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GRAND TRUNK WESTERN IMPROVED RAILROAD OPERATIONS USING A RAILROAD AUTOMATED IDENTIFICATION AND LOCATION SYSTEM

VOLUME I

NEW PROCEDURES FOR TACTICAL OPERATING PLANNING DECISIONS

OCTOBER 1977

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16. Abstract

This volume (Volume 1) documents the new tactical operations planning procedures developed to interface with the Grand Trunk's Railroad Automation Identification and Location System (RAILS). The tactical planning procedures for dispatching and yard management are described in detail, and the results of on-line experiments are presented.

Volume 2 documents the dynamic movement predictor (DMP) simulation. This simulation interfaces with RAILS and predicts train and yard activities for the tactical planning process.

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Preface

This final report documents results of using the RAILS (Railroad Automated Identification and Location System) operations data base to improve railroad operations. The work was performed for the Grand Trunk Western Railroad (GT) by Stanford Research Institute (SRI) under project IS-D-3605; GT was the prime contractor to the Federal Railroad Administration (FRA), U. S. Department of Transportation under contract DOT-FR-4-5020. Mr. H. M. Tischler of GT was the project technical monitor of SRI's subcontract. The contract was administered by Mr. R. Shamberger, FRA. The final report consists of the following two volumes:

- Volume 1: New Procedures for Tactical Operations Planning Decisions
- Volume 2: DMP Technical Documentation

The study was conducted by the Transportation Center at SRI. Dr. R. S. Ratner, director of the Center, was the project supervisor. Dr. P. J. Wong was the project technical leader and directed a team consisting of:

Dr. B. Conrad:	Developed yard decision procedures
Ms. C. V. Elliott:	Programmed the Dynamic Movement Predictor
Ms. M. Hackworth:	Performed data analysis on dispatching operations
Mrs. M. R. Hathorne:	Programmed the Dynamic Movement Predictor
Ms. S. Jeans:	Performed data analysis on yard operations
Mr. J. M. Johnson:	Developed and evaluated yard decision procedures
Dr. A. J. Korsak:	Performed operations analysis to support the construction of the Dynamic Movement Predictor

Dr. M. G. Tashker:	Responsible for the design and development of the Dynamic Movement Predictor
Dr. P. J. Wong:	Responsible for developing and evaluating the dispatcher's decision procedures.

The authors would like to acknowledge the project technical direction provided by Mr. H. M. Tischler, General Manager-Information Services at GT, and the active participation of Mr. N. Lay, Manager-Operations Planning at GT, who was responsible for the field implementation and the training of GT personnel in using the procedures developed herein. In addition, the authors would like to acknowledge the assistance provided by Messrs. C. Burton, D. Hathaway, B. Miles, J. Stone, J. Hurd, W. Terrell, and R. Wilhelm, all of GT.

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EXECUTIVE SUMMARY

A. Introduction

During this research, tactical (short-term) operations planning procedures were developed for improving the shift-by-shift operations of a railroad, in particular, the dispatching and yard management operations.*

The tactical operations planning procedures developed during this research are designed to improve the efficiency of dispatchers and yardmasters by explicitly requiring them to plan their activities for an entire shift at the beginning of the shift, taking into account systemwide operation conditions. These procedures will lead to more efficient local and systemwide operations and will have a positive effect on improving car transit times, car utilization, labor productivity, and trip consistency throughout an entire system.

The tactical planning procedures developed during the course of this research require accurate current and predictive yard inventory, train consist, and train movement data. The Grand Trunk Western's (GT) Railroad Automated Identification and Location System (RAILS), which uses the advanced technologies of automatic car identification (ACI) scanners, wheel sensors, and computer and communication hardware to instrument and monitor the entire GT railroad, provides current data on yard inventory, train consist, and train movement. Predictive data on yard inventory, train consist, and train movement are provided by the dynamic movement predictor (DMP), a systemwide railroad simulation

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*The emphasis on tactical operations planning is to be contrasted with strategic (long-term) planning, which is usually performed by a higher-level railroad officer. The outputs of strategic planning influence monthly or yearly decisions.

model constructed by SRI during this project to interface with RAILS and to run sufficiently fast to be useful in a tactical operating environment.

B. Results

To date, research in developing new tactical operations planning procedures for railroads has been limited; in fact, most of the research on improved planning procedures has been at the strategic planning level. This project has achieved significant advances in developing new tactical operations planning procedures. The results of the research are discussed below.

1. Analysis of Conventional Operational Procedures

Conventional dispatching and yard operations were studied and analyzed. It was found that, due to lack of accurate current and predictive data, both dispatchers and yardmasters planned their shift operations inefficiently; they tended to wait to the last minute to make decisions or they made decisions on an ad hoc basis. Thus, instead of controlling problems, dispatchers and yardmasters merely react to them. Because of a lack of systemwide information at the local level, dispatchers and yardmasters often fail to effectively coordinate their operations from a systemwide perspective. These conditions produce less efficient local and systemwide operations resulting in nonoptimal labor productivity, excessive car transit times, inefficient car utilization, and trip unreliability. (For further details see Volume 1, Section III.)

2. New Tactical Operations Planning Procedures

A nominal systemwide operating plan for both dispatching and yard operations was implemented. The DMP simulation was used to predict future yard inventories and train consists. Detailed tactical dispatching and yard management procedures were developed to use the DMP predictions to plan dispatching and yard operations for a shift.

The dispatching tactical operations planning procedure involves reviewing the DMP outputs to determine whether trains are heavy or light, what yards are congested and when congestion occurs, and what blocks are causing congestions. The dispatching decisions involve cancelling trains, running extra trains, or having trains pick up and set out different blocks than those scheduled. In the yard tactical operation planning procedure, a manually tabulated worksheet whose inputs are RAILS/DMP information displays the connections of cars already switched and to be switched. Priorities are set for the connections, which allows the yardmaster to plan efficiently the sequence of his switching operations for a shift to meet these connections.

Both the dispatching and yard tactical operations planning procedures develop modifications to the nominal plan to meet local operating constraints. After modifications are discussed by both dispatchers and yardmasters, a modified systemwide operating plan is developed for a shift. Improvements to the tactical operations decision-making process of dispatchers and yardmasters are likely to result in a more efficient use of resources at both a local and system-wide level, and improved car transit times in yards and over the road. (For further details, see Volume 1, Section IV.)

3. DMP Simulation

A large, systemwide railroad simulation was constructed to interface directly with a "live" operations data base called RAILS. The simulation modeled over 20 yards in the GTW system; it had sufficient operational fidelity for tactical operations decision-making and it ran sufficiently fast to be useful in a tactical operating environment. (For further details, see Volume 1, Section II, and Volume 2.)

4. Training of Railroad Personnel

GTW personnel were trained to run the computer programs and implement the tactical planning procedures developed in this project. During the training, the procedures were modified to make them amenable to the "real world." As a consequence the procedures developed herein are close to a "production" version as opposed to an idealistic "prototype" version. (For further details, see Volume 1, Section V.)

5. Operational Experiment

The operational experiment took place during the week of 25 July 1977, and included a period of 48 consecutive hours during which the Chicago Division line-haul trains and the eastbound operation of Battle Creek yard were operated using the tactical planning procedures developed during the project. Tactical planning of train and yard operations 8 to 12 hours in advance was routinely accomplished; for certain trains the planning horizon was extended to 16 to 20 hours. The average values of the absolute prediction errors for total train size and train block counts were 19 percent and 26 percent, respectively. This accuracy was considered satisfactory for planning 8 to 12 hours in advance what trains should run, when they depart, what blocks they should carry, and what pickup and setouts should be made. Based on a shift's tactical plan, dispatching and yard operations, power scheduling, and crew assignments could be coordinated.

GT operating personnel involved in implementing the new procedures were uniformly positive about the experiment. They viewed the new procedures as an effective means of planning dispatching and yard operations in advance and of imposing an operating discipline on dispatchers and yardmasters that would constrain them to coordinate their activities on a systemwide basis yet allow them to plan an efficient local operation. (For further details, see Volume 1, Section V.)

6. Measures of Effectiveness on Operating Performance

A selected set of measures of effectiveness (MOEs) for the dispatching and yard operations of the GT railroad were gathered and evaluated from February to August 1977, (i.e., before and during the operational experiment). MOEs were gathered before the experiment to provide a baseline of operational data from which statistical inference could be made on the improvements to GT operations resulting from implementing the tactical operations planning process during the experiment. The analysis revealed a large, daily variation in all MOEs resulting in a large statistical variance. This large variability is due to the large daily variations in traffic, plant, and labor conditions. Using statistical techniques, we found that, in order to detect any significant change in the MOEs, the experiment must be conducted for periods in excess of several months. Even then, because of the large variability in certain MOEs, the detection of a significant change in the entire set of MOEs cannot be guaranteed. Consequently, a definitive statistical analysis of the MOEs before and during the experiment was unconclusive. Definitive statistical conclusions in measuring the change in railroad operating performance are not likely unless improved statistical experiment design procedures are developed. Otherwise, the daily variation in the MOEs due to traffic variabilities and operating disruptions completely mask the effects of any change in operating performance over a short period of time. (For further details, see Volume 1, Section V, and Appendix B.)

C. Conclusions and Recommendations

New tactical operations planning procedures are needed to improve dispatching and yard operations at both the local and systemwide level since ultimately dispatchers and yardmasters run the railroad by controlling trains over the line-haul and switching activity in yards. This research has developed systemwide tactical operations planning procedures for dispatching and yard operations utilizing accurate current information from RAILS and predictive information from DMP.

Based on both the results of our research and the insights gained during the project, we make the following recommendations:

- Install a permanent "production" version of the tactical operations planning procedures on GT.
- Modify the procedures and tools developed herein to interface with a manually input data base on another railroad.

