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RAILROAD RESEARCH NEEDS IN THE PACIFIC NORTHWEST

by

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DISCLAIMER

EXECUTIVE SUMMARY

This report is a summary of railroad research needs in the Pacific Northwest. Background information is presented that was obtained from a literature review of railroad trade publications and reports from railroad research organizations. A list of possible research topics is also presented; this list was formulated with the help of Burlington Northern Railroad's Research and Development Department.

The following topic areas represent a close match between Burlington Northern and TransNow:

1. Intermodal terminal operations and planning. Intermodal terminal operations are an important part of the transportation environment in the Pacific Northwest, and TransNow participants are located in close proximity to several intermodal facilities. Investigations might answer the following questions:

   -- Can strategies be formulated to improve operations coordination and planning between dock facilities and rail yards?

   -- Should containers be collected from several port facilities and loaded at a central rail terminal or should the containers be loaded on rail cars that are placed separately at each dock?

   -- What would be the operational impact of various strategies for handling heavily loaded and overweight containers?

2. Operations Planning and Track Maintenance. This project would include the development of alternative strategies for planning train operations and maintenance activities. It should be noted that railroad operations and maintenance are closely related in the Pacific Northwest, because high density traffic is often confined to a single track in an area where few convenient detour routes exist. The study should be interdisciplinary and should consider trade-offs between maintenance costs and traffic revenue,

and the possible development of innovative maintenance methods and train dispatching strategies.

Researchers might also investigate the impact that crew alertness, highway crossings and advanced signal and control systems have on train operations. An investigation which defines the relationship between freight damage claims and various operating strategies would also be useful.

Burlington Northern Railroad has a strong interest in investigating the effects that heavy axle loads have on its roadway and structures. This interest is evidenced by the commitment of $60,000 in matching funds for a study to estimate bridge service life with regard to fatigue which is caused by cyclic stresses caused by train operation. Although this remains an important topic for the railroads, the full study was not funded by TransNow because a higher priority was placed on other projects that focused more closely on operations and planning.

Two graduate students are working on Master's degree theses that address problems identified by this report. Upon completion, the results of these studies will be reported to TransNow. One student is developing computer modeling techniques that allow records from Burlington Northern's data base to be applied to bridge service life studies. A portion of this work was jointly funded by Burlington Northern and TransNow as part of an exploratory study; this study was initiated before TransNow's operational focus was fully defined. Another graduate student, who is receiving scholarship support, is developing an animated simulation of a container yard operation. It is expected that this simulation will serve as an aid in the development of future intermodal terminal projects.

TABLE OF CONTENTS

FIGURE CAPTIONS

RESEARCH OBJECTIVE

Railroads are a major element in the transportation network of the Pacific Northwest, therefore, railroad research deserves significant attention as an activity for the **TransNow** Transportation Research Center. The objectives of this study are (1) to compile a summary of railroad research needs for the Pacific Northwest (PNW) and (2) to develop specific proposals for possible joint funding by Burlington Northern Railroad (BN) and **TransNow.** This report summarizes the findings with regard to item (1) above; it is intended to stimulate discussion between the railroads and transportation center researcher concerning topics of mutual interest. The proposals that were developed under item (2) are shown in Appendix A and B of this report.

BACKGROUND

Recent Trends in Railroading

The primary business of railroads is the movement of carload freight, particularly bulk commodities such as coal and grain. Railroad involvement with passenger trains is very limited: **Amtrak** and local commuter authorities have overall responsibility for operations, while the railroads contract to provide for the use of trackage and certain other services. Traffic in the intermodal area including containers and highway trailers, has steadily increased in recent years[1]. Railroads are most successful in moving trainloads of bulk commodities, especially in situations where water or pipeline transportation is not feasible. Because of their high labor and capital cost structure, and because of delays associated with collecting enough carloads to form a train, the railroads have had difficulty in competing with motor carriers for short haul business (under 500 miles) and for movement of time sensitive commodities.

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[1]R. T. Sorrow, "Where, How Does Intermodal Fit In?" Modem Railroads, May 1989, p. 21; and Progressive Railroading, "Intermodal Gains on All Fronts," June, 1989, p. 27.

Recently, Class I railroads[2] have experienced improvements in return on investment[3] and safety[4] while revenue ton-miles have held constant or increased moderately[5].. Railroad employment, miles of track, and number of cars and locomotives have all been decreasing[6]-- in other words, the railroads have been doing more with fewer resources. These trends are displayed graphically in Figure **1.** Many give credit for these improvements to the **1981** Staggers Act which allowed the railroads to complete as free enterprises in the open market rather than as a public utility under close government control. Mr. Steve Ditmeyer, **BN's** Chief Engineer of Research, Communications, and Control Systems, credits the deregulated environment for fostering renewed interest among railroads in R&D activities[7]. The theme of recent articles by Mr George Way, Vice President, Research and Test Department, Association of American Railroads, reinforces the need for research as the railroad competes in the open market[8].

Although business is increasing, many industry leaders are concerned because the railroad's share of the freight transportation market is stagnant or eroding. Furthermore, if the nation continues to emphasize a service economy, traffic growth is expected to be greatest in the area where railroads face the most competition: the short **haul/high** service sector, rather than the long **haul/heavy haul/low** cost sector that typifies an

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[2]A Class I railroad, as defined by the Interstate Commerce Commission, has an annual operating revenue of at least **$87.9** million. There are **16** Class I railroads in the USA.

[3]**F. Malone,** "One Good Year Deserves Another," Progressive Railroading, Jan. **1989,** p **36.**

[4]Association of American Railroads **1986-1987** Research **Report,** p. **77.**

[5]**Association** of American **Railroads,** Railroad Facts, **1988** edition.

[6]ibid.

[7]**S.** R. Ditmeyer, "Deregulation and Technological Progress in Railroading: Some Reflections from the Perspective of a Particular Carrier," Transportation Journal, Fall **1987,** p. **5-9.**

[8]**G** H. Way, Jr. in Progressive Railroading "Changing Time Require Research," July **1986, p25;** and "**AAR** Research: Making Railroads Stronger," July **1988,** p. 5.

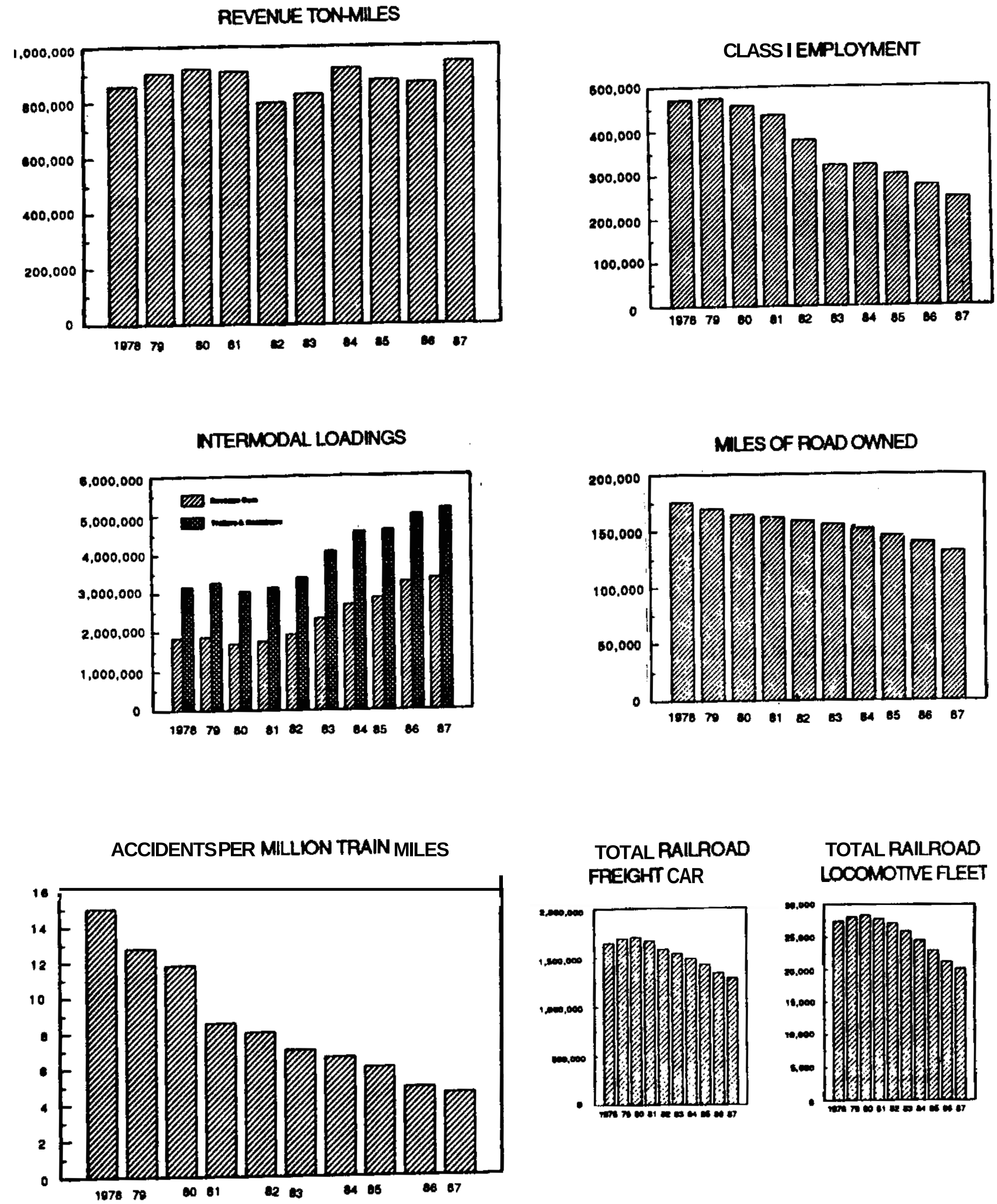

Figure ,1. Recent Trends in Railroading. Source: Railroad Facts, 1988 Edition. Association of American Railroad, Washington, D.C.

industrial economy. Industry leaders have also been alarmed by recent attempts to pass legislation to re-regulate the industry[9].

It is against this background of competition and change that today's railroad research needs are framed.

Railroads in the Pacific Northwest

The PNW is served by three railroad Class I Railroads: Burlington Northern, Southern Pacific, and Union Pacific. Burlington Northern (BN) Railroad is the result of mergers of several railroads; it maintains a 23,500 mile network that stretches from Seattle along a northern corridor to Montana, and then fans out across the Midwest and Rocky Mountain states to the Gulf coast (Figure 2)[10]. Within the PNW, BN serves Washington, western Oregon and the northern tip of Idaho.

The Southern Pacific Transportation Company's (SP) has a major corridor from Portland along the west coast to Los Angeles where connections are made with a southern corridor that provides access to Kansas City, St Louis, and New Orleans (Figure 3). As a result of a recent merger with the Denver and Rio Grande Railroad, a more northerly transcontinental corridor has been opened between San Francisco through Salt Lake City and Denver to Kansas City and St Louis. In the PNW, SP serves western Oregon, and, following the previously mentioned merger, former secondary trackage is being upgraded to provide a more direct route for SP between the PNW and the Midwest[11].

The Union Pacific Railroad (UP), a product of the merger of three railroads, serves the west coast with three major corridors that start in the Seattle/Portland area,

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[9]G. Welty, "Will Congress Drive Railroads Out of the Railroad Business?" Railway Age, July 1987, p. 37.

[10]T. Shedd, "Burlington Northern: Aggressive, Innovative-- and Thoroughly Non-Traditional," Modern Railroads, November 1986, p. 20.

[11]J. Abbott, "SP, D&RGW Rail Combination Builds on the Best of Both Roads," Traffic World, May 8, 1989, p. 6.

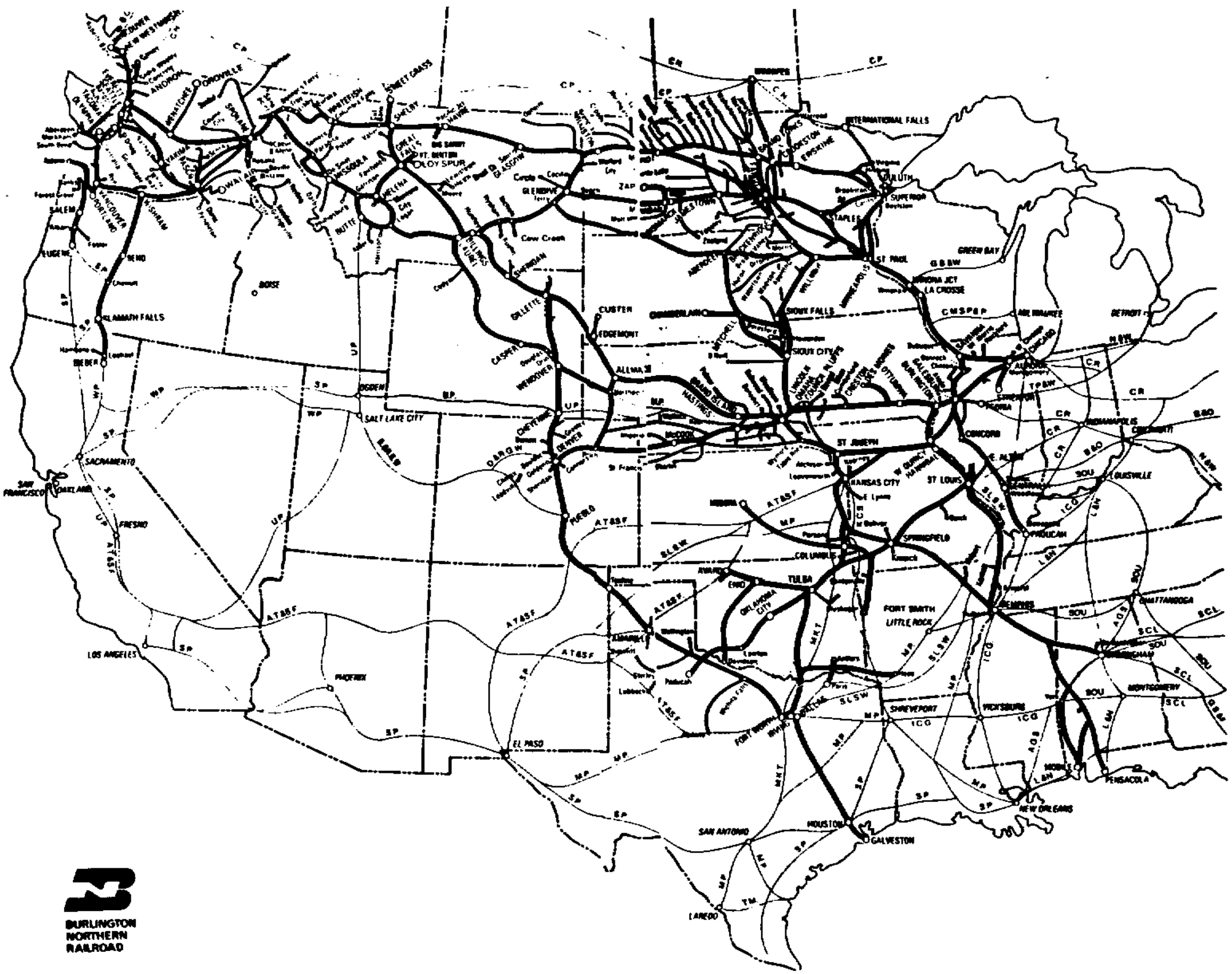

Figure 2. Burlington Northern Railroad. Source: Official Guide, May 1989, Thompson Transportation Press, New York.

