure track lead. It is possible to have more than one route for a pair of origin and des tination links; in this situation the user specifies the priority in which routes are to be utilized. It is assumed that all routes can be used for both directions (from the classification yard to the departure yard, and vice versa). The routes identified in this process are tabu lated for later use. 26

Second, the engine and block movements are identified. Here, each engine trip is specified by its origin track, its destination track, the route to be taken, and the time periods to be spent at key locations in the trip. The trip is specified for both the trim engine and line haul engines. The origin and the destination of a trip are located either at a classification or a departure track. The classification track number from which a block is ready to be pulled at a given time is identified from the output of the yard capacity requirement analysis. The departure track to which the block is pulled must be identified by the designer. The routes to be taken by blocks and light engines are chosen from the route tabulations prepared earlier. If these exist on more than one route, then the highest priority route is selected; if there is a conflict on this route, then the next highest priority route is chosen, and so forth. The time durations spent in these trips are estimated by the designer. To simplify the calculations, these time durations are rounded to the nearest 10 min. Third, the engine conflicts are presented in an engine conflicts diagram (see Figure 7). If a route is taken by an engine, the corres ponding time slot of the route is marked by a number that indicates the departing train being made up by the engine. In Figure 7, route 1 is taken from 3:00 A.M. to 3:30 A.M. by an engine that carries a block of departure train 5. The bar on the top of the number indicates that the engine travels the route in the reverse direction, that is, from the departure yard to the classification yard or from the main line to the departure yard. Whenever one column of the engine conflicts diagram is occupied by two or more moves, a potential conflict is identified. The time slots in which potential conflicts exist are identified by arrows in Figure 7. The engine movements schedule with no conflicts is given in Figure 8, which was made by eliminating the conflicts in Figure 8. A comparison of Figure 8 with Figure 7 shows that departure trains 10 and 11 are delayed by 10 min because of engine conflicts. Conflict evaluation work is completed after a modified engine con flicts diagram is drawn up. The user would then examine when and where conflict occurs and attempt to alter the trim-end geometry (i.e., parallel leads or extra crossovers) to eliminate major conflict points. The above manual evaluation process would continue on each alternative design until the designer is satisfied. 3. Computer-Aided Procedure The computer-aided procedure deals with less simplified assumptions and more comparisons and computations than the manual procedure. How ever, the basic principle of the computer-aided procedure is identical to the manual procedure. The computer-aided procedure is much simpler to use than the manual procedure, even though the computer-aided proce dure gives more outputs. 27

N · 0 0 w I- :J 0 a: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 3: 00 St! ; 15 50 0 , 4. 00 6 0 0 5~ 5 . , I 17 7 I I I I I I , I i 5 5 5 AM I PM , I I I , I I 7: 00 8: 00 9: 00 10 :0 0 11 :0 0 12 :0 0 1: 00 2: 00 - 9 9 9 7 '1' 1 10 77 1/ I I " 11 11 - 9 10 10 10 101 10 - II 7 77 "9 II II i# 10 1 0 II 11 11 t t t tt t FI G UR E 7 EN G IN E CO NF LI CT S D IA G R AM

N '- 0 w I- ::> 0 a: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 3: 00 4: 00 5: 00 ~5 "5 55 S - 5 5 5 AM PM 6 1 0 7: 00 8: 00 9: 00 1O~ 00 11 :0 0 12~ 00 1 : 00 2: 00 " f~ 9~ 9 ~ - 77 ? 77 - /I II " I " - 9 'Ie 1 0 10 /() 1/0 1/ '1 77 ~ 9i'1 Iii IO~ ' II II I/ FI G UR E 8 M O DI FI ED E NG IN E CO NF LI CT S D IA G R AM

The inputs to the simulation model are: • Geometry of the yard throat, including links and routes • Classification-track-related information • Departure-track-related information • Engine schedule • Initial status of the system. The outputs of the simulation model are: • All input data. • Traffic flow at each link and route in terms of number of cars and engines (hourly statistics). • Delay time of engines caused by conflict for each link, route, and the combination of link, engine, and route (hourly statistics). • Idle time, break time, route selection time of each engine and its link (hourly statistics). • The number of trips made by each engine and the number of cars carried by each engine (hourly statistics). • Travel time of engines for each link, route, and the com bination of link, engine, and route (hourly statistics). • Engine movements history. The designer would use this program to evaluate a proposed trim-end geometric design. The program would essentially tell the designer when and where conflicts between trim-engines occur. Given this information, the designer would attempt to alter the trim-end geometry to alleviate conflict, that is, parallel leads or extra crossovers. The program would be used to evaluate each successive alternative until the designer is satisfied. A computer-aided trim~end yard geometry design process using this program will be more accurate and less time consuming than the manual procedure. This will allow more experimentation with and evaluation of alternative trim-end geometric designs to minimize trim-engine conflicts and ensure the most optimum design. F. Yard Geometry and Layout 1. Generic Yard Geometries Hump yards can be laid out in many different patterns that invo~ve in-line or parallel arrangements of receiving tracks (R), classification tracks (C), and departure tracks (D). Different generic yard layouts are illustrated in the five cases presented below. 30