- Automate the yard planning process by using interactive graphics.
- Develop a practical (i.e., obtainable at low cost) set of measures of effectiveness for measuring the performance of railroad operations and statistically valid experimental design procedures to measure performance changes.

I INTRODUCTION

A. General

This report documents SRI's work to assist the Grand Trunk Western Railroad Co. (GT) in making its Railroad Automated Identification and Location System (RAILS) operations data base applicable to tactical (short-term) operations planning.

The decision makers who directly control the movement of cars on a railroad on a minute-by-minute basis are the dispatchers and yardmasters. Dispatchers directly control the movement of trains on the line-haul portion of the railroad, and yardmasters directly control the movement of cars within a yard and terminal district. Both the dispatcher and yardmaster are restricted in the amount of short-term planning they can do during their shift, because of the lack of reliable current and predictive car inventory and movement information. In fact, one of the criticisms of present railroad operations is that most dispatchers and yardmasters tend to react to problems rather than plan and to optimize their own local operations rather than the total systemwide operations.

The car inventory and movement information of most railroads is initially input to a computer information system manually and is therefore subject to human error and often not available in a timely manner. Although cars moving onto a system from local industry and interchange have a big impact on operations, information on their movement is generally imprecise. For these reasons, dispatchers and yardmasters may delay decisions until the last minute, hoping that the information will be more precise at the time the decision is made, or they may follow a routine pattern of decisions which may or may not be responsive to daily traffic variations. Although such decision actions are rather extreme, it is the exception rather than the rule for a dispatcher or a yardmaster to systematically plan his operation at the beginning of his shift and to consider the systemwide impact of his decisions.

It has been conjectured that if accurate current train and yard inventory information and a shift-by-shift systemwide nominal operations plan were fed into a computer model of the railroad, the outputs of this model predicting the yard inventories and train consists resulting from this nominal plan would enhance the ability of dispatchers and yardmasters to perform tactical planning of their own local operations. This tactical planning process for dispatching and yard management involves using the predictions for the nominal plan to develop modifications to the nominal plan. These modifications or exceptions to the nominal plan are communicated and coordinated between dispatchers and yardmasters; this new plan is used to run the railroad over the next shift. Consequently, the nominal operating plan fed into the computer model is the means for coordinating decisions by dispatchers and yardmasters so that the railroad is optimized on a systemwide basis rather than a local basis.

B. Objective and Scope

The objective of this work was to assess the impact and utility of a tactical, systemwide, computer model of a railroad and new tactical operations planning procedures for dispatching and yard management on the operations of the yard and line-haul portions of a railroad. To this end SRI developed a tactical operations simulation model called the dynamic movement predictor (DMP), to interface with the RAILS system; designed tactical operations planning procedures for aiding shift-by-shift dispatching and yard decision making using RAILS/DMP information; and assisted GT in the conduct and evaluation of experiments using the new procedures.

C. Grand Trunk Western Railroad Co.

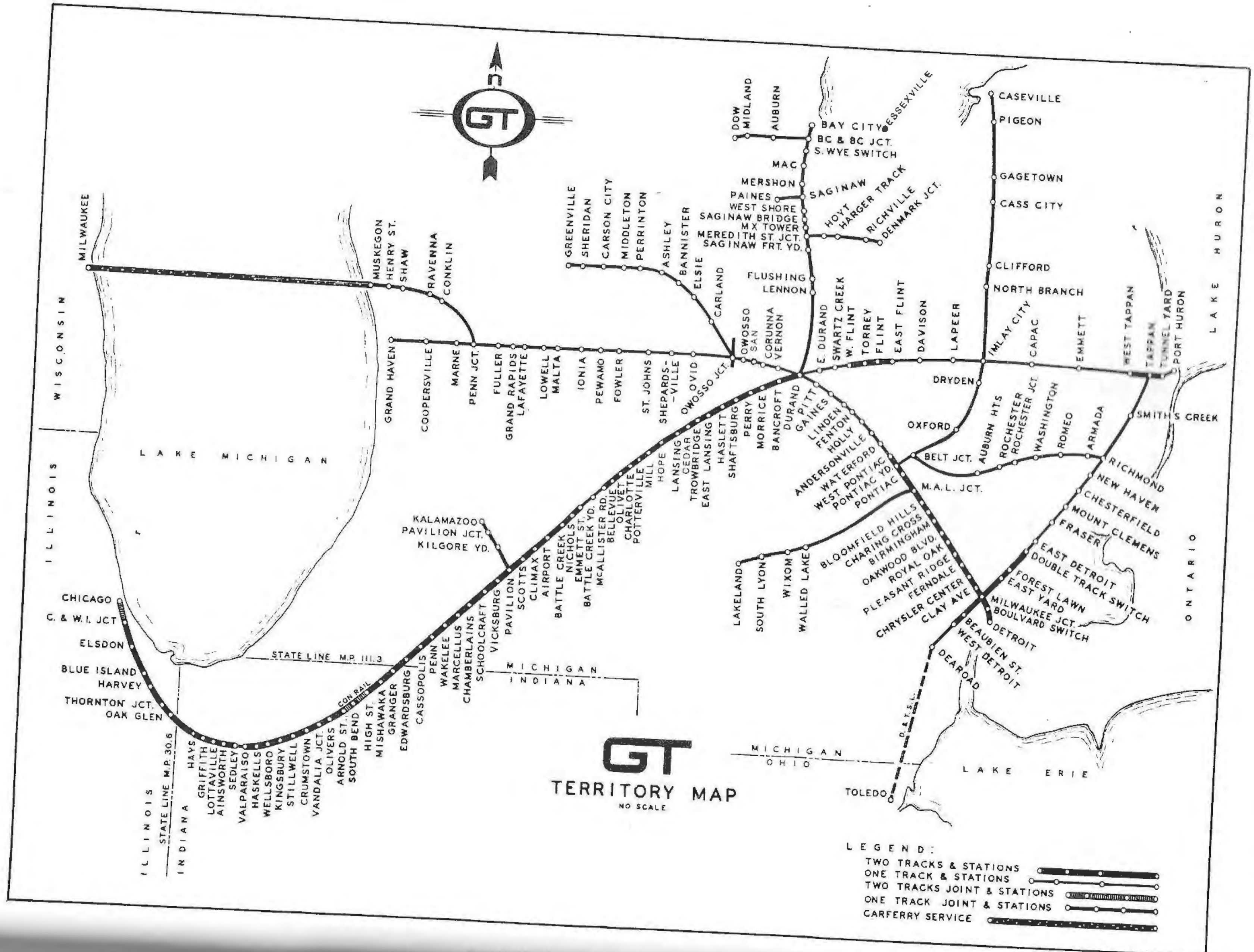
The Grand Trunk Western Railroad Co. (GT), a U.S. Class I railroad headquartered in Detroit, operates in the four midwestern states of Illinois, Indiana, Michigan, and Wisconsin (see Figure 1).

GT operates 1,320 route miles (including carferry mileage across Lake Michigan) with 2,148 miles of running and switching tracks, and 11 primary flat switchyards (no hump yards). It is predominantly a Michigan railroad; 85% of its route mileage is located in that state (see Figure 1).

At the end of 1976, GT's equipment fleet consisted of 187 locomotive units, 10,183 freight train cars, and 402 units of work equipment. Its operations employ about 4,276 persons and are entirely freight, except for three commuter trains, which operate between Pontiac and Detroit and one Amtrak train each way between Port Huron and Battle Creek. In 1976, GT handled 468,790 revenue carloads of freight amounting to 18.9 million tons.

The GT property is characterized by its small geographic size and dense traffic centers populated with service-conscious customers. This combination of circumstances produces fast and short line-haul train operations. A high percentage of the revenue carloads consists of automobiles and automobile-related products due to the automotive manufacturing plants located along GT rights-of-way. To keep the automobile plants working at maximum efficiency, GT's service must be both dependable and rapid. The bulk of the traffic hauled by GT moves in the corridor between Chicago and Port Huron. In the Chicago terminal area the GT interchanges with a number of railroads including the ATSF, BN, BOCT, BRC, CNW, CO, CR, EJE, ICG, IHB, MILW, MP, NW, and RI. At Port Huron the GT interchanges with the CN.

The railroad is divided into two operating divisions. One is headquartered at Battle Creek, Michigan, and is known as the Chicago Division. This division operates the main line from Chicago to Port Huron, Michigan (a distance of 334 miles) and a short branch line serving Kalamazoo, Michigan. The Chicago Division main line has a basic freight train speed