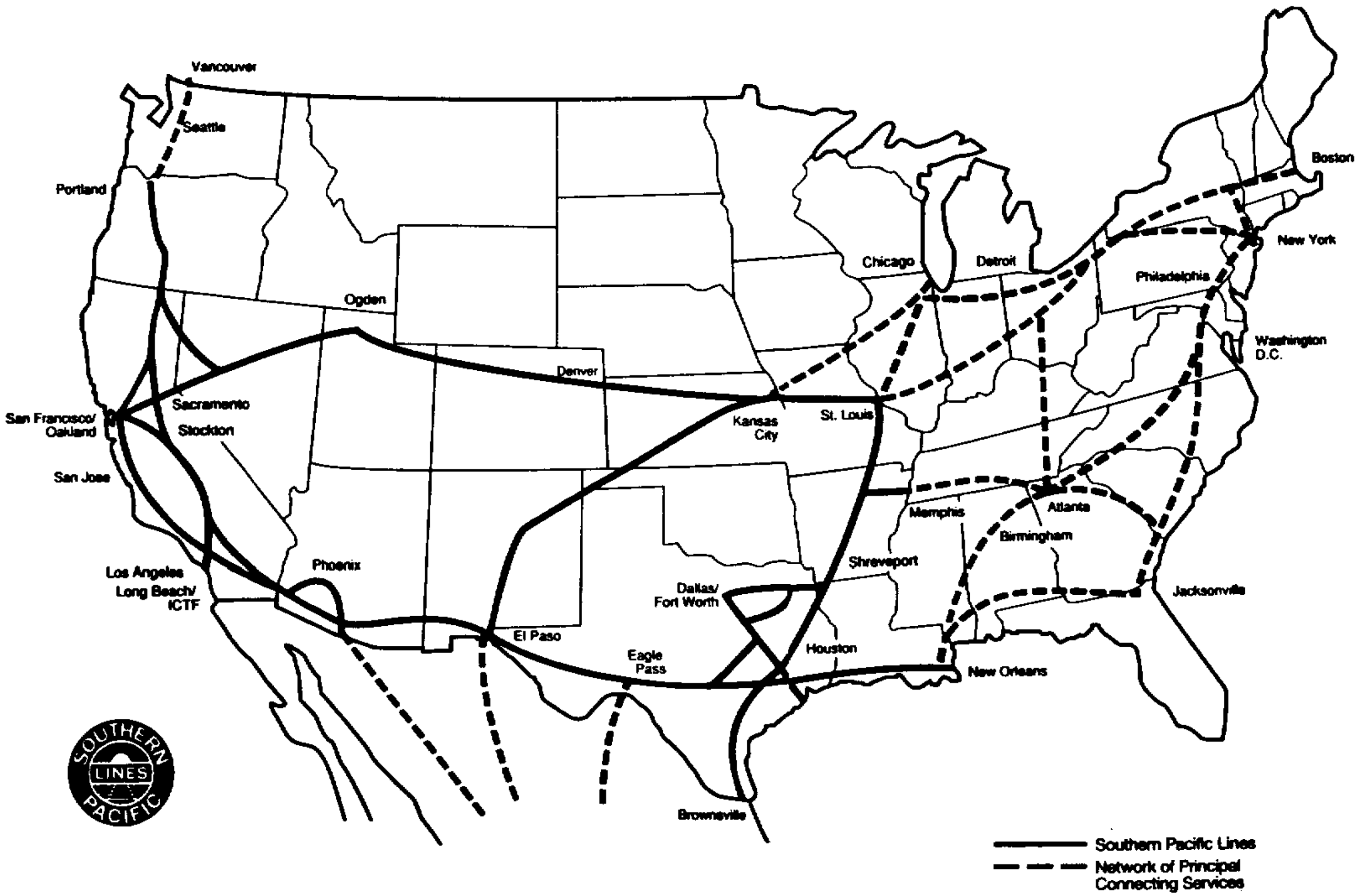

Figure 3. Southern Pacific Transportation Co. Source: Official Guide, May 1989, Thompson Transportation Press, New York.

San Francisco, and Los Angeles and then converge in Salt Lake City and Wyoming (Figure 4). From there traffic is concentrated in a single corridor and then distributed to connecting railroads in the Midwest or funnelled through Kansas City to UP's network in the southern Midwest, Louisiana and Texas[12]. In the PNW, UP serves Washington, Northern Oregon and Idaho.

Alaska Railroad and Washington Central Railroad are examples of regional railroads that serve the Pacific Northwest. The Alaska Railroad (ARR) runs from Seward/Whittier through Anchorage to Fairbanks and has rail-barge connections to Seattle. Washington Central Railroad (WCRC) is a network of former Burlington Northern Branch lines that serves its namesake[13]; it is typical of recent efforts of Class I railroads to sell branch lines to operators who can provide improved service at a lower cost. In addition, several other regional, shortline terminal carriers serve as feeders to Class I railroads. Complete information about the route structure of the railroads may be obtained from industry guide books[14]. Important facts concerning PNW railroads are summarized in Table 1.

The railroad traffic mix in the PNW includes forest products, grain and various industrial products. Intermodal traffic also makes a large contribution and the operation of intermodal terminals at ports is a significant activity. Most traffic is concentrated into relatively few, heavily traveled corridors and there are few detour routes available to relieve track blockages. Trackage is often located in remote mountain and desert areas where extremes of weather exist and track maintenance and train handling is difficult.

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[12] J. R. Davis, "The New Environment for Operation," Progressive Railroading, June 1986, p. 25.

[13] E. G. Nelson, "In the Path of the North Coast Limited," Trains, Nov. 1987, p. 40-3.

[14] The Official Guide of the Railroads, Thompson Transportation Press, New York; and Handy Railroad Atlas by Rand McNally Publishing Company, Chicago, IL.

TABLE 1. PACIFIC NORTHWEST RAILROAD FACTS[1]

Railroad	Miles of Track	Locomotives	Freight Cars
BN	23,500[2]	2,957	88,858
SP[3]	11,927	2,122	52,507
UP	22,068	3,002	117,139
ARR	1,180	48	1,238
WCRC[4]	400	7	0

[1]The Pocket List of Railroad Officials, International Thomson Press, New York, 3rd Quarter, 1988.

[2]W. E. Glavin, "BN becomes roadway innovator," Progressive Railroading, March 1989, p27.

[3]To reflect the recent merger of SP and the Denver and Rio Grande Railroad, entries represent the total for both railroad.

[4]E. G. Nelson, "In the path of the North Coast Limited," Trains, Nov. 1987, p. 40-3.

Railroad Research Organizations

Railroad research is sponsored and conducted on a wide variety of topics by the Federal Railroad Administration, The Association of American Railroads, railroad suppliers and the railroads themselves. Much of this research involves railroad components that are found in great number throughout the industry; examples are track components such as ties and rail or car components such as wheels, braking systems, and roller bearing. Projects are also undertaken if there is a potential for a high return over a short payoff period (for example, new generation train control, signal, and communications systems) or if there is an urgent need for safety improvements (for example, consider the past studies concerning mitigation of the effects of derailments involving tank cars carrying hazardous and flammable materials[15]).

The Federal Railroad Administration (FRA) primarily sponsors safety related research[16] while the Association of American Railroads (AAR) sponsors research that is of mutual benefit to several of its members[17].

Two railroad test facilities are operated by the AAR. The Chicago Technical Center (CTC), which is located on the campus of the Illinois Institute of Technology, conducts studies on a variety of issues involving track systems, railroad vehicle dynamics and metallurgy. The Transportation Test Center (TTC), a facility for railroad field tests, is owned by the ERA and operated under contract by the AAR. TTC maintains several

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[15]Federal Railroad Administration, Recent Develoomentsin Railroad Safety Research, (DOTIWORD-88/03) Office of Research and Development, Washington, D. C. 20590, January 1988, p. 10-17.

[16]*ibid*, entire document; also see ERA Research Programs, issued annually.

[17]Association of American Railroads 1986-1987 Research Report; and G H. Way, Jr. in Proeressive Railroading "Changing Time Requires Research," July 1986, p25 and "AAR Research: Making Railroads Stronger," July 1988, p. 5.

miles of track in loop configurations and a Rail Dynamics Laboratory where tests are made that simulate in-train motions while vehicles are in a stationary **position**[18] .

The exact nature of research programs of individual suppliers and railroads is quite variable, and because much of the work is proprietary in nature, detailed information concerning these programs is usually not disseminated.

Because of Burlington Northern's participation in this project, the make-up of BN's **R&D** program was of special interest. BN's research program is designed to support the company's current goal of designing transportation services that provide an improved match with the customer's needs while maintaining cost **controls**[19]. This often requires improvements in the speed and reliability of deliveries. More information concerning BN's corporate philosophy and marketing policies is available in the open literature[u]).

The **R&D** focus is on low risk projects that are likely to show real economic benefit and may be implemented within five years. "While any project is expected to offer long-term benefits, marketing requirements can change dramatically relatively quickly, and it is essential that we [BN] retain the flexibility in our **R&D** program to adapt to changing **requirements."**[21] Most research is done under contract with research institutes, universities, and many other organizations and participation by the department within the railroad that will be the final user of products of the research is required.

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[18]**FRA, Recent Developments, p. 29.**

[19]D. W. Henderson, "Research and Development at the Burlington Northern Railroad," **Progressive Railroading**, July **1987,** p. **23-28.**

[20]**T.** Shedd, "Burlington Northern: Aggressive, Innovative-- and Thoroughly Non-Traditional," Modern Railroads, November **1986,** p. **20;** G. **Welty, *"The*** Architects of Change: Darius W. Gaskins, Jr." Railwav Aee, Oct. **1987, 39-43;** T. Shedd, "Meeting the Future Head-On: BN's Darius W. Gaskins **Jr." Modern** Railroads, Jan. **1988,** p. **19-26;** and W. **E.** Greenwood, "BN Moves Marketing to the Forefront," Proeressive Railroading, Oct. **1988,** p. 25.

[21]**D.** W. Henderson, "Research and Development at the Burlington Northern **Railroad," Progressive Railroading,** July **1987,** p. 24.

RESEARCH APPROACH

Literature searches, interviews, and field observations were used as tools to identify railroad research needs.

A literature search was conducted to identify areas of research activity as well as recent trends and innovations in the railroad industry. Preliminary findings were discussed with BN's **R&D** Department managers and a group of research topic summaries was developed. A questionnaire form was developed which **R&D** managers could use to obtain feedback from potential research users as to the accuracy of the topic statements and to asses the possibilities for financial and in-kind support. Comments and corrections were placed on two of the questionnaire forms and these forms were returned to the PI so that comment could be included in the topic summaries (See **Appendix** A).

After this process, conclusions were drawn concerning possible areas of mutual interest between the railroads and university-based researchers.

DESCRIPTION OF AREAS OF RAILROAD RESEARCH ACTIVITY

This section of the report describes recent railroad research activity with an emphasis on topics that are likely to be of particular interest within the PNW. Because of the participation of BN's **R&D** Department, their current areas of interest are also emphasized. This is not intended to be an exhaustive summary of all recent railroad research activities, but instead is intended to give the reader a background regarding the research topics developed under this study and also to provide a list of references for further study. The research descriptions are organized into the areas of track and structures, equipment, signals and communication, intermodal terminals, marketing, and human **factors/safety.** Where appropriate, references are made to the topic summaries in (Appendix A) that were developed in cooperation with BN's R & D department.

Eauiomement

New types of railroad equipment have recently been developed in response to changing needs for freight transportation[22] and the railroads are expected to increase their car and locomotive purchases in the near future[23]. Perhaps the most visible equipment innovation in the PNW is the double stack articulated car for intermodal containers[24] (Figure 5). These cars come in sets of five permanently coupled wells, each well accommodating two marine containers stacked one on top of the other. The result is greater efficiency for the railroad for two reasons: 1) more containers may be packed into a shorter length of train, and 2) less freight damage results for the shipper because the permanent connections between the articulated wells eliminate much of the slack action. A standard non-permanent coupling device may have as much as one foot of slack which causes high impact loads as trains stop or move over hills.

Intermodal double stack equipment development has led to the introduction of cars with 125 ton well capacities[25]. This represents an increase in axle loadings over the 100 ton car which represented the previous maximum load. AAR is conducting a series of tests at the Transportation Test Center at Pueblo, Colorado, to investigate relationships between the track structure, the wheels, and the car's suspension system[26]. Previous research has indicated that important relationships may be overlooked unless the entire vehicle-track system is considered as one unit during testing. The research approach includes instrumentation of track and vehicles during test runs of trains under various

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[22]G. Welty, "Freight Cars: Tending to Higher Tech," Railwav Age, June 1989, p. 43; and "Freight Cars 1989... A Service-Oriented Business," Progressive Railroading, April 1989, p. 53.

[23]G. Welty, "Re-Equipping America's Railroads" Railwav Age, September 1988, p. 35; and F. Malone, "Motive Power: Enough, Soon Enough?" Progressive Railroading, April 1989, p 33.

[24]Railwav Age, "Equipment Builders Respond to the Intermodal Challenge," April 1988, p. 44.

[25]G. Welty, "Tracking Heavy-Car Impact," Railwav Age, March 1989 p. 29.

[26]AAR 1986-1987 Research Report; and FRA, Recent Developments.