* Case 1: ~vo-Sided Parallel Receiving/Two-Sided Parallel Departure "/(D D E==~I c It:=:::::!: stubbed-end pull-back leads· Examples: D D • CONRAIL's Frontier Yard • Sp's Englewood Yard Considerations: • Receiving activittes can interfere with departure activities. • Taking cars from receiving track to hump involves pulling and pushing, which may be less efficient than simply pushing. The diagrams for all cases are "symbolic" representations, not schematic drawings. 31

Case 2: One-Sided Parallel Receiving/One-Sided Parallel Departure D ::=::::tl c I~ D Examples: • CONRAIL's Avon Yard • CONRAIL's Buckeye Yard Considerations: • Minimizes interference between receiving and departure activities. • Taking cars from receiving track to hump involves pulling and pushing, which may be less efficient than simply pushing. Case 3: In-line Receiving/In-line Departure DDD Examples: • CONRAIL's "old" Syracuse Yard Considerations: • Minimizes interference between receiving and departure activities. • Taking cars from receiving track to hump is simply a pushing operation, which is likely to be more efficient than pulling and pushing. • Supervision and logistics for efficiently utilizing crews is made more difficult since areas of work are spread out (e.g., it is difficult to timeshare car men and yard engines for receiving and departure activities). 32

• Excessive trim-engine travel time from far end of departure track to pullout end of classification track. • Requires doubling of classification tracks by trim engine to build train on departure track. Case 4: In-line Receiving/One-Sided Parallel Departure Examples: • Sant3 Fe's Barstow Yard Considerations: •. Minimizes interference between receiving and departure activities. • Taking cars from receiving track to hump involves simply pushing, which is likely to be more efficient than pulling and pushing. • Since departure tracks are only on one side of the yard, more interference than necessary is caused by the fact that blocks from all classification tracks must be pulled or pushed to one side of the yard. Case 5: In-line Receiving/Two-Sided Parallel Departure D 01 c I~ o 33

Examples: • CONRAIL's Selkirk Yard • CONRAIL's Elkard Yard Considerations: • Minimizes interference between receiving and departure activities. • Taking cars from receiving tracks to hump involves only pushing, which is likely to be m6re efficient than pulling and pushing. • Since departure tracks are on both sides of the yard, interference is minimized since blocks from the upper classification tracks go to the upper departure yard, and blocks from the lower classifi cation tracks go to lower departure yard. Crossover traffic may cause interference problems. 2. General Design Criteria The design of a classification yard is highly dependent on land constraints, weather, and how the yard must interface with the main line. Consequently, it is virtually impossible to say that one generic design is better than another. However, assuming that there are no constraints, Case 5 (in-line receiving/two-sided parallel departure) has many desirable attributes. The general design criteria for a well-designed hump yard include: • Minimize interference between receiving, classifying, makeup, and departing activities. • Minimize makeup interference in the "throat" (i.e., bowl-end of yard) • • Minimize yard engine travel times - From receiving track to hump and return. - From classification track to departure track and return. • Minimize reverse movements of traffic over the same track seg ments. • Allow suitable timesharing of yard-engine and car men resources among receiving and departing activities to minimize yard costs. • Make design flexible and fault-tolerant to allow for such oper ational errors and emergencies as derailments, misclassification of cars in classification tracks, bad-order cars in departure tracks, and wrong assignment of classification tracks causing crossovers. 34