GT
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MICHIGAN
OHIO
ONTARIO
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
STATE LINE M.P. 30.6
STATE LINE M.P. 111.3
CON RAIL
D.&T.S.L.
MILWAUKEE
CHICAGO
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GRIFFITH
LOTTAVILLE
AINSWORTH
SEDLEY
VALPARAISO
HASKELLS
WELLSBORO
KINGSBURY
STILLWELL
CRUMSTOWN
VANDALIA JCT.
OLIVERS
ARNOLD ST.
SOUTH BEND
HIGH ST.
MISHAWAKA
GRANGER
EDWARDSBURG
CASSOPOLIS
PENN
WAKELEE
MARCELLUS
CHAMBERLAINS
SCHOOLCRAFT
VICKSBURG
PAVILION
SCOTTS
CLIMAX
AIRPORT
BATTLE CREEK
NICHOLS
EMMETT ST.
BATTLE CREEK YD.
McALLISTER RD.
BELLEVUE
OLIVET
CHARLOTTE
POTTERVILLE
MILL
HOPE
LANSING
CEDAR
TROWBRIDGE
EAST LANSING
HASLETT
SHAFTSBURG
PERRY
MORRICE
BANCROFT
DURAND
PITT
GAINES
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ANDERSONVILLE
WATERFORD
WEST PONTIAC
PONTIAC YD.
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KALAMAZOO
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KILGORE YD.
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GRAND HAVEN
COOPERSVILLE
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GRAND RAPIDS
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CORUNNA
VERNON
GREENVILLE
SHERIDAN
CARSON CITY
MIDDLETON
PERRINTON
ASHLEY
BANNISTER
ELSIE
CARLAND
DOW
MIDLAND
AUBURN
BAY CITY
ESSEXVILLE
BC & BC JCT.
S. WYE SWITCH
MAC
MERSHON
PAINES
WEST SHORE
SAGINAW BRIDGE
MX TOWER
MEREDITH ST. JCT.
SAGINAW FRT. YD.
SAGINAW
HOYT
HARGER TRACK
RICHVILLE
DENMARK JCT.
FLUSHING
LENNON
E. DURAND
SWARTZ CREEK
W. FLINT
TORREY
FLINT
EAST FLINT
DAVISON
LAPEER
DRYDEN
OXFORD
BELT JCT.
M.A.L. JCT.
AUBURN HTS
ROCHESTER
ROCHESTER JCT.
WASHINGTON
ROMEO
ARMADA
CASEVILLE
PIGEON
GAGETOWN
CASS CITY
CLIFFORD
NORTH BRANCH
IMLAY CITY
CAPAC
EMMETT
WEST TAPPAN
TAPPAN
TUNNEL YARD
PORT HURON
SMITHS CREEK
RICHMOND
NEW HAVEN
CHESTERFIELD
MOUNT CLEMENS
FRASER
EAST DETROIT
DOUBLE TRACK SWITCH
FOREST LAWN
EAST YARD
MILWAUKEE JCT.
BOULVARD SWITCH
DETROIT
BEAUBIEN ST.
WEST DETROIT
DEAROAD
LAKELAND
SOUTH LYON
WIXOM
WALLED LAKE
BLOOMFIELD HILLS
CHARING CROSS
BIRMINGHAM
OAKWOOD BLVD.
ROYAL OAK
PLEASANT RIDGE
FERNDALE
CHRYSLER CENTER
CLAY AVE
TOLEDO

limit of 60 mph. The major yards on the Chicago Division are: Elsdon, Blue Island, Harvey, Kalamazoo, Battle Creek, Lansing, Flint, and Port Huron.

GT's second operating division is headquartered at Pontiac, Michigan, and is known as the Detroit Division. This division operates the main line from Detroit to Muskegon, Michigan (a distance of 194 miles) and from Detroit to Port Huron (a distance of 57 miles). In addition, the Detroit Division operates the several branch lines feeding into Pontiac and Durand, Michigan and the branch line serving Grand Haven, Michigan. The Detroit Division main line has a freight train speed limit of 60 mph in signal system territory and 45 and 49 mph in nonsignal system territory. The major yards on the Detroit Division are Pontiac and Durand, and the two major yards in the Detroit terminal area, namely, Ferndale and East Yard.

FIGURE 1 MAP OF GT SYSTEM

II ACCURATE CURRENT AND PREDICTIVE YARD INVENTORY AND TRAIN CONSISTS INFORMATION: RAILS AND DMP

RAILS is an automated car inventory and movement information system that provides accurate, current information on yard inventory and train consists at any given time and estimates of interchange and industry traffic. This information, along with a shift-by-shift nominal system-wide operation plan, can be input to the DMP simulation to predict future yard inventories and train consists. This predictive information for a nominal plan is the basis for new tactical planning procedures discussed in Section IV.

A. RAILS: Current Inventory for Tactical Operations Planning

1. Purpose and Function

RAILS is an integrated, automated information system on car movements, operations, and revenues. It is a railroad-wide information and management system combining operating and revenue data, using the current technologies of optical automatic car identification (ACI) scanners, wheel sensors, computer-stored repetitive waybill data, medium-high speed data communication channels, and distributed processing computer hardware.

For tactical operations planning, RAILS can provide a current inventory of the railroad. In particular, at any given instant of time, current yard inventory and train consist and location information are available. This current system status information is used to provide the "initial conditions" for the DMP simulation (discussed Section II.B) to predict future yard inventory, train consists, and train movements. In addition, to support yard activities, RAILS can provide for each major yard a complete inbound/outbound train list, an automatic switch list, and a track standing inventory.

2. System Inputs

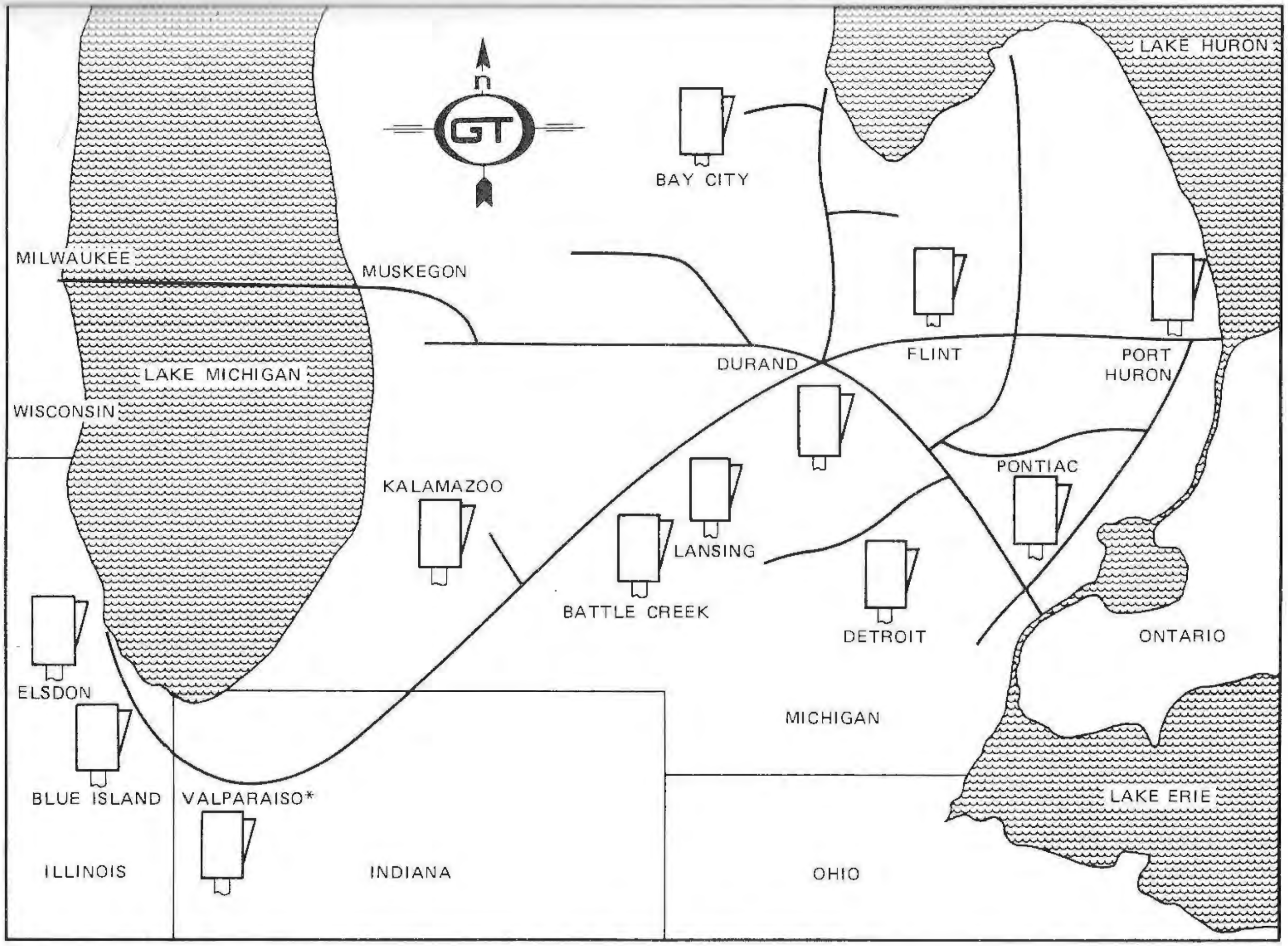
a. Scanner Inputs and Data Enhancements

The ACI scanner is an electrooptical device located along trackside. Its purpose is to read a color-coded label which is placed per the regulations of the American Association of Railroads (AAR) on each side of railroad freight cars and locomotives and on other pieces of railroad equipment.

Each color-coded label is designed according to the AAR ACI standard for North American and contains 13 distinct lines: the first or bottom line is the start module. The second line is the equipment code identification, which indicates the type of equipment (e.g., freight car, locomotive, caboose, trailer, container, work equipment, or passenger equipment). The third, fourth, and fifth lines give the car owner's code, such as 308 for the GT. The sixth through eleventh lines give the car number, and the twelfth line is the stop module, which tells the scanner it has completed reading the car initial and number. The thirteenth or top line of each label is a digit serving as a validity check to verify that the label has been read properly.

The ACI scanners on GT property are activated and deactivated by approach monitor devices (wheel sensors) placed along trackside at appropriate distances from the scanners. Upon activation, an ACI scanner reads the AAR color-coded label on the car passing in front of it from bottom to top and forwards the information to a regional computer called the Node computer.

Scanners are located at the entrance and exit points of 12 principal GT terminals (see Figure 2). Within the heavier volume terminals, scanners are located at key points to record car location changes. The 61 individual scanner locations in RAILS were selected to capture as complete a coverage as possible of GT line-haul operations and interchange and industry activities. The scanner cannot capture the following movements: (1) a car that comes on line at other than one of the 12 principal terminals and goes off line before passing through



*The scanner at the way station of Valparaiso, Indiana, also serves as an entrance/exit scanner for the Harvey, Illinois, terminal.