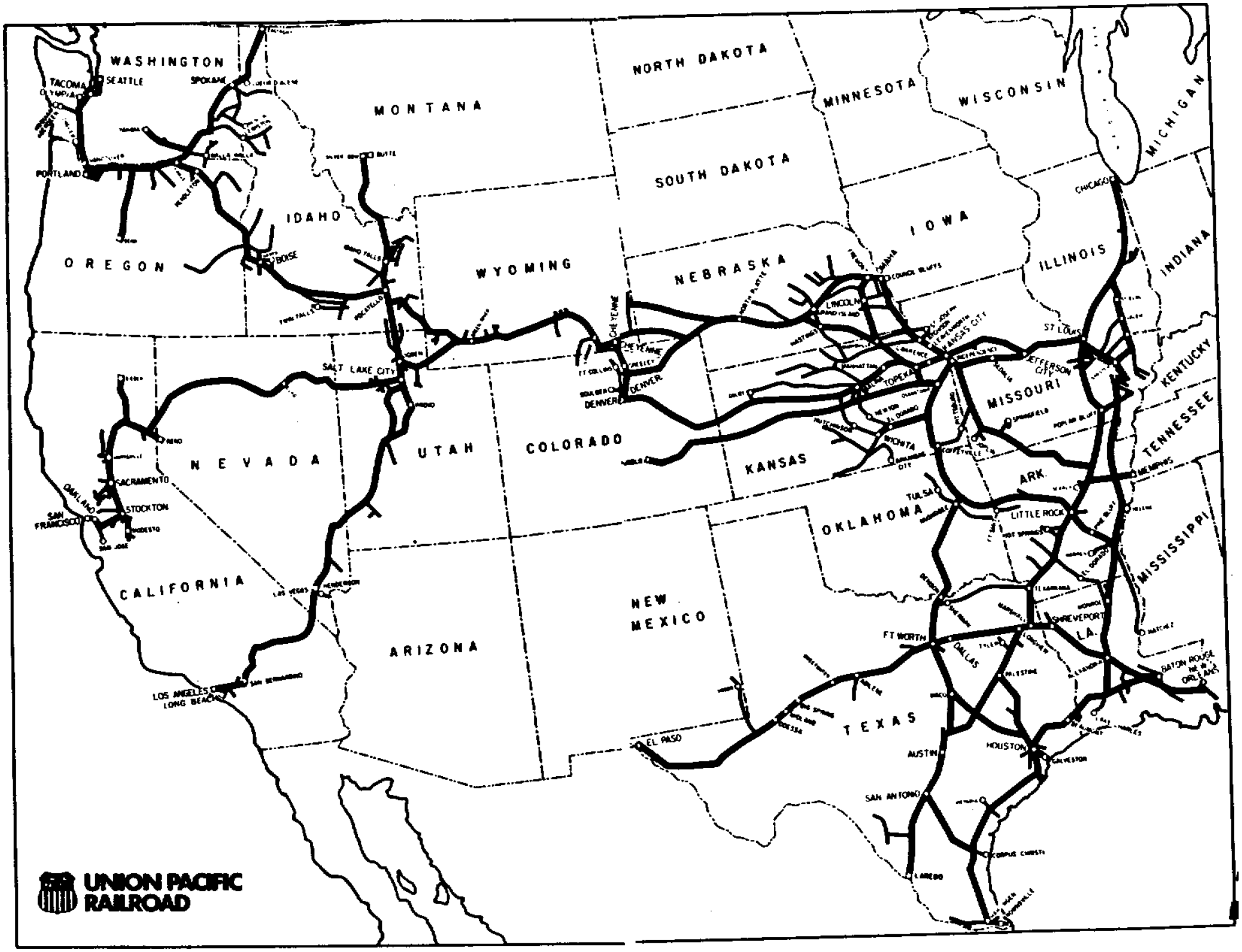

Figure Union Pacific Railroad. Source: Official Guide, May 1989, Thompson Transportation Press, New York.

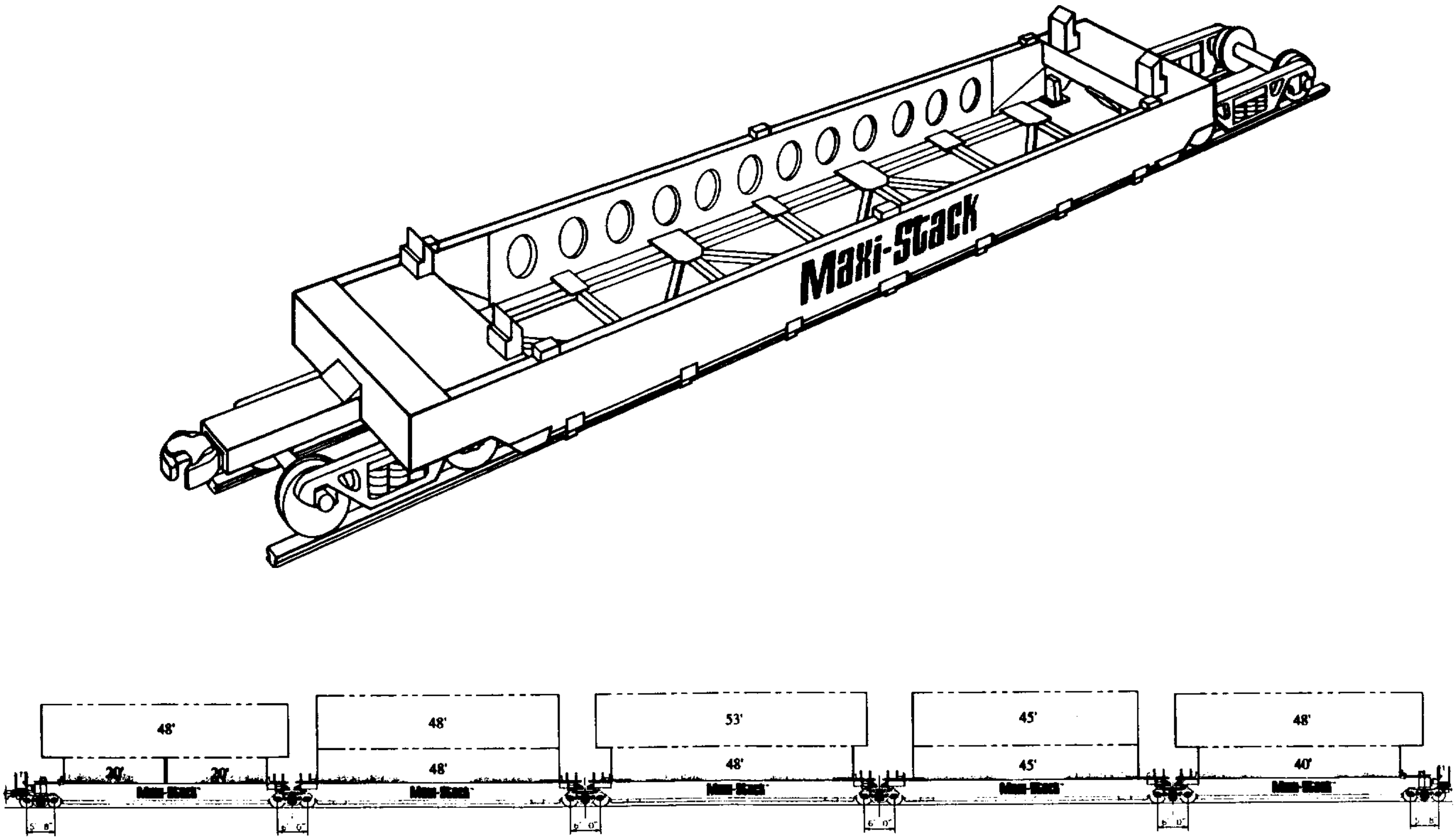

Figure 5. Double Stack Intermodal Car. Source: Product Literature, Greenbrier Intermodal, Walnut Creek, CA 94596.

conditions. **Observations** are made concerning track deterioration and vehicle performance during test runs of a heavy train which runs on a 2.7 mile loop. A special track loading vehicle may also be used to place a predetermined load on the track while the vehicle is stationary or in motion.

A recent brain-storming project sponsored by AAR promoted the development of High Productivity Integral Trains **(HPIT)**[27]. Standard railroad equipment is designed for unrestricted interchange among all railroads; it must conform to rigid design standards so that proper train handling characteristics and safety standards are maintained. It was hoped that significant savings and increases in productivity could be realized by developing special-purpose trains. Designs were developed that could potentially eliminate slack action, reduce tare weight, and improve efficiency by using permanently coupled cars, mid-train locomotives and combinations of railroad and highway equipment. A few concepts were field tested under the project.

A concept that was field tested in the HPIT study, the Roadrailer, is currently in use in the Midwest. This concept involves the use of special highway trailers that are fitted with railroad wheels which are engaged to the track during the rail portion of the haul. This provides the advantages of door-to-door service that motor carriers offer and economy of scale which rail transportation offers. The cost of the equipment is high, therefore initial successes with Roadrailer operation have been limited to corridors where the railroads could accommodate freight moving in both directions, thereby eliminating the need for inefficient empty backhauls.

Railroads have been actively investigating the use of alternative fuels for locomotives. The **1986-1987 AAR** Research Report describes a study that investigates the use of lower grade diesel fuel and the U. S. Department of Energy at the Morgantown Energy Technology Center is investigating the use of a coal and water slurry as diesel

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[27]**J.** H. **Armstrong,** "High Productivity Trains, How Integral? How Imminent?" Railwav **Age,** Sept. **1987,** p. **43.**

fuel[28]. In a telephone interview, Mr. **Les** Olson of **BN's R&D** department reported that BN is continuing to study the possible use of natural gas and methanol as diesel fuel. Although BN's studies involving the use of coal have been suspended because of the high cost of processing the coal into slurries or powder, it was suggested that the use of coal may become economical if a method is developed to use run-of-the-mine coal. Topic summaries involving locomotives are found in Appendix A, Items 6 and 7.

Defects in wheels and wheel bearing are items of high concern within the railroad research community and this concern has resulted in intense activity on the part of the **AAR, FRA**[29] and Railroad **Suppliers**[30]. Most of this research involves the determination of root causes of defects and development of methods for the early detection . Wheel bearing defects occur when excessive friction develops in the bearing due to wear or malfunction. If no action is taken, the resulting high heat will destroy the bearing, possibly causing a derailment. At present, heat-sensing wayside scanners will detect many bearing problems before catastrophic failure occurs; however, the defective car must be removed from the train immediately causing considerable delay in most cases; also, some bearings fail too quickly to be detected in time. It would be desirable to develop a method that would detect incipient failure so that the bearing could be replaced at a more convenient maintenance location. Recent studies have examined the quality of rebuilt **bearing**[31] and have investigated acoustic methods as a possible detection **strategy**[32]. A topic summary involving wheel bearings is found in Appendix A, Item 8.

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[28]**D.** L. Champagne, "Coal-Water Fuel for Locomotive," Proeressive **Railroading**, April 1989, p. 55.

[29]**AAR** 1986-1987 Research Reoort; and FRA, Recent **Develooments.**

[30]**Progressive** Railroading, "A New Perspective on Roller Bearings," Sept. 1988, p. **89**-90.

[31]*ibid*.

[32]**AAR** 1986-1987 Research **Report**; and FRA, Recent **Develoonents**.

Several studies involving braking systems have been or are being conducted by the AAR and **FRA**[33]**.** Efforts have concentrated on reducing the number of undesired brake applications and improving the balance of train braking forces.

Basic knowledge of railroad brakes is required to understand the causes of undesired brake applications. The brakes are controlled by the amount of air pressure that exists in a brake pipe running runs the length of the train: the brakes are released when air pressure in the train line pipe is high and they are applied when pressure is lost. This characteristic makes the braking system somewhat fail-safe because an emergency brake application is **initiated** if the train comes apart or if any of the air hoses are damaged. Normal brake applications are made by slowly removing the air from the brake pipe. Although undesired brake applications are usually not catastrophic, they do result in much inconvenience and expense. The most common causes of undesired brake application are fluctuations in brake pipe pressure which result from slack action, hose flexing, and quick brake **applications**[34]**.**

Braking systems on a train must be balanced so that baking forces are applied in a uniform manner throughout the train. Otherwise, certain axles on the train may overheat or skid while others remain relatively free-wheeling, and overall braking efficiency is compromised. Planned studies will investigate the causes of air brake system **unbalance**[35]**.**

Many wheel defects are caused by high residual stresses and thermal damage as a the result of heating during brake application on long downgrade portions of **track**[36]**.** Unbalanced brake rigging, as described in the previous paragraph, may concentrate thermal input on certain wheels. Because of the numerous mountain grades in the PNW

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[33]**AAR 1986-1987** Research **Report**, p **37;** and **FRA 1988** Research Program.

[34]*ibid*.

[35]**ibid.**

[36]**ibid**, AAR p. 40.

this is a germane topic for this region. Defects are characterized by the presence of cracks in the flange and the tread. Ultrasonic methods are being considered as an improvement for detection of wheels that are prone to defects.

Track and Structures

Concentrated, heavy traffic and heavier axle loads have brought new challenges to railroad track and structure engineers. BN has mounted a world-wide search for new technologies that will have longer lives and decrease service interruption for maintenance and replacement operations[37], and several other railroads are experimenting with new track technology[38]. For BN, a new direction that has come out of its technology search is the installation of unprecedented numbers of concrete cross-ties in curves on high-density main lines. Some of the early installations were made in the Cascade mountains, just east of Seattle. A topic summary that is related to track maintenance concerns is found in Appendix A, Item 10.

Turnouts or switches are another area of change: BN is installing prefabricated switches with concrete cross ties, and both AAR and BN are considering changes in switch geometry that will reduce forces and permit higher running speeds[39]. Switch frogs, which are devices allowing railroad wheels to cross the rails of an intersecting track, have traditionally been high maintenance items requiring frequent replacement on high density track. Improvements have been sought for frogs by making metallurgical improvements or by providing a swing nose that eliminates the gap that usually occurs in the rail running surface at a standard frog.

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[37] W. E. Glavin, "BN Becomes Roadway Innovator," Progressive Railroading, March 1989, p. 27.

[38] G. Welty, "Track: A Material Difference," Railwav Age, March 1988, p. 31.

[39] G. Welty, "What's New in Turnouts," Railwav Age, April 1989, p. 29; AAR 1986-1987 Research Report, p. 56.

Track buckling occurs when the track develops a horizontal **"kink"** because thermally induced compressive forces in the rails exceed the lateral resistance of the track **structure**[40]. This problem is especially significant for continuous welded rail (CWR) installations in areas with wide temperature **variations,a** common situation in the PNW. If the rail was laid at a low temperature, high compressive forces will develop on hot days because CWR cannot accommodate thermal expansion. Studies have shown that the frictional resistance between the ties and ballast may be reduced due to uplift forces as the train crosses the track and the track may buckle just ahead of or under the **train**[41]. It would be desirable to develop a device that could detect excessive compressive forces in CWR while traveling on a rail mounted vehicle. This would be a difficult device to develop because most technologies for stress measurement involve comparison between the material in the stressed state and unstressed state and it is unlikely that a method could be developed to release the rail from its stressed state as part of an expedient testing method. These views are supported by Mr. Ron **Newman** of BN **R&D** (see Appendix A, Item 3) and a draft research needs statement from Transportation Research Board (TRB) Committee **A2M01,** Committee on Railroad Track Structure System Design.

Railroad bridge service life is another area of ongoing research concern. Many of the nations railroad bridges are over 50 years old and plans must be made for the orderly replacement of these important assets. In many cases the safe service life of these bridges may exceed their original design life because they were conservatively designed for steam locomotives which had higher axle loads and impact characteristics than modern diesel locomotives. However, researchers also have to consider recent trends that suggest that the average axle loads for freight cases will continue to increase. This trend will be discussed further in the next section. Typical research approaches involve

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[40]**FRA,** Recent **Developments,** p. **18.**

[41]**ibid,** p. **20.**

instrumentation of the bridges to document stress cycles while the bridge is in service followed by an estimate of the service life based on the field data and an estimate of the load history[42]. A topic summary regarding preservation and replacement of structures is formed Appendix A, Item 12.