G. Yard Hardware Systems The primary function of a classification yard is to disassemble and reassemble freight trains made of individual rail cars. To handle these heavy rolling stocks, a classification yard must be hardware intensive. As a matter of fact, the amount and variety of hardware in a yard are extensive. Needless to say, a yard designer should know what type of hardware is available. Thus, the yard design manual will present a com pilation of existing hardware information at the generic (i.e., non-vendor specific) level to facilitate the intelligent use of vendor brochures and data. 1. Hardware Identification During Phase 1 of this project, in order to systematically compile hardware information at the generic level, a literature search was per formed and vendor brochures and manuals were collected. Railroad suppliers and manufacturers were consulted, as were railroad personnel who have had extensive experience in yard operations. Major yard hardware systems were identified (see Table 3), and we began to determine the principle of oper ation, special features, track record, and so forth, for each piece of hardware identified. This work is expected to continue throughout Phases 2 and 3 of the project. The hardware identified in Table 3 is expected to be included in the yard design manual. The basic hardware components used in a yard are relatively few, because these basic components are ingeniously combined into a variety of yard hardware systems. It is for this reason that the subject under discussion has been divided into the categories of "basic building blocks," "other yard operating tools," and "state-of-the-art systems." The division between basic building blocks and other tools is at times vague. As a general rule, a device is classified as a basic building block if it can be purchased off the shelf from a supplier and its installation requires little or no design effort. All other equipment or systems are considered tools. 2. Problems in Hardware Identification Although hardware identification is relatively straightforward, a few problems complicate the process. The difficulties discussed below may very well account for the absence of a consolidated document on yard hardware despite the fact that most hardware systems have been in exis tence for many years. In a few instances, universal terminology does not exist. For example, the meaning of the term flip switch is obvious to some people but not to others. A number of interchangeable terms, namely, variable switch and spring switch, are used for the same device. Future work may well indicate that minor variations may be associated with the various terminologies. 35

Table 3 YARD HARDWARE IDENTIFIED DURING PHASE 1 Basic Building Blocks Switches (turnouts) Retarders Radar \fueel detector Photocell Weigh rail Presence monitor Dragging equipment detector Hot box detector Rail head oiler Other Yard Operating Tools Locomotive speed control system Retarder speed control system Track circuit Movement indicator Cut length measuring system Track block indicator Car space detection system Retarder occupancy relay Shove indicator Clearance track circuit Approach track presence Stall indicator Closed-circuit TV camera Warning lights Audible alarm Distance-to-couple measurement system State of-the-Art Systems Dowty system Hydraulic retarder Cable device Electrodynamic retarder Linear-motor booster retarder Rubber retarder Hydrabrake retarder Pusher trolleys Electronic dragging equipment detector Wheel flaw detector Lack of standardization presents another problem in hardware iden tification. For example, the toe lengths for No.7 frog--part of a turnout track work--have the following different values: • Racor industrial turnout frog: 4 ft - 6 ft • Racor bolted rigid frog: 4 ft - 8.5 ft • SP self-guarded frog (90 Ib rail): 1 in. - 11 in. Such variations make quantitative cataloging of certain items extremely difficul t. There are many rules of thumb in yard design practice. It is our intention, whenever possible, to substantiate these rules by rationales so that the user can judge their applicability to a particular situation. Examples of such rules of thumb include: 36

• Reverse curvature is undesirable. • Tandem switch configuration facilities switching operation but introduces sharper curvature. Finally, differences in personal opLnLons complicate the task of hardware identification and make objective evaluations of devices nearly impossible. A good example is the coupled-in-motion scale- some people swear by it; others are of the opinion that it is not suf ficiently reliable to do any good. H. Yard Computer Systems 1. Background Most railroads are convinced of the usefulness of computer systems to aid yard operations. New yards that are built today almost always include provision for a sophisticated computer system to perform process control and ~!IS functions. Rebuilding and upgrading of existing yards generally include the replacement of a manual retardation and switching opera ti-on wi th a computer-au toma ted process; a Iso, manual card-PICL7(systems can be replaced by computerized car inventory systems. The initial cost of a sophisticated yard computer system can be $1 million or more. If one considers the operating costs associated with maintenance, computer operator, and the like, the investment in a yard computer system can be sizable. The sophistication of individual railroads in computer technology varies greatly. Consequently, the ability of individual railroads to make sophisticated judgments in the design and purchase of yard computer systems also varies greatly. This problem is exacerbated by the fact that computer and communication technologies are changing rapidly and that generally each railroad sees its own needs as specialized. Depend ing on its sophistication, an individual railroad has two choices in purchasing yard computer systems: it can purchase a "turnkey" system from a vendor, or it can act as its own prime contractor and develop its own computer design with the assistance of a vendor or a private consulting organization. Because of the large capital and operating costs of yard computer systems, the sophistication and rapidly changing technology of computers, and the need to make informed decisions when interacting with vendors and consultants, it is clear that the railroad industry needs information, guidelines, and procedures to decide which yard computer system best meets its needs. Perpetual inventory and car location. 37