FIGURE 2 ACI SCANNER LOCATIONS ON THE GT SYSTEM one of said terminals; and (2) a car that is switched into an industry served jointly by GT and another railroad and is taken out of the industry by the other railroad without passing a GT scanner.

To increase the accuracy of car identification beyond the raw scanner reading RAILS makes extensive use of the concept of data enhancement. This concept uses the data from advance consist waybill information which is initially entered for each car at its originating point on GT property to enhance the ACI scanner readings. The enhancement concept as used in RAILS provides a virtually complete inbound train list in train standing order with no missing car initials and numbers, upon the arrival of a train in a yard which has an ACI scanner at the yard entrance.

The enhancement process works as follows: An advance train consist is sent to a Node computer covering 1 of the 12 principal yards. As a train arrives at that yard it passes the yard entrance scanner at which time the ACI input is sequentially matched with the advance consist information previously stored in the Node computer. The scanner input is used as the primary source of data for car initial and number as well as train standing order; the advance consist data are used for cars which for some reason were not read by the scanners. The inbound train list, which is the product of the inbound enhancement process, notes as an exception a car that was part of the advance consist but was not found by the scanner.

b. CRT Video Display Terminals and Repetitive Waybill Entry

The cathode ray tube (CRT) video display terminal is an electronic input and output device. Fifty-nine CRT devices are installed in the field and attached to RAILS Node computers. These devices replace all field punch card equipment as input devices. Thirteen devices are installed at headquarters.

The CRT devices used by GT display a maximum of 1,920 characters at any one time and handle preformatted input displays as well as string input, such as a punch card image would represent.

Waybill information is entered in the field via the CRT terminals; this information is normally handled through the use of the Repetitive Waybill Code (RWC). The RWC concept is built around the repeated use of computer-stored constant data for repetitive traffic moving between two points. On the GT, repetitive traffic is local, interline forwarded, interline received, as well as overhead. RWC processing is basically handled by the central computer with the exception that printers attached to a regional computer actually print the waybills, and the waybill origin and destination information is automatically fed into the data base of the proper regional computer for further yard and agency use.

3. Computer System Description

a. Node Computers

RAILS consists of several computer processing capabilities distributed between the field and GT headquarters (see Figure 3).

The field processing capabilities revolve around four regional computer centers, or Nodes, which are themselves linked to the headquarters computer complex via data communication facilities. These centers use minicomputer configurations to receive data from online data terminals, ACI scanners, and car inventory wheel sensors and to send processed information back to the online terminals for display and/or printing. Many data terminals, scanners, and sensors located at various yards, agencies, and outlying locations along rights-of-way are connected with the same minicomputer configuration to centralize certain related data flows and to provide for the maximum in backup capabilities.

Information from the Node processor deals with first-line management problems, which are basically the proper and efficient handling of cars and the paperwork related thereto. The Node automates the paper flow process and forwards information needed for essential monitor and control functions to the headquarters computer complex.

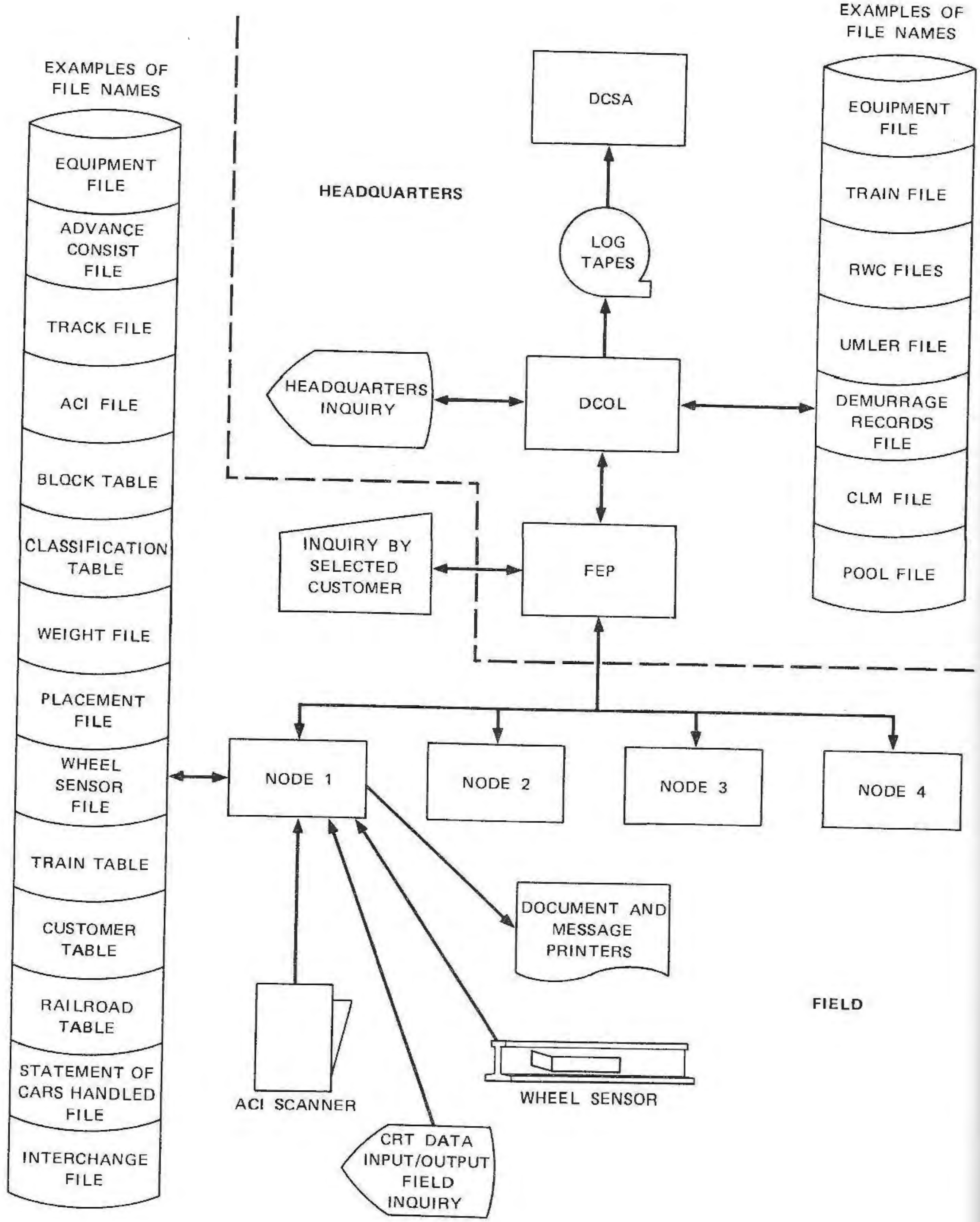


FIGURE 3 COMPUTER SYSTEM HIERARCHY

The geographical coverage of the four Node configurations has been determined by operating territory and traffic volume considerations and is as follows (see Figure 3): The Node 1 configuration covers the westernmost portion of the Chicago Division, which is essentially the Chicago terminal area. The Node 2 configuration covers the middle portion of the Chicago Division, which includes the industrial areas of Kalamazoo, Battle Creek, and Lansing, Michigan. The Node 3 configuration covers the easternmost portion of the Chicago Division and what is essentially the western half of the Detroit Division. The Node 4 configuration covers the heavily industrialized Detroit-Pontiac area of the Detroit Division.

Every Node configuration contains a primary and secondary processor, each with its own disk, to maintain duplicate data bases on a continuous basis. If the primary computer fails due to a hardware problem, the secondary processor will instantaneously take over the ongoing processing and will permit continued communications with the various field devices as well as with the computer complex located at headquarters.

b. Central Computers

Three principal functions are carried out in the central computer complex located at headquarters (see Figure 3). The first principal function is the collection of data from the four Nodes for use at headquarters as well as the transmission of data between the Nodes. This function, which essentially is one of providing data communication capability, is handled by a minicomputer configuration referred to as the Front End Processor (FEP). The FEP configuration, like each Node, contains a primary and secondary processor, each with its own disk. However, unlike the Nodes, the secondary processor does not maintain a continuous duplicate data base of the primary system. Therefore, should the primary system fail due to a hardware problem, several minutes are consumed in switching over to the secondary processor. This switchover involves the physical transfer of disk packs in addition to the manipulation of certain two-way switches.

The second principal function carried out at headquarters is the editing, composing, and expanding of the data received from the FEP and the compilation of it into one large online data base in which certain movement information will be retained for periods of weeks. A System 370 computer configuration with disk, referred to as the Data Central OnLine (DCOL) processor, handles this second principal function. It is from the DCOL processor that data will be provided to data inquiry terminals at headquarters, traffic offices, and customer locations. The DCOL System 370 configuration is backed up by another System 370 configuration which will normally be used for the third principal headquarters function.

The third headquarters function is to receive information from the DCOL processor via log tape and use this information in an offline environment to prepare the various management reports required at regular or semiregular intervals. The computer configuration handling the third function is referred to as the Data Central Scheduled Application (DCSA) processor. The DCSA processor is the terminating point for the RAILS flow of data.

B. DMP: Predictions for Tactical Operations Planning*

1. Purpose and Function

RAILS provides information about current yard inventory, train movements, and train consists. The DMP uses this current information and a nominal operating plan to predict future yard inventory, train movements, and train consists. The tactical operations planning process uses both the current and predicted information to develop modifications

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*The DMP is discussed and documented more extensively in Vol. 2 of this report.

to the nominal operating plan. The modified plan is then used to operate the railroad over the next shift.