Signals and Communications

Automatic train control systems (ATCS) are bringing significant changes to the area of signal and communications[43]. ATCS is being developed under a joint project sponsored by several railroads and coordinated by AAR. Initial testing is being conducted on the Union Pacific Railroad between North Platte and Omaha, Nebraska. The purpose of the system is to increase safety and efficiency of train operations by using the latest electronic technology for communications and train control. Under existing methods, trains are given authority to move by written messages, voice communication, signals and operating rules. Track maintenance forces receive limited protection from existing signal systems and few systems exist that will automatically stop a train that exceeds its operating authority; thus, human vigilance is required to prevent unauthorized train movements. The system has a modular design and it is expected that railroads may choose the level of complexity that will fit their needs for differing situations by purchasing only the modules that they need. A simple system may provide an enhanced communications ability for sending and acknowledging orders. A more complex system may also track the location of each train, force trains to stop before they conduct unauthorized movements, monitor wayside devices such as car defect detectors and road

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[42]D. A. Foutch, et.al., "Load Spectra for Railway Bridges Under Current Operating Conditions;" R. W. Kritzler, "Rating of Railroad Bridges by Field Load Testing;" and J. W. Fischer, et. al., "Fatigue Life Evaluation of Some Railroad Bridges with Welded Coverplates;" 6th Annual International Bridge Conference and Exhibition, Pittsburgh, PA, June 12-14,1989.

[43]AAR 1986-1987 Research Report, p. 70; Railway Age, "ATCS: An Evolving Science," June 1989, p. 55; Progressive Railroading, "The Electronic Railroad Emerges," May 1989, p. 23.

crossing signals, and pace the speed of trains to eliminate unnecessary stops and to conserve fuel.

BN, in partnership with **Rockwell** International is implementing a different train control system: the Advanced Railroad Electronics System (ARES)[44]. The ARES system is able to utilize satellite positioning to determine train locations in addition to the transponders that are used for ATCS. Research topic summaries that involve signals and communications are found in Appendix A, Items **4, 5** and **9.**

Intermodal Terminals

Intermodal traffic has become increasingly important to the railroads on a nation-wide basis and is especially important within the PNW because of prominence of its **ports**[45]. The productivity and efficiency of intermodal terminals is an important issue because of the limited availability of land in port areas and the critical role that terminals play in the movement of freight.

Although regarding **intermodal** terminals does not appear in either the **FRA** or AAR research programs, this area appears to hold some promising research opportunities. Draft research needs statements which were prepared in **1989** by **TRB** Committee **A2MO3** - Intermodal Freight Terminal Design suggest studies involving possible improvements in lift equipment design and documentation, pavement design, and development of low-cost methods for container transfer that would increase the economic viability of low volume terminals. Recent moves to develop **dockside** loading for rail **cars**[46] may create further opportunities for researchers as railroad and port authorities

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[44]G. **Welty,** "BN and ARES: 'Control' in a New Dimension," **Railway Age,** May **1988,** p. **24.**

[45]**R.** T. Sorrow, "Where, How Does Intermodal Fit In?" Modern **Railroads,** May **1989,** p. **21;** and **Progressive** Railroading, "Intermodal Gains on All Fronts," June, **1989,** p. **27.**

[46]**A.** Chancellor, "Take a Load Off at Dockside," Modern Railroads, May **1989,** p. **37-41.**

search for more efficient arrangements for intermodal transfer. Another possible project is described in a research topic summary found in Appendix A, Item **2.**

Marketing

With the advent of deregulation, railroads have placed an increased emphasis on marketing activities as they attempt to tailor their services to fit their customer's needs more closely. BN's marketing activities are an example of this **movement**[47]**,** especially the sale of certificates of **transportation**[48]**.** These certificates may be redeemed for the transportation of grain in certain rail corridors within certain time windows. They are transferrable, which means they may be bought and sold on the open market in a manner that is similar to farm commodities. This is desirable for customers because the holder is assured of having the use of grain cars at predictable times and because transfer of certificates on the open market is a familiar process to participants in the agriculture industry.

In the intermodal business, railroads are endeavoring to work in partnership with motor carriers and shipping lines to develop high-quality service. For intermodal to be successful, it is particularly important that service be transparent to the customer with regard to billing, load tracing, and damage claim **resolution**[49]**.** An example of an innovative service is BN's Expediter trains[5']. BN looks to motor **carriers** as the primary customer base for these trains and has hired people with experience in the trucking industry to manage the operation. The trains operate on schedules similar to those of passenger trains under a special labor agreement that substantially reduces costs. Several

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[47]**W.** E. Greenwood, "BN Moves Marketing to the Forefront," e Railroading, Oct. **1988,** p. **23-28.**

[48]**T.** Shedd, "Burlington Northern: Certificates of **Transportation," Modern Railroads,** June **1989,** p. **26.**

[49]**Sorrow,** R. T., "Where, How Does Intermodal Fit In?" Modern Railroads, May **1989,** p. **22.**

[50]F. K. **Plous,** "BN's Extraordinary Expediters," Railwav Aee, Nov. **1987,** p. 30-6.

other railroads have made recent improvements and changes to their **intermodal** services[51].

In an effort to increase their market share in the transportation industry, railroads are investigating the transportation of commodities that are not traditional rail commodities. Increases in urban populations and shortages of landfill space have created possible opportunities for the transportation of garbage and hazardous wastes. Improved equipment technology and possible changes in labor agreements may also open up opportunities for **construction** aggregate transportation[52].

In an effort to reduce labor costs and improve marketing effectiveness, several railroad branch lines have been sold to shortline and regional railroad operators. In many cases, the **shortline** operators have been able to increase traffic and improve service, but there have been some failures[53]. This movement has caused great concern among the railroad labor unions, because the employees and the previous labor agreements were not transferred with the property in many cases. The new operators usually work on a non-union basis or negotiate a labor agreement with liberalized work **rules** and lower wage costs. A recent court decision specifies that existing labor agreements will be transferred in all future sales. Railroads contend that because of this restriction, future sales will not be economically feasible, and therefore they intend to dispose of uneconomic branch lines by abandonment instead. However, many hope that changes in labor agreements, court decisions or legislation will improve the prospects for branchline sales or resumption of profitable branchline operation by large railroads. Topic summaries that are related to marketing are shown in **Appendix** A, Items **10** and **12.**

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[51]**G. Welty, "ATSF** Watches Its 'Q's'," Railway Aee, Feb. **1989** p. **31;** and L. **S.** Miller, **"Conrail** Intermodal: Improving a Winning **Game," Railway Age,** June **1989,** p. **34.**

[52]**J.** P. Lamb, "Rock-hauler **Extraordinaire" Trains,** August **1988,** p. **24-32.**

[53]**Railway Age, "Regional** Railroading: The Risks and Reward.' Jan. **1987,** p. **30;** and F. **Malone, "Regionals Gird f**or Next Round," Proeressive **Railroading,** p **34.**

Human Factors

The safety and efficiency of railroad operations often rely on the alertness and good judgment of railroad employees. AAR and FRA have sponsored a variety of studies on employee safety, derailment, and hazardous materials[54]. In a telephone interview, Mr. Arne Bang[55] of the Federal Railroad Administration Office of Research and Development, emphasized that there was a continuing need for research in this area. Possible topics include a comparison of the results of various strategies to eliminate substance abuse among train crews, an investigation regarding the effects of unpredictable working hours on train crew alertness, and human factors impacts involved with new-generation automatic train control systems.

SPECIFIC PROPOSALS

Initial discussions with the staff of Burlington Northern's Pacific Division of Seattle and the Research and Development Department of Overland Park, Kansas suggested that the most likely areas of mutual interest were projects involving the measurement of actual forces through instrumentation in trains and bridges, and studies involving intermodal yard planning, operation, and productivity. Burlington Northern Management indicated a strong desire to develop a proposal for possible joint funding by TransNow that would involve field instrumentation of a bridge and a prediction of its service life. To accommodate BN's and TransNow's technical and budgetary review processes, development of this proposal was started immediately at the beginning of the study period. A graduate student who had funding outside of this project, developed an interest in intermodal terminal simulation and began a study involving BN's Seattle International Gateway Intermodal Terminal. The initial contact for this study was developed through TransNow.

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[54] AAR 1986-1987 Research Report p. 73-89; and FRA 1988 Research Program.

[55] June 30, 1989.

Railroad Bridge Service Life

The service life of many railroad bridges is limited by the fatigue life of the bridge's components. Fatigue damage is caused by repeated or cyclic stresses, in other words, stresses that are applied and removed several times. Thus every time a train crosses a bridge, fatigue damage occurs. Structural analysis may be used to estimate cyclic stresses, but the results are likely to be inaccurate because it is difficult to model structural connections with complete correctness and because the effect of dynamic loads and vibrations from the movement of the train are difficult to estimate.

The objectives of the study are to use field instrumentation to provide a better estimate of the cyclic loading that a railroad bridge receives and to expand the data base of actual railroad bridge loads that other researches may draw on. Also to be investigated are differences in cyclic loading characteristics among train types and bridge members. Burlington Northern's Ballard Bridge in Seattle, Washington was selected as the test site for this project because of its critical location in the PNW railroad network, its proximity to the research institution, and because of the presence of a bridge tender's shack which provides a safe location and power source for the instrumentation. A full proposal for this project is found in Appendix B.

A preliminary study has been funded by Burlington Northern Railroad and TransNow with the purpose of computer modeling, gathering historical data, and refining strategies for instrumentation and data acquisition. It is expected that these results will facilitate the start-up of the instrumentation project. A unique effort within this preliminary study will be the development of computer load models of actual trains which will be derived from train lists obtained from BN's computer system. This will allow the researchers to rapidly model the cyclic load effects of a large number of different types of trains on different bridge members, providing a baseline for future field instrumentation studies. A full proposal for the preliminary study is provided in Appendix C.

Development of the Bridge Service Life proposal and associated preliminary research represents a considerable portion of the effort associated with this study. Mr. John Rooker, a structural engineering student within the University of Washington's Department of Civil Engineering, will develop a master's degree thesis based on the findings of the preliminary study. Completion is expected in December of 1989.

Simulation of Intermodal Terminal Operations

The objective of this study is to develop a animated computer simulation for container terminal operations. As with most simulations, it is expected that this one will aid planners as they predict the impact of changes in terminal operating procedures and physical layout. It is expected that the animated simulation will have several advantages over non-animated simulation: managers will be able to visualize the result of the simulation more easily without having to wade through large amounts of computer output; mistakes in simulation logic will be more apparent; and communication will be easier when future plans are described to people who are unfamiliar with container terminals.

The Author and Ms. Donna Hollar, a construction engineering and management graduate student in the Department of Civil Engineering, worked closely with managers at BN's Seattle International Gateway (SIG) Terminal to develop this proposal. Initial observations are the SIG yard's operations are so highly interdependent with other Seattle port facilities that it may be necessary to model the operations among several facilities in order to make accurate predictions regarding the SIG facility. Intended approach is to gain experience with the software by first modeling easily defined portions of the operations and then expand the model. Completion is expected in December 1989. A full thesis proposal is provided in Appendix D. Funding for Ms. Hollar's support was provided by the Valle Scandinavian Exchange Program and University of Washington.

CONCLUSIONS;

Areas of railroad research activity that were considered under this study may be arranged in the following broad categories:

- Equipment
  - High productivity rail cars
    - intermodal cars.
    - vehicle track interaction
  - Defect detection and mitigation
    - wheels
    - bearings
    - braking systems
  - Alternative locomotive fuels
- Track and Structures
  - Improvement for track components
  - Track buckling
  - Bridge service life and rehabilitation
  - Maintenance strategies for high density-single track lines
- Signals and Communication - New generation train control systems
  - Revised operating and dispatching strategies
  - Enhanced rail break detection
- Intermodal Terminals
  - Improvements in operations
  - Construction cost reduction
- Marketing
  - Non-traditional commodities
  - Improved coordination of service with intermodal partners
  - Regional and shortline railroads vs branchline operation
  - Freight damage

Human **Factors/Safety**

Train crew alertness

Various safety issues

Many of the topic summaries **(Appendix** A) that were developed in cooperation with the BN **R&D** Department reflect issues that are of general concern throughout the railroad industry; however, many reflect **BN's** special needs that result from the geography, climate and traffic mix of the area that BN serves. For example:

-- shelled wheels (Appendix A, Item 1) are more likely to be found on trains that traverse mountainous regions in cold weather. BN has heavy freight traffic that runs over mountain passes in the winter.

-- conflicts between track maintenance and operations (Appendix A, Item 10) occur most often on high-density, single-track lines which are prevalent on BN. Improved train control techniques (Items 4 and 9) would be most helpful on such lines.

-- Intermodal terminal activities (Appendix A, Item 2) are concentrated in locations near major ports such as Seattle, Tacoma, and Portland.

In pointing out possible topics, BN managers attempted to avoid topics that are being fully researched by other organizations. No evidence of substantial research efforts was found in the open literature for the following topics from Appendix A:

2. Load Planning for intermodal terminals.
10. Cost and Benefits of on-time service
11. Freight Damage Studies

Conclusions were made regarding which research topics provide the best match between BN and **TransNow.** In making these conclusions the following items were considered:

The research focus of TransNow

Transportation Operations Management

Transportation Planning

Special attributes of TransNow

Interdisciplinary mandate

Resources available from seven universities

Location in the PNW

BN's research needs as explained in **Appendix** A and the section on specific projects.

The existence of research programs that are performing similar studies.

The following topic areas represent a close match between BN and TransNow research interests:

1. **Intermodal** terminal oaeration and **planning**. TransNow member universities are located near the major container ports of Seattle, Tacoma and Portland; and extensive research activity was not found in the open literature. Possible subtopics include:
   - Formulation of strategies to improve coordination between port facilities
   - Comparison of the efficiency of **dockside** loading to rail cars to rail terminal loading
   - Development of methods to control axle loads on container trains by modifying the information exchange and loading process.
2. **Operations Planning and Track Maintenance.** This project would include the development of alternative strategies for planning train operations and maintenance activities. It should be noted that railroad operation and maintenance are closely related in the PNW, because high density traffic is often confined to a single track in an area where few convenient detour routes exist. The study should be interdisciplinary and consider cost **trade-**

offs between maintenance costs and traffic revenue, the possible development of innovative maintenance methods and train dispatching strategies. The study should be coordinated with current railroad efforts to develop improved methods for maintenance scheduling.

3. **Bridge Service Life.** While this topic does not focus on operations, it has received strong support from BN, especially from the Pacific Division Office in Seattle. This support is evidenced by the commitment of matching funds. It is possible that a follow on study could be developed that would focus on operational and construction strategies during bridge rehabilitation or the development of new operational strategies that would mitigate fatigue damage.

The operational and planning aspects of other topics that were discussed in this report could be investigated:

-- Strategies for reducing freight damage

-- **Rail/Highway** crossing elimination (Consider impacts on both highway and rail operations)

-- Changes in crew scheduling policy.

To keep abreast of changing railroad research needs, a file of publications and a list of points of contact should be maintained (Appendix E). Publications include trade magazines, industry guide books, research program summaries and lists of suggested research topics. Points of contact include research personnel with Association of American Railroads, The Federal Railroad Administration, The Transportation Research Board and major railroads that serve the PNW.