2. Generic Functions Certain generic information and control processing functions must be performed in most hump yards regardless of whether or not these functions are automated. Information and control processing functions can be divided into process control and MIS as follows:* • Process Control - Retarder control--measure velocity of cars in retarders, calculate car rolling resistance, and control retardation force to achieve a desired exit velocity. - Switch control--align switches to route cars to proper classification track. - Hump engine speed control. Signaling/communication requirements for yard engine movements--for example, control of power switches in receiving yard, throat, or departure yard. - Specialized control functions--for example, oil spray to reduce retarder noise. • Management Information System - Yard inventory--car and train inventory of what is on receiving, classification, and departure tracks. - Receive, process, and transmit advanced consist in formation. - Receive, process, and transmit accounting and financial information--for exa~ple, weighing, billing, routing, shipper, and consignee data. A hump yard can be considered to be automated when the first two process control functions (retarder control and switch control) are computerized;t the MIS functions may be manual or computerized. In some sense, a minimal yard computer system can be defined as one that per forms only retarder and switch control; the MIS functions are performed manually. Because MIS functions can be computerized in a number of ways, the levels of yard computer sophistication beyond the minimal sys tem are based on the sophistication of the MIS function. A minimal MIS must be sufficient to support a manual (e.g., card PICL) yard inventory system. This minimal system must have the ability to accept as input a list of cars to be humped and print out a switch list telling where cars went. (A yardmaster checks and corrects the * In flat yards, we are mainly concerned with the MIS functions. t There are many levels of sophistication in automating the process con- trol function. 38

switch list.) The computer must have the capacity to process three trains: train at hump, next train to be switched, and train already switched. Yard inventory is maintained manually using a card-PICL. A sophisticated MIS would include the ability to obtain instanta neous car inventory, a list for pullout conductor telling what is on each track, and various types of management reports. For example, a sophisticated terminal system that supports a main yard, satellite yards, and industrial sidings might have the following operational functions: * • Inputs - Provide/transmit advanced consists (detail/summary counts; store in file). - Load industrial data from release information and reports from shippers. - Allow positive verification and correction of inbound train list (i.e., validate and correct against advanced consist file), • Yard inventory (disk-PICL*) - Maintain track-standing inventory (i.e., what cars are on each track and their order) of receiving, classifica tion, and departure tracks of main yard. - Maintain semi-track-standing inventory (i.e., what cars on each track, but not ordered) of repair, engine, and work equipment tracks. - Maintain bulk inventory (i.e., what cars are in a geo graphical area) of industry and support yards. - Update inventory after switching; can be done manually (i.e., track assign on an individual car basis) or auto matically updated as switched (i.e., by list). - Move trains between several yards in the terminal area (corresponds to a drag movement between main yard and support yard). - Access disk-PICL to see what is there by track, or by yard, or by area. - Maintain outbound train makeup. • Outputs and reports - Switch list that shows what track a car has been switched to. - Block summaries (i.e., block count) by area, zone, or track. - Yard summary, number of cars on each track. Computer equivalent of card-PICL. 39

- Track standing inventory. - Tonnage summary by area, zone, track. - Track overflow report--length of cars on each track and length of track. - Track status reports (e.g., track assignments, spiking tracks, overflow, maintenance, out of service). - General-purpose inquiry reports--Where is car "x"? Where are all cars of type "x"? - Car characteristics (weight, length) through a mini-UMLER file (i.e., cars are ranged; contain ID, weight, and length; 60,000 car entries sufficient). 3. Alternative Design Configurations To accomplish the generic functions and operations described above, many yard computer configurations and design philosophies have evolved. For example, one can use a multiple computer approach with four or five small process control computers, one of which is a "hot spare." The hot spare can take over the functions of one of the other computers in the event of a single computer failure. Alternatively, one can use a single, medium-sized computer performing most of the yard functions; a hot spare will be available in the event that the primary computer fails. In addition, there is the question as to where certain computerized functions ought to be carried out--at the yard or at a central computing facility at the railroad's headquarters. A systematic treatment of the pros and cons of the many computer system architectures for yards does not exist. The problem becomes even more complex for railroads contemplating installing or updating yard computer systems when we consider that CPU costs are decreasing rapidly, communication costs are likely to be a dominant factor, and each railroad sees its own particular requirements as unique and therefore requiring custom installation. 4. Yard Computer System Guidelines The exact nature of the yard computer system section of the yard design manual is not known at this time. However, the section is ex pected to include fundamental guidelines on computer main-frames, peripherals, data communications, software, and fail-safe techniques. Procedures will be presented for ascertaining the level of computer sophistication needed for a yard as a function of yard requirements. The levels of sophistication will include no, minimal, intermediate, and large computer systems. The trade-offs of such yard computer configura tions as centralized versus decentralized and large computer versus multiple small computers will be considered. 40