The DMP is an event-step computer simulation of railroad network operations. Given a user-specified network configuration and a set of train and yard marshalling instructions, the DMP will simulate the movement of trains, blocks, and cars in and out of yards for a user-specified period of time (e.g., 8 to 10 hours). Inputs to the DMP has been structured so that changes to nominal train and marshalling instructions can be accomplished easily. Output statistics are generated concerning train and yard activity so that system performance can be evaluated easily. The DMP can interface with both a real-time car movement data base, such as RAILS, and synthetic inputs generated from historical data.

The entire set of simulation programs can be run in either a batch or time-shared environment. Regardless of the environment, rapid transfer of a railroads's computerized inventory is necessary. In the course of this project, the simulation was run on two computers and operating systems: an IBM 370/135 under OS/VS1; and a commercial time-sharing system under VM/CMS. To run a 12-hour simulation period, the DMP executive program (the simulation logic exclusive of input, inventory processing, and output reports) requires approximately six minutes under OS and two minutes under VM. The time required to run auxiliary programs (input and output) depends on the quanitity of input and the type of reports specified.

The simulation has been designed for ease of use by railroad personnel. The simulation parameters have been documented in railroad terminology.

Although the DMP is used in this research as a short-term, tactical, predictive simulation tool, it can also be used for long-term strategy planning in which a myriad of alternative strategies for operating a railroad can be evaluated. For example, the user can evaluate the following:

- Previous day's operating policy by using the traffic loading of the previous day and experimenting with the timetable, marshalling instructions, call-times for trains, decisions not to run trains, and the like to see if improvements in performance can be obtained.
- New alternative timetable and marshalling instructions when a yard becomes overloaded or underloaded, or when traffic loading changes.
- Costs versus revenues of taking on new traffic or providing a new service.
- Desirability of making new interline agreements to build solid trains for interchange before these agreements are entered into.
- Benefits of changes to plant capacity (e.g., new yard, changes in road-haul engines, changes in yard engines, changes in classification tracks).

2. System Inputs and Data Interfaces

Inputs to the DMP can be categorized as follows (see Figure 4):

- Initial car inventory and train consists
- Interchange and industry traffic projections
- Train and marshalling instructions (i.e., nominal operating plan)
- Network configuration and characteristics

At the start of the simulation, the DMP requires the initial inventories and consists of trains in transit. These data, which constitute the "initial condition" for the simulation, are supplied by the RAILS system to a special computer file that is accessed by the DMP.

The DMP also requires a projected traffic loading that consists of two time histories: (1) cars entering the system via interchange, and (2) cars entering the system via local industry. For example, the interchange projections from the CN at Port Huron are automatically input to the DMP based on data from the CN computer information system at Montreal. On the other hand, many industry projections are manually input to DMP because of the rapid offering of cars for movement. These data are obtained from either telephone calls to the cognizant station or from historical data.

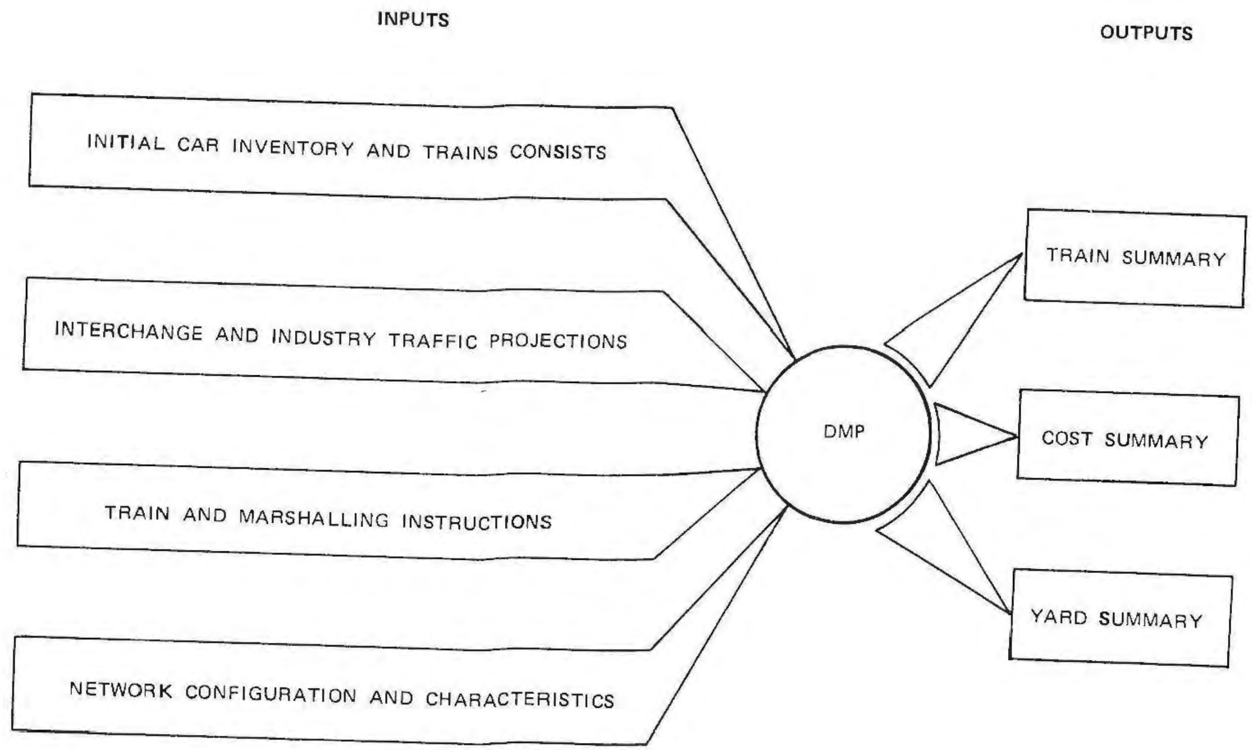

FIGURE 4 OVERVIEW OF DMP INPUTS AND OUTPUTS

The train and marshalling instruction provide operating instructions for train movement and yard marshalling, and thus constitute the nominal operating plan for the railroad. In particular, these instructions specify:

- Departure time for each train.
- Assigned horsepower for each train.
- Maximum car limit for each train.
- Station stops and route for each train.
- Blocks to be picked up or set out at each station for each train.
- Cutoff time for blocks at each station, specifying the latest time a car must be at a station to make a pickup.
- Nominal delay for work at each station.

These operating instructions are manually input to the DMP. An "input editor" efficiently allows a small number of modifications to be made to a nominal schedule.

The network configuration and characteristics specify the geographical and physical features of the railroad network (e.g., the location of yards and the line-haul segments interconnecting the yards). Figure 5 indicates the yards and single and double track portions of the GT network; this figure should be compared with the map of the GT system in Figure 1. Maximum speed limits and grade factors for each line-haul segment are also specified in the computer model.

A summary of the inputs and data interfaces to DMP when DMP is used for tactical operation planning is shown in Table 1. The data interfaces are a mixture of automated and manual procedures.

Both the initial car inventory and train consists and the interchange and industry projections can be specified entirely from historical data on an individual car basis or in terms of "supercars." A supercar is a grouping of cars that enters and leaves the system as a group and therefore can be considered as a single entity. In addition, the DMP can flexibly represent networks on either a coarse or detailed level. The user can decide on the level of fidelity of network representation, depending on whether detailed or approximate results are