Discussion Concerning **Implementation**

Research findings will be implemented in a variety of ways. The Author will meet with representatives of **BN's R&D** Department to present the results of the Railroad Research Needs study and discuss the possibility of developing specific proposals for future funding. For the benefit of **TransNow** researches, the Author will continue to act as a liaison between the **TransNow** and the railroads. Photocopies of journal articles that were referenced by this report will be retained and the file of suggested publications (see list in Appendix E) will be maintained. Reports will be made available to interested parties within AAR, FRA, TRB, state transportation planning agencies, railroad and railroad suppliers.

Graduate students are preparing theses which will describe the results of specific railroad research projects regarding bridge service life and intermodal terminals; articles will also be submitted to appropriate archival journals. These projects are being developed with close cooperation from BN personnel, therefore the technology transfer will occur throughout the studies.

Burlington Northern Railroad and University of Washington have committed **$75,000** in cash and **$30,000** of in-kind contributions to cover the local share of the Bridge Service Life Project described in **Appendix** B.

APPENDIX A

TOPIC SUMMARIES

TOPIC SUMMARIES

These topic summaries were developed in cooperation with Burlington Northern's Research and Development Department. These summaries indicate areas of interest for BN; they have been developed only to provide information to researchers and there is no commitment by BN to do work in these areas. In some cases, BN has parallel or equivalent work in progress that involves some of the topic areas. The main text of each topic was developed after telephone and personal interviews with BN's R&D Managers. These topics were circulated among the R&D managers who made comments on behalf of potential research end users within the company. The items marked "additional comments" were paraphrased from the hand written notes that were placed in the margins of the topic summaries.

1. Wheel Defect Detection [Shelled Wheels]

The "shelled wheel", is a costly defect that is frequently found during routine car inspections, long before it poses a safety hazard. However, many defects are found and a costly wheel replacement is required for each one. The defect is characterized by cracks in the area of the tread and it has been suggested that it may be caused by uneven heating that occurs in cold weather during braking on long downgrades. The problem may be aggravated if inappropriate braking ratios cause an unbalance of braking forces within a train. There is a need to find the defect's root causes and to develop a method for cost mitigation.

Additional comments:

1. Wheels can shell within six months time, with as little as 60,000 accumulated miles. The railroads need to determine the cause and origin of this problem.
2. Existing railroad research centers, such as those administered by AAR, have better resources for investigating these problems.

2. Load Planning for Intermodal Terminals

A system to plan the loading of container trains is needed to increase intermodal terminal efficiency and prevent container equipment overloads. Load planning is difficult because containers do not come off a ship in the correct order for loading on a train. Containers must be segregated by rail destination, oversized boxes specially placed and heavy loads dispersed. Also, equipment movement and container handling should be minimized. Furthermore, container weight may not be accurately recorded. This makes it impossible to load the train properly so that the axels are not overloaded and exposes the railorad to fines when subcontracting motor carriers that move containers between the port and rail terminal which exceed to highway overload fines while the container is being transferred between the port and rail terminal.

It would be desirable to develop a system that would expedite the transfer of containers from ship to train. This system would include a combination of container handling equipment, computer hardware, software and communication links that would assist employees with load planning and the operations direction. To develop a near-optional load plan, the system would use information such as the ship's manifest (a list of container weights and destinations), the location of the rail cars for each destination in the yard, and a series of rules to develop a near-optimal load plan. It would also be desirable to develop equipment that could confirm the weight of the container before it leaves the port.

Additional comments:

1. This is a good topic for TransNow because of locations near ports. Researchers should consider highway loads, flow through terminal, data handling, capacity, etc.

3. **Track Buckling Prevention**

Rail can develop high compressive forces when thermal expansion is not possible due to the rail's confinement in the trackbed. Hot weather and the use of concentrated locomotive braking may exacerbate the situation. If the trackbed is unable to restrain the rail, a "Sun Kink" may develop as the rails buckle laterally; a derailment may follow. It would be desirable to develop techniques to detect excessive compressive rail forces from a moving vehicle. Areas that are subject to excessive forces could then be located so that maintenance crews could to make necessary adjustments.

Additional comments:

1. This type of work is being done elsewhere (AAR, TTC, BN)

4. **Computer Aided Dispatching**

Railroad dispatching is a challenging task. However, new technologies are available that will provide assistance for this activity. New train control systems will allow dispatchers to know the positions of all trains and send instructions without the use of trackside signals. This will allow trains to travel at shorter headways and meet ech other with on a single track with more flexibility. Trains may operate in unsignaled territory with more efficiency than trains now operate in fully signaled territory under existing technology. This system is known as ***ARES*** (Advanced Railroad Electronics System) within Burlington Northern and ATCS (Advanced Train Control System) within the Association of American Railroads. Further improvement may be realized by developing expert systems and new standard procedures that could aid dispatchers. (See Item 9 for more information on expert systems.)

Additional comments:

1. ARES and Rockwell are working on this, but TransNow could possibly provide additional assistance.

5. **Broken Rail Detection**

Existing signal systems serve two purposes; one is to prevent conflicting train movements, the other to detect broken rails. It would be desirable to develop an alternative method for rail break detection when the ARES train control system is implemented so that existing signals could be removed. (See Item 4 for more information on ARES). The existing signal system could be maintained for rail break protection only, but many of the benefits of the ARES system would not be realized because existing block lengths are too long to allow short headway operation. The ideal system could be installed with rail that does not have special connections (for ensuring electrical continuity) and it would still operate properly despite the presence of road crossing signals or trains.

Additional comments:

1. Rail integrity is and will be important. Researchers should consider development of extended length track circuits (5-10 miles in length), on board train devices to check rail ahead of the train or after the train has passed.
2. This work is already underway by BN.

6. Alternative Energy Sources for Locomotives

Consideration may be given to the development of alternative energy sources for locomotives. Diesel fuel may be replaced by natural gas or methanol for internal combustion engines. A process may be developed to utilize coal for internal combustion or modern steam locomotives. In the past technologies have been developed that use coal powder or coal slurries. However, it would be most desirable to use coal in the form delivered to power plants - crushed to a one inch maximum size.

Additional comments:

1. This is a low priority topic because BN has done much work on this in the past; future needs for this type of research depends on the price of fuel.

7. **Diesel Emissions Control**

More efficient diesel emissions control may be developed with research. It may be possible to develop a system that could be retrofitted in existing locomotives.

Additional comments:

1. This is a hot topic in California and on BN.

8. **Roller Bearing Failures**

More information is needed so that better detection, prevention, and life extension technologies may be developed. This problem might be studied by placing strain gages, thermocouples and other instrumentation near a wheel bearing in a moving train. By examining the results of the instrumentation, further information may be obtained concerning possible causes of failure.

Additional comments:

1. Impact forces that occur during coal loading operations cause the roller bearing to dent the metal surfaces that they roll against. An instrumentation study might be used to investigate this possibility.
2. Test labs such as **AAR's** facility would be the best place to do this.

9. **Expert Systems Applications**

Expert systems are computer based decision making aids. Applications are found in just about every field of engineering and management. While expert systems cannot replace the human decision maker, they can take the drudgery out of complex decision making and allow people to expend more effort in consideration of overall strategies. Expert systems may help to preserve part of the knowledge base that a company normally looses when experienced employees retire. An expert system might streamline a decision that must be made in accordance with company policy by making suggestions that would be reviewed by the decision maker before implementation. Applications may exist in the areas of dispatching (Item 4), crew scheduling, maintenance planning, container loading and train blocking. Other applications may exist in addition to the ones listed.

Additional comments:

1. This might be a good topic for **TransNow.** It has been difficult to develop expert systems for such areas as derailment investigation, track, etc. This might be a good topic for an application involving fatigue damage in a railroad context.

10. Cost and Benefits of On-Time Service

It would be desirable to have more quantitative information regarding the costs and benefits associated with various levels of service quality. How much market share could be gained if on time performance were improved or transit time reduced? How much for prompt delivery or better rolling stock? In light of this, how should track maintenance be managed? When should train operations be given priority over maintenance activities and vice versa? These and other questions might fall under a topic that could be studied by an interdisciplinary group involving experts in marketing, cost analysis, maintenance operations, and train operations.

Additional comments:

1. This is a **Very** Good **Topic.** Railroads may find ways to generate new traffic and the study may provide justifications for providing good service.

11. **Freight** Damaee Studies

It would be desirable to determine the effect that equipment **types** and train handling techniques have on freight damage. Comparisons could be made between the use of various braking systems, articulated double stack cars and standard intermodal cars, as well as various track conditions and alignments. Comparisons could also be made among rail, water and highway transit.

Additional comments:

1. Good topic-- BN suffers large losses in this area, therefore, any reduction is a benefit. Collect data on the basis of percentage of goods delivered.

12. Preservation and Replacement of Assets

The railroad relies on many older structures for proper operation of its network. Because of intense competition in the transportation field, capital expenditures for these assets must be thoughtfully made. Better methods are needed to inspect, preserve, repair and replace this inventory of older assets. In particular, methods that can predict optimum times for inspection, maintenance and replacement of these assets would be helpful in reducing costs and planning for capital expenditures.

Additional comments:

1. This would be a good topic.

Additional **Topic: Rail/Highway crossing elimination.** This project should include a review of standards and policy for funding the elimination of **rail/highway** crossing. The following items should be considered: Accidents rates, public exposure, cost, and obligations regarding bridge maintenance after construction.

APPENDIX B

THE SERVICE LIFE OF RAILROAD BRIDGES

SPECIFIC PROPOSAL

THE SERVICE LIFE OF RAILROAD BRIDGES

RESEARCH PROPOSAL

BY CHARLES T. JAHREN

UNIVERSITY OF WASHINGTON

SUBMITTED TO

BURLINGTON NORTHERN RAILROAD

AND

TransNow

NORTHWEST REGIONAL TRANSPORTATION CENTER

ABSTRACT

Problem: The Burlington Northern Railroad relies on the continued performance of bridges at critical points on the system. Many of these bridges are more than 60 years old. Because of the age of these bridges, plans must be made for the repair and replacement. An accurate prediction of the service life is important for the planning of capital expenditures. Also, early detection of fatigue problems is desirable, because repair may be made at a lower cost if severe damage is prevented. However, a generally-accepted methodology does not exist for the determination of fatigue life of older railroad bridges. Also, little is known concerning load histories, typical stress ranges and dynamic (impact) loadings.

Research Approach: A method for the determination of the service life of railroad bridges will be developed and applied to Burlington Northern's Ballard Lift Span. Typical stress ranges will be determined by static and dynamic readings of strain gage instrumentation on the bridge. Historical studies will be undertaken to estimate the past load history and material properties of the bridge. A survey will be made of existing service life prediction methodologies and a determination will be made of their applicability to railroad bridges. After the method is developed, the traffic load and material property data will be used to predict the service life of the bridge. Suggestions will be made as to how the results of this project may be applied to future service life studies.

Benefits: A method for predicting service life will be developed that may be used as the basis for future projects. Knowledge will be gained concerning the location of critical members with regard to fatigue. Insight will be gained concerning the timing and cost of repairs and replacement of bridges. Information concerning dynamic (impact) load effects and stress ranges during normal traffic may be used to develop service life criteria for other bridges.

INTRODUCTION

The service life of bridges is a point of concern for the safe and efficient operation of a railroad. In the United States, many important railroad bridges have reached the age of 60 to 100 years. The cost of replacing these structures is substantial. Therefore, it is undesirable to require the unnecessary or premature replacement of a bridge. Also, when replacement is necessary, careful financial planning must be undertaken in order to fund the project. However, because of potential problems with regard to safety and disruption of service it is critical that the service life of a bridge not be over-estimated. Predictions of the safe service lives are not easily developed, thus it difficult to make plans for bridge replacement.

The service life of many bridges is limited by the components' fatigue lives. Fatigue damage is caused by repeated or cyclic stresses, in other words, stresses that are applied and removed several times. Thus every time a train crosses a bridge, fatigue damage occurs. The level of cyclic stress that causes fatigue damage is much lower than the level of stress that will cause damage as a result of one application.

The rate of fatigue damage accumulation depends on the live load stress range, the dead load stress, the number of repetitions and the material properties. The live load stress range is the difference between the peak stress and the lowest stress that a component experiences as the train moves across the bridge. The stress range has the largest impact on the service life of a component. The dead load stress is the amount of stress that a component experiences when there is no traffic on the bridge. A relatively high dead load stress in tension may reduce the service life of a component in certain instances. The number of repetitions that a component experiences is dependent on its location within the bridge, the load sequence and the length of track that contributes to the components loading (tributary length of track). A component that supports a short tributary length of track will experience a stress cycle as every axle crosses the bridge. A component with a very long tributary length may only experience one cycle per train rather than one cycle per axle. This is because several axles are contributing to the stress, thus as axles roll on and off the bridge the addition and subtraction of one axle has a small impact on the stress range.

The constant amplitude fatigue life of common bridge materials is well known due to a history of extensive testing. S-N curves have been produced that indicate the fatigue life in number of cycles versus the constant amplitude stress range. However, bridge components experience variable amplitude stress rather than constant amplitude stress. Thus, a method is needed to determine what constant amplitude stress range and number of stress cycles are equivalent to a sequence of variable amplitude stress cycles. Several possible methods exist (Bright **1977)** and further discussion on this topic will occur later in this proposal.

Information for estimating the past fatigue damage for typical railroad bridge is difficult to obtain. Load history information is sparse. Most records concerning rail traffic were collected for accounting and marketing purposes, not engineering estimates. Therefore, they are of limited value, if they exist at all. Records that are available indicate a trend toward higher axle loads. Structural analysis may be used to estimate the magnitude of stress cycles. However, it is difficult to devise an accurate structural model because it is hard to model connections correctly and unintended stiffness may be introduced by bridge floor and deck components that is hard to evaluate. Therefore, the actual stresses may be quite different from stresses obtained from structural models.

One object of the proposed study is to use instrumentation to provide a better estimate of the actual stress ranges and number of cycles that a railroad bridge experiences under normal traffic. It is expected that the instrumentation data will enhance the usefulness of available historical data and provide an improved estimate of the service life. Furthermore, it is hoped that the methodology and the data may be applied to future projects so that improved service life estimates may be made for other railroad bridges.