IV CONCLUDING REMARKS This interim report has described the preliminary yard design method ology developed in Phase 1 of the project. Phase 2 will exercise the methodology on CONRAIL yard design problems. As a result of the rea1- world applications of the methodology during Phase 2, the methodology will be refined and modified. To further ensure that the methodology is real istic and practical, periodic workshops with railroad industry personnel are being planned, so that a wide spectrum of expertise can be represented in the methodology. Finally, Phase 3 documents the design methodology in the form of a yard design manual that will be readily usable by the railroad industry at large. 41

REFERENCES Grant, E. L., Ireson, W. G., & Leavenworth, R. S., Principles of Engi neering Economy, 6th edition (The Ronald Press Company, New York, New York, 1976). GRS, "GRS Classification Systems with Automation," Folder 237, General Railway Signal, Rochester, New York (November 1926). Lewis, C. D., et al., "St. Louis Railroad Gateway Restructuring Project: Phase I," Final Report FRA/OPPD-78-6, Consad Research Corporation, Pittsburgh, Pennsylvania (December 1977). Lorie, J. H., & Savage, L. J., "Three Problems in Rationing Capital," in E. Solomon, ed., The Management of Corporate Capital (The Free Press of Glencoe, New York, New York, 1964). MIT, "Studies in Railroad Operations and Economics," Vols. 1-9, Depart ment of Civil'Engineering, School of Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts (1972). Petracek, S. J., et al., "Railroad Classification Yard Technology: A Survey and Assessment," Final Report FRA/ORD-76-304, Stanford Re search Institute, Menlo Park, California (July 1976). Shaffer, F. E., & Roberts, R., "Hump Yards: Are the Critics Right?" Modern Railroads, pp. 52-56 (July 1973). Solomon, E., The Arithmetic of Capital-Budgeting Decision," in E. Solomon, ed., The Management of Corporate Capital (The Free Press of Glencoe, New York, New York, 1964). USRA, "United States Railway Association Final System Plan for Restruc turing Railroads in the Northeast and Midwest Regions Pursuant to the Regional Rail Reorganization Act of 1973," Vols. 1 and 2, United States Rail Reorganization Act of 1973," Vols. 1 and 2, United States Railway Association, Washington, D. C. (July 26, 1975). WABCO, "Railroad Freight Car Classification Yards: Installations 1924- 1976," Bulletin 300, Union Switch and Signal Division, Westinghouse Air Brake Co., Swissdale, Pennsylvania (1976). Welty, G., "The New Class Yards: How Are They Working?" Railway Age, pp. 21-28 (March 27, 1978). Wahl, M. & Marton, B. V., Traffic Systems Analysis for Engineers and Planners (McGraw-Hill Book Company, New York, New York, 1967). 42

1. Report No. 2. Government Accession No. FRA ORD-78/67 4. Title and Subtitle RAILROAD CLASSIFICATION YARD TECHNOLOGY Design Methodology Study T echnical ~eport Documentation Page 3. Recipient's Cotolog No. 190481 5. Report Date September 1978 6. Performing Orgonizotion Code !-:;;--~;--;--;---------------------------i 8. Performing Organi zotion Report No. 7. Author!.) P. J. Wong, C. V. Elliott, R. L. Kiang, M. Sakasita. W. A. Stock 9. Performing Organization Name and Address Stanford Research Institute 333 Ravenswood Avenue Menlo Park, CA 94025 SRI Project 6364 10. Work Unit No. (TRAIS), 11. Controct or Grant No. DOT-TSC-1337 r-::--:--------:----:-~---------,---------....j 13. Type of Report and Period Covered 12. Sponsoring Agency Name and Address Interim Report ! U. S. Department of Transportation July 1977 - September 1978 Federal Railroad Administration Research and Development Washington, D. C. 20590 14. Sponsoring Agency Code " 15. Supplementary Notes Under contract to: U. S. Department of Transportation Transportation Systems Center v"' .... ,l ... ll Square 16. Abstract Cambridge, MA 02142 This interim report documents the first phase of a three-phase effort to develop a railroad classification yard design methodology. Topics discussed include: site selection, hump grade profile design, sub-yard capacity re quirements, trim-end conflict resolution, yard geometry and layout, yard hardware systems, and yard computer systems. 17. Key Words Railroad yard--Design, operations, performance, evaluation, hardware, computers, mod