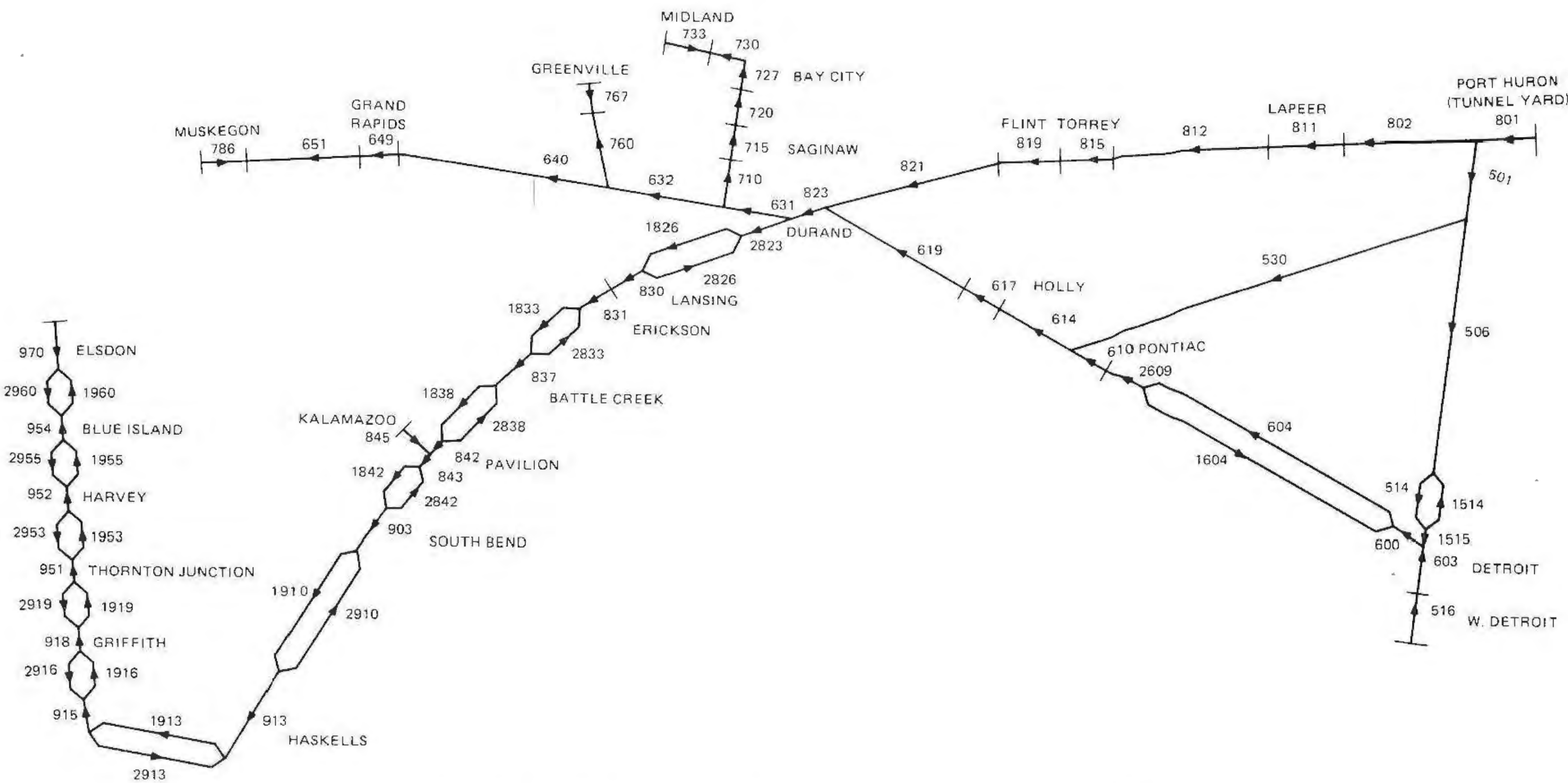

FIGURE 5 DMP NETWORK REPRESENTATION OF THE GT SYSTEM

Table 1

SUMMARY OF INPUT AND DATA INTERFACES TO DMP
WHEN USED FOR TACTICAL OPERATIONS PLANNING

Input	Data Interface
Initial car inventory and train consists	Obtained from RAILS system via speciall created initialization file; automated input to DMP.
Interchange projections	CN and DTSL interchange data are obtai from a data link. The remainder of the interchange data are obtained from phon calls, historical data, or advance consists and are manually input to DMP.
Industry traffic projections	In general, obtained from RAILS. Becau of the rapid offering of cars for movement, however, automobile industry traffic data are obtained from telephone calls or from historical data.
Train and marshalling instructions	Manually input to DMP; an "input editor" efficiently allows modifications to a nominal set of instructions.
Network configuration and characteristics	Manually input to DMP.

desired. Furthermore, hypothetical network configurations can be represented corresponding to new yards or new trackage. These features are particularly useful when the DMP is used for long-term strategy planning studies rather than for tactical operations planning.

3. Train Movement Simulation Logic

The simulation is based on event-step rather than time-step logic. This means that the simulation timeclock advances to the next time that an event is scheduled or calculated to occur, rather than advancing in uniform, discrete increments of time. Typical events include:

- Train makeup in origin station
- Train departs from a station
- Train enters a new line-haul segment
- Train arrives at a station
- Train pickup at a station
- Train setout at a station
- Train departs from a station
- Train disbands at a destination station.

Events are generated in time by many different trains from different locations in the system and are processed in chronological order of their occurrence.

For purposes of illustration, let us follow the events of a specific train. The events and the logic associated with the movement of the train can be described as follows: At the origin station, makeup instructions detail which blocks are to be picked up by the train. For each block, all cars in the yard prior to a specified cutoff time are allowed to be picked up; limits on the total number of cars to be picked up are specified. At the origin station, the scheduled departure time determines the departure of the train. The transit time over the line-haul segment to the next station is determined by the horsepower-to-weight ratio, grade factors, and speed limits. When the train arrives at the next station, the setout and pickup instructions indicate which blocks are to be set out and picked up. For pickups, only those cars in the yard prior to a specified cut-off time are allowed to be picked up; in addition, these pickups are subject to train size limits. From an intermediate station, train departures are not governed by a scheduled departure time but are calculated by adding to the arrival time and the time delay associated with the work done at the yard. The train departs at the calculated time, and the train logic moves the train over line-haul segments, stopping at intermediate yards for pickups and setouts, in the manner described previously. At the destination station, the train sets out all cars in its consist and disbands.

4. Outputs and Reports

The outputs and reports of DMP have been designed specifically to facilitate the tactical planning and decision-making associated with the dispatching and yard management functions. Three outputs are provided: train summary, yard summary, and cost summary.

In the numerical coding scheme associated with trains, yards, and blocks, trains are designated with a three-digit number (e.g., 391); an extra section of the train is designated by placing the number "2" in front of the normal train number (e.g., 2391). Yards and stations are coded with a three-digit number. The DMP models only the major yards and stations listed in Table 2.

Blocks are coded with a two-digit number and represent an aggregation of station destinations (see Table 3). The station destination numbers associated with a block are also shown in Table 3. If the destination is a major yard, then a block can be associated with both the destination yard and the interchange railroad at that destination (e.g., block 2 represents destination Elsdon and interchange to the BN railroad.)

An example train summary is shown in Figure 6. This output provides the following information for each train:

Table 2

YARDS AND STATIONS MODELED IN DMP

Name	No.
Elsdon	970
Blue Island	954
Harvey	952
Thornton Junction	951
Griffith	918
Haskells	913
South Bend	903
Kalamazoo	845
Pavilion	842
Battle Creek	837
Erickson	831
Lansing	830
Durand	823
Flint	819
Lapeer	811
Port Huron	801
Detroit	603
W. Detroit	516
Pontiac	610
Holly	617
Greenville	767
Grand Rapids	649
Muskegon	786
Saginaw	715
Bay City	727
Midland	733

Note: See Figure 5 for the network modeled in DMP.

Table 3

BLOCK NAMES AND NUMBERS

Block Number	Block Name	Station Numbers
1	Elsdon	970 & 973-990
2	Elsdon/ATSF	970 ATSF
3	Elsdon/CNW	970 CNW
4	Elsdon/Railport	972
5	Spare	999
6	Blue Island	954
7	Blue Island/RI	954 RI
8	Blue Island/MILW	954 MILW
9	Blue Island/IHB	954 IHB
10	Harvey	952-953
11	Thornton Jct	950-951
12	Griffith	918-920
13	Haskells (913)	905-917
14	South Bend	903-904
15	Pavilion/Kalamazoo	842-845
16	South Bend Sub. East	838-841 & 850-902
17	Battle Creek	837
18	Battle Creek/CR	837 CR
19	Erickson/Flint Sub. West	820-822, 824-829 & 831-836
20	Lansing	830
21	Durand	823
22	Holly Sub. North	611-622
23	Grand Rapids	630-649
24	Milwaukee	690
25	Muskegon	784-786
26	Grand Haven	651-665
27	Saginaw	707-717
28	Bay City	719-728
29	Greenville	750-767
30	Flint	814-819
31	Lapeer/Flint Sub. East	802-813

Table 3 (Continued)

BLOCK NAMES AND NUMBERS

Block Number	Block Name	Station Numbers
32	Port Huron	800-801 & 500-502
33	Sarnia ETY	801 CNE
34	Port Huron/CN Tunnel	801 CN
35	Port Huron/CN Boat	801 CNB
36	Canadian Perish	801 CNP
37	Canadian Sand	801 CNX
38	Pontiac	610
39	Jackson Sub.	537-556
40	Romeo Sub.	530-536
41	Cass City Sub.	560-586
42	Holly Sub. South	606-609
43	Detroit/DTSL	516 DTSL OR DTS
44	Detroit	514-516 & 603-605 & 503
45	Detroit/CR	516 CR
46	Detroit/Perish	603 P
47	Mt. Clemens Sub. South	504-513

*** TRAIN SUMMARY ***

TRAIN NUMBER	YARD NUMBER	ARRIVAL TIME	ARRIVAL DAY	WITH CARS	******** SETOUT ******** NO. OF CARS (BLOCK NO.)			******** PICKUP ******** NO. OF CARS (BLOCK NO.)			DEPARTURE TIME	DEPARTURE DAY	WITH CARS	GROSS TONS	CAR MILES
387	811	0	0								235	208	56	2743	2430
	815	0	0	56							300	208	56	2743	3539
	819	0	0	56							300	208	56	2743	3544
	823	320	208	56	1(21)	7(23)	4(24)	5(20)	15(1)	4(5)	410	208	130	4870	4446
					2(27)	2(28)	0(0)	2(7)	8(3)	4(10)					
					0(0)	0(0)	0(0)	12(11)	21(12)	9(13)					
					0(0)	0(0)	0(0)	10(15)	0(0)	0(0)					
	830	501	208	130	5(20)	0(0)	0(0)	0(0)	0(0)	0(0)	512	208	125	4615	8749
	831	0	0	125							512	208	125	4615	8761
	837	512	208	125	16(1)	4(5)	6(7)	0(0)	0(0)	0(0)	0	0	0	0	13961
					13(8)	3(9)	6(10)								
					25(11)	23(12)	9(13)								
					12(15)	7(17)	1(19)								

TRAIN NUMBER	YARD NUMBER	ARRIVAL TIME	ARRIVAL DAY	WITH CARS	******** SETOUT ******** NO. OF CARS (BLOCK NO.)			******** PICKUP ******** NO. OF CARS (BLOCK NO.)			DEPARTURE TIME	DEPARTURE DAY	WITH CARS	GROSS TONS	CAR MILES
389	801	0	0		0(0)	0(0)	0(0)	19(5)	35(30)	1(13)	1700	208	60	2295	0
								5(8)	0(0)	0(0)					
	811	0	0	60							1755	208	60	2295	2604
	815	1820	208	60	35(30)	0(0)	0(0)	19(14)	2(1)	3(7)	1930	208	65	3049	3792
					0(0)	0(0)	0(0)	5(8)	7(10)	4(11)					