Burlington Northern's **Ballard** Bridge in Seattle, Washington has been selected as the test site for this project (see Figure 1**)**. It is a riveted steel truss bridge with built up members and a bascule draw span that was built in **1910.** This bridge was chosen because of its critical location on the Pacific Northwest railroad network, its proximity to the research institution, and because of the presence of a bridge tender's shack which provides a safe location for the instrumentation that is needed for long term monitoring. Except for the draw span arrangement, the bridge is typical of many railroad steel truss bridges. Although the presence of the draw span will require some special treatment of the data, it is expected that many of the

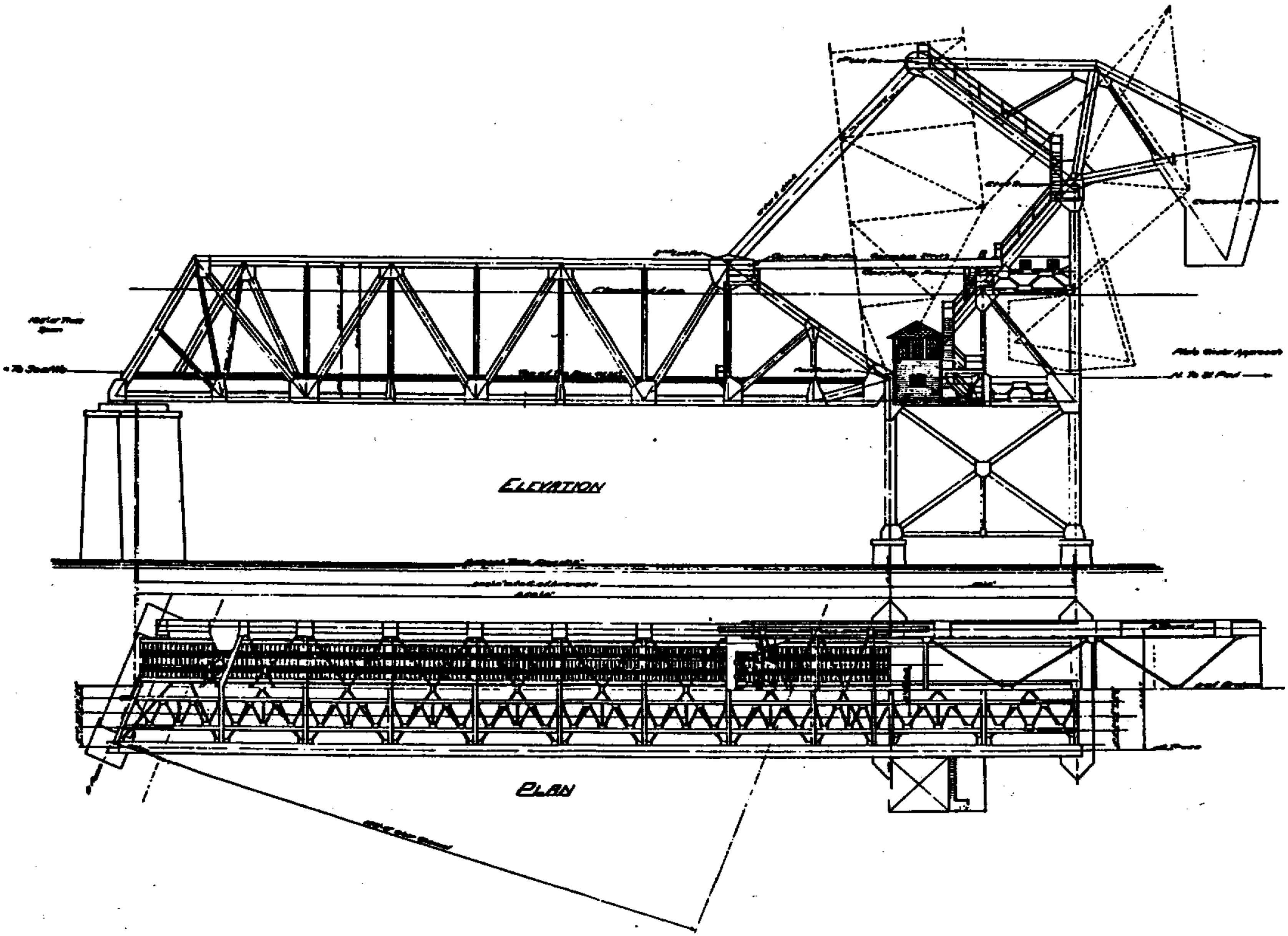


Figure 1 - Plan and Elevation of the Ballard Bridge

results may be applied to other structures. This is especially true of findings regarding traffic loads.

METHODOLOGY

The project will commence with historical studies to determine the traffic history and type of materials used for the Ballard Bridge. Also, structural analysis will be conducted to determine the location of measurement points for the instrumentation. After the instrumentation is in place, static load tests will be conducted using a test train with known loads. This will provide calibration for the instrumentation and insight as to which measurement locations receive the most fatigue activity. Next, dynamic readings will be taken using the test train. These measurements may be compared with the static measurements to confirm the amount of fatigue activity and to determine the amount of impact loading that occurs. Subsequently, samples of the fatigue activity that occurs during six months of normal traffic will be collected. The contributions of various types of traffic to the fatigue damage of the bridge will be estimated by comparing the records of movement of different types of trains with data obtained at the bridge.

An investigation will be conducted to identify methods available for estimating the fatigue life by using the data obtained from the instrumentation. In particular, a method for estimating the service life of highway bridges will be considered (Moses, et. al. 1987). If this method is chosen, appropriate modifications will be made before application to this project. An estimate of the past load history will be developed using available historical data which will have been enhanced by knowledge gained from the behavior of the bridge under existing traffic. Based on this information, an estimate of the service life of the bridge will be made.

The results of this project will be presented in a format that will be most helpful to investigators that are conducting similar projects. It seems likely the fatigue life is influenced by variations in the gross tonnage carried by the bridge, the traffic mix and the tributary length of trackage that supplies load to the component. In so far as possible, field instrumentation data will be matched with the characteristics of the train that caused the activity. These characteristics may include the type of train, type and number of locomotives, gross tonnage, number of loaded and empty cars, and train length. This information may be the basis for improved criteria concerning the service life of railroad bridges.

DETAILED METHODOLOGY

Historical study of Traffic Patterns

An investigation will be conducted concerning past traffic patterns for the Ballard Bridge. It is desired to obtain information that will allow an estimate of the number, weight and spacing of axle loads. It is expected that an estimate must rely on samples of information obtained for representative time periods during the bridge's history. Possible sources of information include dispatcher's train sheets and train lists that may exist in company records, museums or private collections. Interviews with retired railroad workers may be helpful in determining the general nature of past traffic patterns. BN's computer data base will be accessed to gain available information on recent traffic patterns.

Dispatchers train sheets give information for each train movement including a count of loaded and empty cars, locomotive numbers and gross tonnage. Old train lists would be helpful because the car number could be compared against the Official Equipment Register to determine details of the rolling stock of a sample train. Outdated copies of the Official Equipment Register and dimensions and weights of retired locomotives exist in various museums and private collections. Any information that exists on the train lists concerning the gross weight of each car would be helpful. An investigation will also be conducted concerning records that document the operation of the draw span.

Historical Study of Bridge Materials

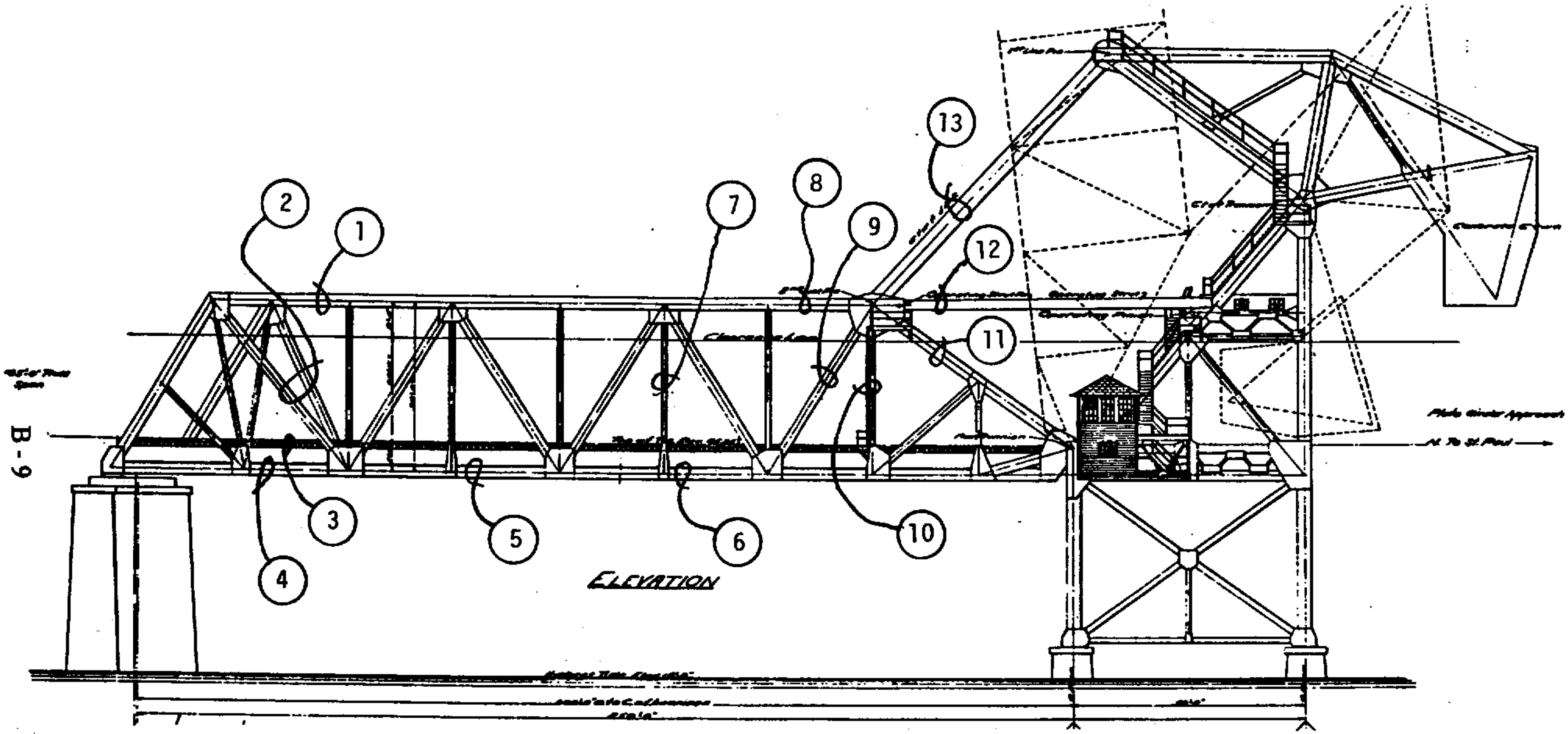
An investigation will be conducted regarding the materials in the bridge. Possible sources of information include the original contract for construction of the bridge and review of the literature concerning similar bridges.

Structural Analysis and Inspection

A structural analysis of the bridge will be conducted to identify areas of most intense fatigue activity. This analysis will be used as a basis for locating measurement points for instrumentation. The analysis will make use of the SAP 90 program to produce a three dimensional linear-elastic model. The analysis will be repeated using the assumption that the joints are pinned and fixed. The effect of the draw span motion will also be investigated.

The bridge will be inspected to locate areas of fatigue distress. During the inspections the bridge will be examined for evidence of cracking and distortion near the joints. The location of welded and damaged areas will also be noted.

Measurement points will be located in areas of maximum fatigue activity and on members that have varying tributary length of track (See Figure 2). Measurement points will also be arranged so that the results may be validated by providing static equilibrium checks. Conversations with BN bridge engineers indicate that fatigue problems occur most frequently in floor systems and hangers. Therefore, a set of floor beams and a hanger were selected for measurement (Numbers 3 and 7 in Figure 2). A preliminary two-dimensional structural analysis was conducted on the moving leaf before the submission of this proposal. Based on this analysis, members 2, 4, 5, 6 and 8 in Figure 2 have been selected for stress measurement because they exhibited the highest tensile stress ranges. Other members to provide a static equilibrium check for other instruments. Up to six measurement points may be required for each member in order to detect uneven



NOTE: **Gages will be installed on members on both sides of the Truss**
Assume three to six gages are required per member
At position #3, gages will be placed 'on all four stringers
Total Requirement: 120 gages

Figure 2 Strain Gage locations

stress distribution due to unintended bending stresses and non-uniform response of individual elements of built-up members.

Up to 30 additional gages may be required to acquire additional information near joints, welds and areas of restraint and distortion. Identification of these areas is important because they have been shown to be the source of many primary fatigue cracks in riveted bridges. (Fisher, **et. al. 1987,** Kulac, **et. al. 1987).** The location of these gages will be determined after further structural analysis and inspection. Also, the location of gages shown in Figure 2 may be shifted in response to further structural analysis findings.

Calibration Procedure

Data gathering will be initiated by testing the response of the bridge to a test train with a known load. This procedure will allow comparisons with previous calculations and give information as to how loads are carried by the bridge. The train will be stopped at intervals along the bridge and measurements will be taken. Stresses at various draw span positions will also be noted. The data will allow investigators to plot the stress cycles that result from a train's movement.

Next, dynamic measurement will be taken as the test train moves across the bridge at various speeds. Dynamic measurements will also be taken during draw span operation. These dynamic measurements will be compared with static measurements to determine the affect of impact and vibrations on fatigue activity. Prior to taking dynamic measurements the results of the static measurements will be reviewed to determine if it is necessary to take measurements from all the gages. Certain gages may be eliminated from the measurement list because of lack of activity or because their measurements are strongly correlated to measurements obtained from other gages.

Long Term Dynamic Measurements

Dynamic measurements will be taken from a representative sample of normal train traffic and draw span movement for a period six months. The data may be recorded in digital or analog form. If the data is recorded in digital form, the demand for data storage will be extremely high. The volume of data will depend on the number of strain gages monitored, the frequency of readings, and the length of time required for a train to cross the bridge. Preliminary estimates indicate that each train movement may produce enough data to fill a computer hard disk. In consideration of these data storage and processing requirements, it is expected that a sample of 50 to 100 trains may be obtained. It is expected that the capabilities for storing and processing the data will be improved during this project. These improvements, along with insight gained by examining other data, may allow the data storage requirement to be reduced. In this case, the number of sampled train movements will be increased.

Analog recording will result in more compact storage and may allow an increase in the number of trains sampled. The advantages and disadvantages of analog recording are discussed in the next section.

The date and time of each train movement will be recorded with the data. These times will be compared with reports of train activity supplied by BN's Transportation Department for identification of train type. This will allow investigators to correlate the fatigue data with the type of train. Important train characteristics may be determined by knowing the train number, train length, number of loaded and empty cars, and gross tonnage. This data is easily drawn from BN's data base. Additional information such as locomotive numbers and the gross weight of each car may be obtained by examining the train list from the data base. If necessary, the length, type and empty weight of each car may be obtained from a computer data base version of the Official Equipment Register known as the Umlar File.

Instrumentation and Data Acquisition

The Ballard Bridge will be a difficult environment for instrumentation and data acquisition. However, products and techniques are available to overcome these problems. Problems include application of strain gages, protection of strain gages from moisture and mechanical damage, and interpretation and protection of weak voltage signals.

Electric resistance strain gages will be the primary transducers at measurement points. Many of these gages must be installed and serviced on structural members that will be difficult to reach. Also, investigators must arrange their activities so that they may leave quickly when the bridge must be drawn. Burlington Northern will assist the investigators in reaching inaccessible measurement points, preferably by providing a rail-mounted lift truck during the installation phase or when needed for servicing. Alternatively, scaffolding may be provided.

The Department of Civil Engineering has data acquisition equipment that is appropriate for taking static measurements. However, additional equipment purchases are required before dynamic measurements may be taken. It will be necessary to sample each strain gage at 1000 times a second so that the peak strain of each cycle is recorded. Also, it will be desirable to sample 15 to 30 strain gages simultaneously so that data may be compared between measurement points. The system should be capable of storing the data that is generated during five minutes of activity. Signal conditioning will be necessary to cope with the low strain gage outputs and large amount of electrical interference that is expected.

One possible approach would be to monitor the strain gages using signal conditioning and excitation modules that are connected at the test site to a personal computer. The data would be converted to a digital format and streamed to a hard disk. It could be later be transferred to magnetic tape for permanent storage. An example of this system is illustrated in the block diagram in Figure 3. A cost

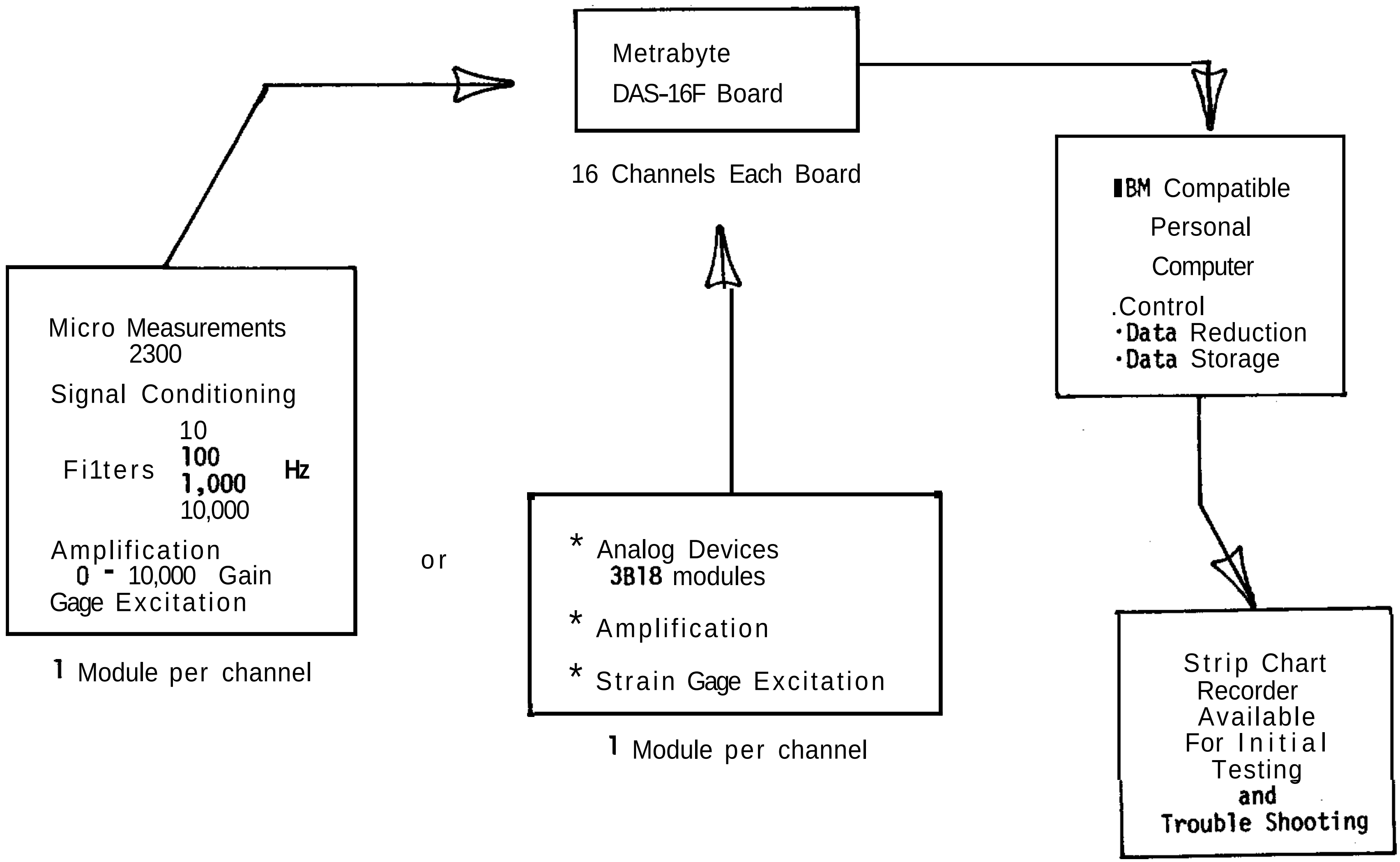


Figure 3 Block Diagram
of Instrumentation

Table 1 Cost of Proposed Data Acquisition System

Equipment Budget	Qty	Unit Cost	Extension
Computer			
Personal Computers	2	3,000	6,000
			0
Subtotal			6,000
Data Acquisition System			
Metrabyte DAS 16F Analog Interface Board	2	1,115	2,230
STA 16 Screw Termination Panel	2	150	300
Cables	2	25	50
Analog Devices 3B18 Strain Gage Module	32	185	5,920
Four Channel Baseboard	8	155	1,240
Power Supply	8	110	880
			0
			0
Subtotal			10,620
Micro Measurements Signal Cond.			
2311 Signal Conditioning Amplifier	10	1,575	15,750
2350 Rack Adapter	1	495	495
			0
			0
Subtotal			16,245
Software			
Metrabyte STREAMER	1	250	250
Labtech Notebook	1	995	995
ASYST W/ Modules 1,2,3	1	2,095	2,095
			0
Subtotal			3,340
TOTAL w/o tax			36,205
Tax and shipping (say 10%)			3,621
EQUIPMENT TOTAL			39,826

estimate is provided in Table 1. It should be noted that components from different manufacturers that provide the same function may be substituted to provide better performance or better compatibility with existing equipment.

Alternatively, unfiltered data could be recorded on magnetic tape in analog format. The data from this tape may be filtered and digitized in the laboratory. The advantage of analog recording is that the unfiltered data is preserved - thus the preserved data is closer to its raw form. Also, mass storage of analog data is easier. The disadvantages are that analog data must ultimately be digitized before computer manipulation. Therefore, an extra step is required in the data reduction process. Also, there is considerable expense in providing analog recording equipment. However, future equipment purchases for other Civil Engineering Department projects might be coordinated so that analog recording may be provided for the same cost.

During field tests, the data acquisition system will be housed in the bridge tender's shack, where light, heat, weather protection and 110 volt AC power is available. A railroad employee is at this location 24 hours a day, 365 days per year. All instrumentation will be removed from the bridge when the project is complete.

Consideration will be given to the provision of backup and auxiliary instrumentation and measurements. During a six month installation in field conditions, a mortality rate of 50% or more is not uncommon for strain gages. Because temperature may affect strain gage readings, at least two temperature sensors will be provided. If wind speed is likely to influence the results, provisions will be made for detecting and recording wind speed. Consideration will be given to the use of optical surveying techniques to measure midspan deflections during static calibration tests and the use of scratch gages to verify the results of dynamic tests.

Estimate of Fatigue Damage from Dynamic Data

The service life of materials with regard to constant-amplitude cyclic loading is well documented. However, less is known with regard to variable amplitude loading. Unfortunately, railroad bridge's undergo variable amplitude loading. A common approach is to relate a variable amplitude stress spectrum to an equivalent number of cycles and stress range of constant amplitude stress. The service life of the material is then estimated according to this equivalent situation. Several procedures are available for performing this task but none can claim the complete confidence of the research community (Bright, 1977). Under this project, a review will be conducted and an appropriate method will be chosen.

Fatigue damage occurs every time a train crosses the bridge or the draw span moves. The amount of damage may be estimated by knowing the equivalent stress range and number of cycles that may be attributed to the dynamic data. The fatigue damage caused by past traffic may be estimated by comparing the axle loads and spacing of past trains with present trains and modifying the results of the dynamic field data accordingly. The characteristics of past traffic will be researched as part of this project.

Estimate of Remaining Service Life

The service life of the structure ends when it reaches the end of its capacity to safely accept fatigue damage. It will be possible to estimate the total amount of fatigue damage by correlating the dynamic field data with the historical knowledge of traffic patterns. By making projection about the nature of future traffic, it is possible to predict the rate of damage accumulation and thus estimate the remaining safe life of the bridge. Past research and case studies are available that provide information about the service life and failure modes of riveted structures (Fisher, et al, 1987; Kulak, et. al, 1987, Fisher, 1984).

In making service life predictions, there are several sources of uncertainty. The service life of materials under cyclic loading is quite variable. The published limits for material service life are usually conservative, but it is possible to have an occasional failure before this limit is reached. The method used to determine the equivalent constant amplitude stress range and number of cycles from a variable amplitude stress spectrum is also a source of uncertainty. Studies have shown that these methods produce results that are subject to considerable variation. However, these methods are still used because a better one has not been discovered. Further uncertainty develops when the results of field instrumentation are reduced and interpreted. Also, there will be considerable uncertainty about the assumptions made from the historical data. These uncertainties must be accounted for in a systematic manner.

Statistical methods such as those described by Moses, **et al.** (1987) are examples of tools that might be used to account for uncertainty involved in prediction for this project. Under these methods a mean **service** life is estimated for the bridge. This is a service life that has a ***50%*** chance of being attained. This also implies a ***50%*** chance of premature failure. For most engineering predictions, a ***50%*** percent chance of premature failure is not acceptable. The chance of premature failure that is tolerated for service life calculations is likely to be higher than those for calculations involving the ultimate collapse of the structure. If the service life ends prematurely, it is expected that structural inspections will detect the presence of cracks, long before the structure collapse. Therefore, the consequence of a premature end to service life is more likely to be unexpected traffic restrictions, bridge closures and capital outlays rather than the complete destruction of a structure with possible loss of life. Thus, the consequences of overestimating the service life are less severe than those for overestimating ultimate strength. For example, it was proposed that the service life of a highway bridge be estimated with a ***95%*** probability or confidence level that the service life will be exceeded (Moses, et. al 1987). This 95% confidence level life is used to choose the safe service life. An appropriate confidence level for the Ballard Bridge will be proposed as part of this study.

The procedure for estimating a safe service life begins by assigning a mean and standard deviation to each item that carries uncertainty. The mean represents the central tendency for the item and the standard deviation represents dispersion which is an indication of uncertainty. This information may be mathematically combined to provide a mean result and standard deviation for the service life prediction. Statistical methods may then be used to determine an appropriate difference between the mean and safe service life.

Preliminary Study:

A preliminary study has been funded by Burlington Northern Railroad and TransNow. Its purpose is to complete the three dimensional computer modeling, gather historical data, and to refine the instrumentation and data acquisition strategy. It is expected that the results will facilitate the start up of the proposed project.

APPLICABILITY OF FINDINGS TO FUTURE PROJECTS

The results of this project are expected to be helpful to future researchers in several ways. The instrumentation plan and computer software may be applied to future projects that have similar objectives. The dynamic data will be linked with the train movement that caused it. Future studies may be undertaken to determine what influence the type of train and the tributary length of track has on the accumulation of fatigue damage. Ultimately, it may be possible to determine the service life of a member by knowing the gross tonnage of each type of traffic, the tributary length of track, the relationship between the load on the bridge and the stress in the member, and the material properties of the member. However, it may be necessary to combine data from several projects similar to this one, before it is possible to use such a procedure with confidence.

The bridge will be carefully calibrated to determine the stress response to applied loads. Therefore, by examining the dynamic data, researchers may be able to determine the frequency distribution of axle loads and detect the presence of overweight cars. The existence of overweight cars is an area of concern for bridge and track maintenance.

SUMMARY

Accurate estimates of the service life of railroad bridges are desirable because of the advanced age, high cost or replacement, and critical location on many structures. Service life is frequently controlled by accumulated fatigue damage from cyclic loading caused by train movements. Under this project a method for fatigue life determination will be demonstrated on the Burlington Northern's Ballard Bridge in Seattle, Washington. Significant activities in the project include collection of historical data on past traffic, identification of materials used in the bridge, instrumentation to determine the nature of cyclic loading under today's traffic, and a prediction of the bridge's service life based on the previous findings. The method used to determine the service life will be developed after a literature review that will identify existing methods that may be used with appropriate modifications. The findings will be presented in a manner that will be useful to future researchers who are conducting similar service life studies or developing criteria for the service life rating of railroad bridges.

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APPENDIX C

PRELIMINARY COMPUTER MODELING

FOR

RAILROAD BRIDGE SERVICE LIFE PROJECT

SPECIFIC PROPOSAL

REQUEST FOR ADDITIONAL FUNDING

RAILROAD RESEARCH NEEDS

SUBMITTED TO TransNow

INTRODUCTION:

This request for additional funding will cover preliminary computer modeling that will facilitate the start up of the Railroad Bridge Service Life Project which will be proposed to TransNow for inclusion in the 1989 and 1990 programs. The source of additional funds will be $5,000 from Burlington Northern and $5,000 which will be transferred from other TransNow projects that have been reduced in scope.

An exploratory study is being conducted under TransNow to identify railroad research needs and develop specific proposals for future funding. Burlington Northern Railroad has indicated that the estimation of railroad bridge service life is a high priority topic and will pledge $60,000 as the local match for a proposed 24 month TransNow research project. The Ballard Bridge in Seattle, Washington has been chosen as the test facility for the methodology that will be developed as part of the service life project.

Structural analysis will play a vital role in developing a methodology for estimating the service life. More specifically, a computer model will be necessary in the preliminary stages of this investigation. Field instrumentation results will be compared to the theoretical baseline that will be developed by this model. Also, the model will be used to identify instrument locations and develop data reduction strategies for a field study.

A three dimensional model will be used to develop a preliminary estimate of the remaining service life for the bridge. Computer loads models will be formulated using the characteristics of actual trains. These loads models may be used in conjunction with the structural model to predict the stress ranges and number of cycles caused by train movements. Software will be developed to transform these results into a form that may be used to predict **service** life **(i.e.** equivalent number of constant amplitude cycles at a certain stress range).

If time permits, further investigation will be undertaken concerning possible existence of relationships between fatigue damage and:

-- Gross tonnage of various types of train traffic

-- Tributary length of track to member

-- The amount of fixity in the joints of the bridge

RESEARCH APPROACH:

-1- A variety of sources will be consulted in an effort to compile a load history for the bridge. This data will be used in conjunction with the structural analysis to estimate the total number of cycles for specific members.

-2- The bridge will be modeled in three dimensions using **SAP90.**

-3- The span movement will be modeled to obtain stress ranges for critical members.

-4- Simulated trains will be run across the bridge model. These simulated trains will be based on the make up of actual trains.

-5- Preliminary estimates will be made for the service life of the bridge based on information from the computer model and historical findings.

-6- Preliminary recommendations will be made for the location of strain gages. This information will be used during the instrumentation phase of the project.

APPENDIX D

INTERMODAL CONTAINER TERMINAL SIMULATION

SPECIFIC PROPOSAL

SIMULATION OF INTERMODAL RAILYARD OPERATIONS

by

Donna Alyn Hollar

A thesis proposal prepared for the
Construction Engineering and Management Program
in partial fulfillment of requirements for the degree of

Master of Science in Civil Engineering

University of Washington

July 6, 1989

ACKNOWLEDGEMENTS

I wish to thank Harry Shaffer and Rick Wilson of Burlington Northern for their cooperation and assistance in developing this proposed research, along with Jerry Shaffer and Greg Stevenson of Pacific Rail Services. Many other individuals connected with the Seattle International Gateway facility also provided much assistance during the development of this proposal and displayed enormous patience in answering my endless questions. I am grateful to all such individuals at the SIG facility.