TRAIN NUMBER	YARD NUMBER	ARRIVAL TIME	ARRIVAL DAY	WITH CARS	******** SETOUT ******** NO. OF CARS (BLOCK NO.)			******** PICKUP ******** NO. OF CARS (BLOCK NO.)			DEPARTURE TIME	DEPARTURE DAY	WITH CARS	GROSS TONS	CAR MILES
391	811	0	0								625	208	51	2800	2213
	815	0	0	51							650	208	51	2800	3223
	819	0	0	51							650	208	51	2800	3228
	823	0	0	51							740	208	51	2800	3641
	830	816	208	51	0(0)	0(0)	0(0)	4(11)	0(0)	0(0)	847	208	55	2940	5329
	831	0	0	55							847	208	55	2940	5335
	837	842	208	55	5(1)	10(2)	1(4)	0(0)	0(0)	0(0)	0	0	0	0	9911
					8(5)	3(6)	4(7)								
					1(8)	2(10)	11(11)								
					1(14)	1(15)	9(17)								

FIGURE 6 TRAIN SUMMARY

- "Yard Number" indicates the schedule yard stops.
- For each yard stop, "Arrival Time, Day, With Cars" indicates the arrival time, the day (Julian date), and the number of cars arrived on the train.
- For each yard stop, "Pickup--Block No. (No. of Cars)" indicates the number of cars for each block picked up.
- For each yard stop, "Setout--Block No. (No. of Cars)" indicates the number of cars for each block setout.
- For each yard stop, "Departure Time, Day, With Cars," indicates the departure time, the day (Julian date), and the number of cars departed on the train.
- For each yard stop, "Gross Tons and Car Miles" indicares the gross tons and car miles accumulated by the train up to that stop.

An example yard summary for Battle Creek Yard (Yard 837) is shown in Figure 7. Similar outputs are available for all yards in the system. The blocks are listed in the left-hand column of the figure. The arrival and departure of trains and the time and day (Julian date) of the arrival or departure are listed from left to right in time order. The effect of each train arrival or departure on each block is indicated. In particular, the net change to the number of cars in each block is indicated, and the cumulative total of cars remaining in the block is noted as a direct result of the arrival or departure of a train. Traffic brought to the yard from interchange or local industry is treated similarly to a train arrival but is denoted "TRAF."

An example cost summary is shown in Figure 8A and B. In this summary, per diem car hire costs and car hours are broken down by car destination as well as by totals. Train car miles and costs are broken down by trains and totals.

The DMP has been designed so that the simulation events are sent to a special output file, which is processed to produce the three outputs described above. For other applications, different outputs could be provided by simply processing the output file in a different fashion.

***** YARD 837 *****

CLASS	398 ARRIVES 332/208	522 ARRIVES 425/208	397 DEPARTS 530/208	337 ARRIVES 612/208	511 DEPARTS 615/208	512 ARRIVES 919/208	391 ARRIVES 942/208	-386 DEPARTS 1000/208	433 ARRIVES 1037/208	513 DEPARTS 1200/208
CHICAGO	0(53)	0(53)	0(53)	16(69)	0(69)	0(69)	15(94)	0(94)	2(86)	0(86)
CHGO CNW	0(4)	0(4)	0(4)	0(4)	0(4)	0(4)	0(4)	0(4)	1(5)	0(5)
RAILPORT	0(6)	0(6)	0(6)	0(6)	0(6)	0(6)	1(7)	0(7)	0(7)	0(7)
BISL CNW	0(60)	0(60)	0(60)	4(64)	0(64)	0(64)	8(72)	0(72)	5(77)	0(77)
BLUE I.	0(8)	0(8)	0(8)	3(11)	0(11)	0(11)	3(14)	0(14)	1(15)	-8(7)
ROCK I.	0(25)	0(25)	0(25)	6(31)	0(31)	0(31)	4(35)	0(35)	1(36)	0(36)
MILW	0(17)	0(17)	0(17)	13(30)	0(30)	0(30)	1(31)	0(31)	5(36)	0(36)
HARVEY	0(40)	0(40)	-35(5)	6(11)	0(11)	5(16)	2(18)	0(18)	3(21)	0(21)
THORNTON	0(57)	0(57)	0(57)	25(82)	0(82)	3(85)	11(96)	0(96)	11(107)	0(107)
GRIFFITH	0(19)	0(19)	0(19)	23(42)	0(42)	0(42)	0(42)	0(42)	5(47)	-19(28)
HASKELLS	0(5)	0(5)	0(5)	9(14)	0(14)	0(14)	0(14)	0(14)	1(15)	-5(10)
S BEND	0(3)	0(3)	0(3)	0(3)	-3(0)	0(0)	1(1)	0(1)	3(4)	0(4)
K'ZOO	9(56)	0(56)	0(56)	12(68)	-47(21)	2(23)	1(24)	0(24)	0(24)	0(24)
S BEND S	1(15)	0(15)	0(15)	0(15)	-14(1)	1(2)	0(2)	0(2)	1(3)	0(3)
B CREEK	3(3)	2(5)	0(5)	7(12)	0(12)	31(43)	8(51)	0(51)	3(54)	0(54)
BC CF	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
FLINT Y	0(4)	0(4)	0(4)	1(5)	0(5)	2(7)	0(7)	0(7)	0(7)	0(7)
LANSING	14(45)	0(45)	0(45)	0(45)	0(45)	0(45)	0(45)	0(45)	0(45)	0(45)
DURAND	1(14)	0(14)	0(14)	0(14)	0(14)	2(16)	0(16)	0(16)	0(16)	0(16)
HOLLY N	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	0(1)	-1(0)	0(0)	0(0)
GR RAPD	[illegible](7)	0(7)	0(7)	0(7)	0(7)	1(9)	0(9)	0(9)	0(8)	0(8)
FLINT	22(128)	0(128)	0(128)	0(128)	0(128)	15(143)	0(143)	0(143)	0(143)	0(143)
FLINT E	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)	0(3)
PT HURON	6(21)	0(21)	0(21)	0(21)	0(21)	10(31)	0(31)	-21(10)	0(10)	0(10)
SARNIA X	12(25)	0(25)	0(25)	0(25)	0(25)	11(36)	0(36)	-25(11)	0(11)	0(11)
CNT	7(49)	0(49)	0(49)	0(49)	0(49)	6(55)	0(55)	-42(13)	0(13)	0(13)
CNB	0(1)	0(1)	0(1)	0(1)	0(1)	5(6)	0(6)	-1(5)	0(5)	0(5)
CNP	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
CN SAND	0(10)	0(10)	0(10)	0(10)	0(10)	2(12)	0(12)	0(12)	0(12)	0(12)
PONTIAC	8(24)	0(24)	0(24)	0(24)	0(24)	0(24)	0(24)	0(24)	0(24)	0(24)
DETROIT	4(35)	0(35)	0(35)	0(35)	0(35)	1(36)	0(36)	0(36)	0(36)	0(36)
TOLEDO	0(13)	0(13)	0(13)	0(13)	0(13)	0(13)	0(13)	0(13)	0(13)	0(13)
DET CP	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
OVER AGE	0(237)	0(237)	0(237)	0(237)	0(237)	0(237)	0(237)	0(237)	0(237)	0(237)
TOTAL	87(283)	2(290)	-35(255)	125(1080)	-64(1016)	97(1113)	55(1168)	-90(1078)	42(1120)	-32(1088)

FIGURE 7 EXAMPLE YARD SUMMARY: BATTLE CREEK YARD

FOR THE PERIOD OF D/T 67/ 701 TO D/T 67/1400

3340 CARS AT INITIALIZATION FOR SIMULATED YARDS
995 CARS OMITTED AT INITIALIZATION
44 CARS INJECTED INTO SIMULATED YARDS BY IND AND INT
6 CARS OMITTED FROM IND AND INT INPUT

$ HOURLY CAR HIRE COST

DESTINATION YARD NO.	YARD NAME	CAR HOURS	CAR COST ($)
516	DETROIT	9266.77	
610	PONTIAC	1192.07	
617	HOLLY	1135.35	
649	GR RAPID	875.60	
767	GRNVILLE	729.67	
786	MUSKEGON	1824.17	
801	PT HURON	17845.68	
811	LAPEER	18.30	
815	TORREY	0.0	
819	FLINT	9642.85	
823	DURAND	153.30	
830	LANSING	2450.92	
831	ERIKSON	0.0	
837	B. CREEK	2340.95	
842	PAVILION	0.0	
903	S. BEND	0.0	
913	HASKELLS	280.58	
918	GRIFFITH	729.67	
951	T. JUNCT	4093.43	
952	HARVEY	3429.23	
954	BLUE I.	7359.71	
970	ELSDON	11069.75	
TOTALS		74437.94	

1 YARD(S) OMITTED FROM THE REPORT
THEY ARE - 603

(a) **CAR HIRE COST REPORT**

FIGURE 8 COST SUMMARY REPORT

FOR THE PERIOD OF D/T 67/ 701 TO D/T 67/1400

3340 CARS AT INITIALIZATION FOR SIMULATED YARDS
995 CARS OMITTED AT INITIALIZATION
44 CARS INJECTED INTO SIMULATED YARDS BY IND AND INT
6 CARS OMITTED FROM IND AND INT INPUT

NOTE — * THE TRAIN IS IN THE SYSTEM AT THE START OF THE SIMULATION TIME FRAME
** THE TRAIN IS IN THE SYSTEM AT THE END OF THE SIMULATION TIME FRAME
*** THE TRAIN IS IN THE SYSTEM THROUGHOUT THE SIMULATED TIME FRAME