Funding for the proposed research will be provided by the Valle Scholarship and Scandinavian Exchange Program at the University of Washington and the Department of Civil Engineering. Special thanks to Professor Dale Carlson and Bobbie Greer for their assistance in making this research possible, and Professors Charles Jahren and Jirnrnie Hinze for their role as advisors.

SIMULATION OF INTERMODAL RAILYARD OPERATIONS

PROBLEM STATEMENT

With the increasing use of intermodal containers, the need for efficient transfer between modes is a critical issue as many facilities are operation at capacities that are greater than projected. As the owners of these facilities look toward expansion, analytical tools will be necessary to aid in the planning process. Computer simulation of facility operations is especially promising because it provides facility operators with the ability to evaluate different options without affecting current operations and provides insight for selecting methods that effectively increase capacity and productivity.

By simulating various situations using an animated graphical display, the user can quickly visualize and understand the alternate operating methods without reviewing a large volume of computer output. However, it is necessary to develop a model which adequately portrays the operational and physical constraints of each railyard facility. Burlington Northern's intermodal facility, Seattle International Gateway (SIG), will serve as the test facility for this study. An animated simulation model depicting current operations will be developed, verified, and validated; also the effect of selected operational and physical changes will be tested.

OBJECTIVES

Through the model development and simulation of operations of Burlington Northern's Seattle International Gateway, the research objectives are to complete the following:

- Development and documentation of the empirical distribution for each segment of the operation, including the cycle times and operational constraints of the lifting equipment.
- Documentation of the procedure used to produce a simulation model using a microcomputer with the SIMAN simulation language.

- Explore the applicability of simulation and animation for other complex operations in the railroad, marine, and construction industries.

RESEARCH APPROACH

A simulation model defines the interaction of the components of an operation by describing the facility constraints, both physical and operational. Physical constraints represent limits in terms of size, use, and geometry, while operational constraints involve operating hours, labor availability, and industry regulations. These constraints define the range of applicability of the model. For example, a model developed for a 10 acre intermodal facility may have only limited usefulness for a terminal of 100 acres.

The model also describes the logical rules of operations. Familiarity with the operations, which may be developed through field observations, is required to identify the complex relationship between components and develop these logical rules. Such rules may be illustrated by the fact that a container cannot be loaded onto a rail car without first having been assigned to that car and physically inspected. A clear understanding of operations will be required to insure a logical model is formulated.

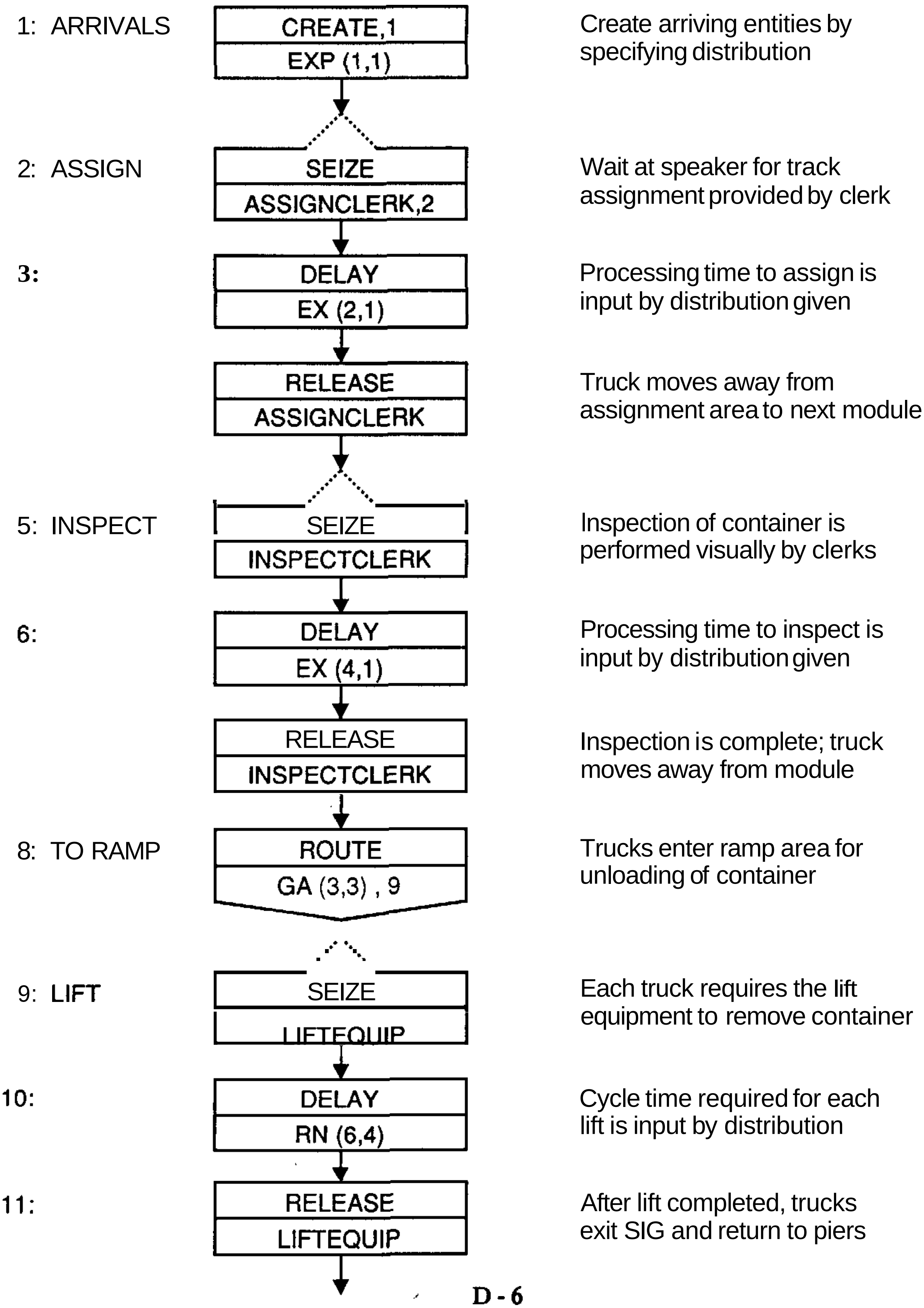
To cope with the complexity of an intermodal terminal, the model will be developed in modules which represent a distinct segment of the operation. For example, the modules for an import operation may include the entrance gate and queuing area, container assignment area, inspection and document area, loading area, and exit gate. Modules may be shared between operations. For example, the cycle time of a piece of lift equipment may be the same for both import and export operations at the SIG facility.

Before its utility in simulation can be realized, a model must be developed so that the simulation software can interpret the model's boundaries and logic. Software which allows trial simulations during the development of the model is recommended. SIMAN, a simulation language developed by System Modeling Corporation, will be used (System Modeling Corp., 1989) because it allows the user to interactively develop the model through graphical flow diagrams without requiring extensive knowledge of the SIMAN language syntax. For example, the basic flow diagram for the import operation of the SIG facility is illustrated in Figure 1. Once the model is completed and well documented, future users should find it quite simple to modify and maintain the model.

Having formulated a model which logically depicts the test facility, simulation can be utilized to investigate the impact of changes which influence the capacity, throughput, or productivity of the facility. Simulation can be thought of as "exercising" the model in order to evaluate these changes. Often the complex interactions of an operation will not allow direct computation of relationships between variables. For example, a manager might hope to increase production by increasing the number of lift trucks. However, in actual operation, an increase in equipment may not increase production because there exists a bottle neck elsewhere in the system. Often a simple mathematical relationship between the number of lift trucks and production can not be identified because other factors are involved. Simulation can be used to evaluate the overall effect of this type of decision even if all of the individual relationships are not fully understood.

As illustrated above, simulation has been found to be very useful in situations where the interaction of components are difficult to define. It can identify the consequences of changing controllable conditions and also assess the impact of uncontrollable factors which may be predicted to occur. Through animation, the simulation can be visualized to better understand which parts of the system are most affected by the proposed changes. Other studies have shown the value of animation in understanding the dynamic behavior of the simulation model which would be otherwise difficult to assess (Brown and Grunwell, 1987; Kheir, 1988). Animation of the simulation will serve as the primary means for the user to check the accuracy of the simulation's logic. In addition, statistical analysis will be performed to quantify the results of each simulation run which suggests a logical end. By using animation, those simulations which depict illogical operations may be rejected quickly, thus increasing efficiency of the analysis.

Figure 1: Import Operation Flow Chart Generated by **SIMAN**



Simulation is performed by defining how an entity is processed through the model. For the intermodal railway yard, the entity is a container and its processing is traced through each module of the model such as arriving, assignment, inspection, loading, and exiting. To determine how the container will be handled at each module, detailed observations of the actual field operations were required to define the processing times. In analyzing this information, randomness was exhibited in the times recorded. For example, the cycle times for loading a container from truck to rail car varied widely, possibly dependent on the operator's skill, the truck driver's familiarity with operations, weather conditions, weight and size of container, and congestion in the loading area. Uncontrollable factors such as these suggest that no single parameter, such as average processing time, can be identified for use in the model.

By compiling the results of all field observations for each module, empirical distributions will be developed. These distributions will allow the model to account for the randomness observed in the processing times by assigning each possible time a probability of occurrence. Thus, the range of processing times will be reflected in the simulation. By knowing the probability of occurrence for each time in the range, the simulation will more closely reflect actual operations by allowing random processing times to be used in the simulation. Each distribution is developed by determining the relative frequency at which all observed processing times occur. This frequency information will be converted into a probability density function and compared with known distributions to determine how well the processing times can be described by common distributions such as the exponential, gamma, erlang, and normal distributions.

Having defined the distributions which describe the processing at each module, the software will use a discrete event simulator to generate the processing time required for each container. Thus, the empirical distributions defined forms the basis upon which the simulation is performed. As the simulation is running, the animation will show the movement of the containers through each module and can also display the current value of selected operating parameters, such as the number of containers processed and the utilization of lift trucks, for easy reference.

The **SIMAN** software structure allows the distributions to be defined in such a way as to facilitate modification to the distributions without extensive changes to the base model. Thus if field observations indicate that the distribution describing truck arrivals has changed, only the assignment of the distribution in the model would be changed. The remainder of the model would be left intact and still operate effectively. The SIMAN language allow such changes easily since the definition of distributions are isolated in one component o the model structure, the experimental frame. This feature extends the usefulness of the model since extensive revisions and modifications should not be necessary to accommodate many operational changes. To validate the simulation modeling procedure, current operations will be simulated and the results compared to actual observations. Through this process the model can be modified to more closely reflect actual operations, thus increasing the confidence in the model's forecasting ability.

BENEFITS OF STUDY

A major benefit derived through developing the simulation will be the documentation of the empirical distributions developed from field observations taken at the test facility. These distributions will describe arrival rate of trucks, inspection time, assignment time, and machinery cycle time. As research develops and standardization of intermodal railway operations occur, such information will be useful for the planning of new and improved facilities. A the current time, documentation of such distributions throughout the industry is very rare, and individual researchers have been forced to develop empirical relationships for most of the test sites studied. By having access to documented data such as the processing distributions for the various segments of the operation, comparison of various alternatives can be made without exhaustive data collection. For example, if information was available on the distributions of cycle times for various types of lifting equipment, a simulation could be quickly performed to determine which type of equipment would provide the most efficient and cost effective processing within a given facility.

The simulation of operations at the Seattle International Gateway is intended to investigate the effects of changes in operating methods such as extension of operation hours, provision of additional lifting equipment, expansion of the loading area, or provision of an additional entrance into the facility. Also, the impact of technological advances such as computerization or the development of new equipment may also be considered. Though the model will be develop using the physical and operational characteristics of the SIG yard, the results of this study will be helpful to future researchers because the process of model development will be similar for any comparable intermodal facility. The logic governing the simulation should be generic, thus only slight modifications will be required to adapt the model for use with other facilities.

RESEARCH METHODOLOGY

The objectives of this study will be met by completing each of the eight major tasks detailed below. The duration of each task is shown in the bar chart of Figure 2. The number sequences printed in the bar chart represent the corresponding task number. The study was begun in March, 1989, and is anticipated to conclude in December, 1989.

Task 1 - Visit test facility to become familiar with the operations of an intermodal railyard.

Task 2 - Review of open and manufacturers' literature pertaining to intermodal terminals, equipment, and applications of animated simulation.

Task 3 - Attain training in the use of SIMAN, and develop base model of test facility including documentation of procedure.

Task 4 - Conduct field observations of test facility including documenting processing times for each module of the operation. Develop and document the empirical distributions demonstrated by the data.

Task 5 - Expand base simulation model to include all operation modules and develop animation graphics. Document animation procedure.

Task 6 - Verify model by simulating current operations using the empirical distributions developed.

Task 7 - Run simulation with animation for various operating methods identified. Evaluate effectiveness of animation graphics in assessing logic of simulation. Perform statistical analysis of simulation output.

Task 8 - Document procedure of running simulation, modification methods, and analysis of output.

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                                1989
MAR    APR    HAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC

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APPENDIX E

RESOURCE LIST

RESOURCE LIST

PUBLICATIONS:

Modern Railroads, Trade Journal, International Thomson Press, 424 W. 33rd Street, New York, NY 10001. Telephone for subscriptions: (800) 345-8112.

Progressing Railroading, Trade Journal, Murphy-Richter Publishing Company, Two North Riverside Plaza, Suite 1825, Chicago, Ill. 60606. Telephone: (312) 454-9155.

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Association of American Railroads -- J. R. **Lundgren,** Research and Test Department, 50 F Street, N. W., Washington, D. C. 20001. (202) 639-2100.

Federal Railroad Administration -- Arne J. Bang, Program Coordinator, Office of Research and Development, Washington, D. C. **20590.**

Transportation Research Board -- Elaine King, Rail Transport Specialist, 2101 Constitution Ave., N. W., **20418.** (202) 334-3206. Also, consider the following committees:

A2MO1 - Committee on Railroad Track Structure System Design

A2MO3 - Committee on Intermodal Freight Terminal Design

Burlington Northern Railroad -- Research and Development Department, 9401 Indian Creek Parkway, P. **O.** Box 29136, Overland Park, KS 66201-9136

Steve **Dittmeye**r -- Chief Engineer; Research, Communications & Control Systems (913) **661-4168**

Ron **Newman** -- Mechanical and Electronics Projects (913) 661-4409

Les Olson -- **Energy** Projects (913) 661-4408

Henry Lees -- Track and Structures Projects (913) 661-4410

Michael Smith -- Economics, **Cost/Benefit** analyses, expert systems (913) 661-4474

Burlington Northern -- Pacific Division, 999 3rd Avenue, 20th Floor, Seattle, WA 98104

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Southern Pacific Railroad -- Phil Lively, Assistant Vice President, Research, Southern Pacific Transportation Co., 1 Market Plaza, Room 605, San Francisco, CA 94105 (415) 541-1000.

Union Pacific Railroad -- Guerdon S. Sines, 1416 Dodge Street Room 235, Omaha, NE 68179 (402) 271-5000.