*** TRAIN COST PARAMETERS ***

$	CAR-HIRE COST, PER MILE
$	CAR, PER MILE
$	LOCOMOTIVE, PER MILE
$	CABOOSE, PER MILE
$	TRAIN, PER MILE
$	TRAIN DISPATCH, PER TRAIN
$	CREW WAGES, PER TRAIN
$	LOSS AND DAMAGE, PER NET TON
$	MAINTENANCE WAY AND FUEL, PER GROSS-TON MILE

	TRAIN NO.	CAR MILES	CAR HIRE COSTS $	TRAIN MILES	TRAIN COSTS $
*	383	3995.70		70.10	
*	385	13584.80		153.30	
	386	307.60		153.80	
*	387	2949.50		34.70	
*	389	3078.40		41.60	
**	392	8581.60		122.30	
**	393	3804.10		63.40	
*	394	11365.60		123.40	
*	395	5779.20		68.80	
*	397	5250.90		76.10	
*	398	2201.80		21.80	
*	400	1256.70		17.70	
**	410	3806.90		64.10	
*	420	5.40		0.10	
*	431	2412.80		41.60	
*	433	0.0		138.90	
*	435	560.00		11.20	
*	450	492.00		12.00	
**	451	0.0		22.20	
*	452	407.10		17.70	
	453	3446.00		77.80	
**	500	7630.50		110.80	

(b) TRAIN COST REPORT

FIGURE 8 COST SUMMARY REPORT (Concluded)

III GT CONVENTIONAL OPERATIONAL PROCEDURES

GT railroad operations and procedures are fairly standard. The dispatching and yard management functions control the movement of cars on a minute-by-minute basis. The dispatching function controls the movement of trains and their associated work on the line-haul portion of the railroad, that is, between yards. The yard management function controls the switching and transferring of cars in yards from an inbound train to an outbound train.

A. Dispatching

1. Introduction

GT train operations are based on a schedule known as the "GT Freight Train Schedule and Marshalling Instructions," which specifies when trains should depart, the proposed sequence of stops, and what blocks should be picked up or set out at each stop. However, traffic varies considerably on both a seasonal and a daily basis. For this reason, dispatchers are required to modify the train schedule on a shift-by-shift basis to adjust the running of the trains to match the daily traffic and operating conditions. Although most of the trains have flexibility in the way they can be operated, certain trains ("hotshot" trains) are relatively inviolate and must be run as prescribed in the schedule. The job of the dispatcher is to run the trains in such a way as to move traffic effectively yet keep train costs reasonable; the train schedule is used as a guide.

The GT Chicago Division dispatchers are located in Battle Creek, Michigan; they control the bulk of the express and manifest train movements and tonnage. The Detroit Division dispatchers are located in Pontiac, Michigan; their operations deal with more local train operations, that is, they provide service to smaller yards and local industries. Most of the effort in this project focused on operations of the Chicago Division.

The Chicago Division dispatching operation is run by a team for each shift. Each team consists of a chief dispatcher and two assistant dispatchers (an east-end and a west-end dispatcher) who monitor and control train movements on their division. The chief dispatcher plans the power and crew for all trains on the Chicago Division and dispatches trains east and west out of Battle Creek to Elsdon and Port Huron, Michigan, respectively. The west-end dispatcher dispatches trains east out of Elsdon to Battle Creek. The east-end dispatcher dispatches trains west out of Port Huron to Battle Creek.

We describe below the following functions of the dispatching team:

- Power planning
- Caboose planning
- Train makeup
- Train cancellation
- Car pickup and setout
- Network disruptions
- Train monitoring and control.

In particular, we focus on how much planning or scheduling is done to assign power units and cabooses to a new train; how much time is given to planning a makeup or a cancellation of a train; and how much and when pertinent information is available to plan or schedule train operations.

2. Functions of Dispatching Team

a. Power Planning

Power scheduling, at present, is done manually by the chief dispatcher of the division (or an assistant chief dispatcher) in cooperation with the operations control center in Detroit. A large pegboard in the chief dispatcher's office shows, at any time, the location of each power unit, which is represented by a uniquely numbered chip. This chip not only identifies the power unit but also indicates the horsepower of the unit. The board shows whether a power unit is on a currently running train, in a yard for new assignment to a train, or in the roundhouse for maintenance or repair. Colored tags are attached to the numbered chips to indicate the status of a power unit, for example, up for monthly maintenance, something may be wrong with the unit, or something is wrong with the unit. The chief dispatcher also keeps records of maintenance schedules, which he updates as required. He also contacts the roundhouse each morning to get estimates on when units to be repaired or serviced will be available.

Under normal conditions, present power assignment and scheduling procedures are reasonably effective for 12 hours in advance. However, because of excessive power breakdowns, or extreme traffic and weather conditions, there will be times when power assignments become a problem (e.g., yards that originate trains are left without power for some time because of power shortages). Prohlems also occur when trains running times are altered since, in most cases, power units of terminating trains are transferred immediately to a departing train. Under these circumstances, the assignment of units is made more or less as a reaction to system conditions. It appears that under abnormal conditions the present planning and scheduling of power units can be improved.

b. Caboose Planning

Presently, as cabooses are not associated with a specific crew, they are interchangeable. Cabooses are monitored in a way similar to that of power units. Chips carrying the identification number of a caboose are used to show whether the caboose is on a train, in a yard waiting for a new assignment, out for repairs, or out to be serviced. Cabooses will be serviced every seven days in Chicago. The chief dispatcher keeps a caboose service log, which indicates by color code which caboose must go to Chicago to be serviced. Green means the caboose has been serviced, and red indicates the day the caboose must be serviced. This log is maintained on a daily basis. Each morning, the chief dispatcher prepares a list of cabooses that need servicing and hands this list to each shift of dispatchers for consideration. In general, under normal conditions there does not appear to be any problem in the cycling and scheduling of cabooses.

c. Train Makeup

Trains are made up in close collaboration with yardmasters. At the beginning of each shift, each dispatcher will contact the yardmasters under his jurisdiction. They will obtain from the yardmasters car counts according to destination. The yardmaster also will inform the dispatcher when a train has been built or is ready to be called. At this time the dispatcher will ascertain whether he has the power units and the crew for the train. If so, he will contact the crew dispatcher to have the crew assigned.* Crew members must be notified no later than two hours before the train is called and must have rested at least eight hours since their last assignment. A train may depart from the yard any time after the call time, but not before.

To ensure efficient scheduling of trains, each dispatcher keeps a list of away-from-home crew members presently available and a list of power units that are ready or will become ready within hours for assignment at the various yards. Furthermore, each dispatcher knows that a specific number of "regular" trains must be run daily. There seems to be a fixed set of these regular trains which are scheduled as close as possible to the existing timetable. In most cases these trains are manifiest trains that move whole blocks and need not be marshalled. Power and crews are given priority for this set of trains, and therefore power and crew are nearly always available.

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*Crew dispatching is a separate operation; it is handled by different personnel at a different location. Its main function is to manage the assignment of crews to trains and to ensure that the calling of crews upholds the agreed labor regulations.

Uncertainties in planning and scheduling of trains arise, however, when dispatchers have to make decisions about "drags," that is, trains that are not regular. Drags are made up when warranted by the traffic. In most cases, there is not enough information available at the stations about the number of cars ready to be moved by a drag.

Drags also pose a problem to crew and power scheduling. These trains are very often made up on the spur of the moment because of heavy unforeseen interchange deliveries. The dispatcher is often not aware of such a delivery until the cars have been switched at the receiving yard and are ready to be moved. Under these circumstances, power units and rested crews may not be available until a regular train is scheduled. This results in added accumulation delays to the cars in the yard and the performance of unnecessary work in the yard, namely, building a train that cannot be called. Occasionally a train already built may have to be taken apart because of lack of power.

d. Train Cancellation

A dispatcher may decide to cancel a train because the information he has gathered indicates the train will have too few cars. This information may be quite inaccurate, however, because it is not timely. This is especially true of deliveries from industry and interchange. Yet, cancelling a train may have very serious and far-reaching effects on the system. It may affect power and crew cycling, it may contribute to yard congestion, it may affect the running time of later scheduled trains because of the resultant excessive car handling and car loads, and it may cause excess accumulation delays in yards. Most dispatchers are not sure what impact cancelling of trains has on the system at the time a decision is made.

e. Car Pickup and Setout

Dispatchers also monitor the pickup and setout of cars. Unwritten rules dictate which blocks, ranked by priority, must be picked up by a specific train. For example, consider train 393. If it is known that a great number of cars with destination Harvey are in the system, train 393 could very well be a train made up only of Harvey cars. But more likely, it will be a train that gives priority to cars with destination Harvey. Consequently, at Port Huron, the originating station of the train, room will be saved for pickup of Harvey cars at other stations along its route. If it is determined that there is not a sufficient number of Harvey cars to be picked up along the route, then the train at Port Huron would be made up with other cars in addition to Harvey cars, most likely Chicago. This decision is difficult to make unless reliable information on the cars ready to be moved at various yards is known.

Depending on the time of the day, dispatchers may have little information on the number of cars that can be picked up by a train. The number of blocks and the size of blocks may not be known far enough in advance to have any effect on the planning of train operations. He will not know with certainty whether a train is going to be light or heavy unless it is a run-through train. He also cannot predict if a train, by its setout operations, will contribute to yard congestion since he does not know the state of the yard before tbe arrival of the train he is monitoring. In general, none of the dispatchers seems to know precisely the thresholds for yard congestion. Yardmasters will contact tbe dispatchers when their yards become congested. Unfortunately the dispatcher does not have this information well enough in advance to allow for alternate scheduling of trains.

f. Network Disruptions

At certain times train operations are changed because constraints are put on the network. Such contraints may be planned network disruptions or disruptions caused by untoward events. Planned disruptions are known some time in advance. They may be track outages because of track repair or slow order movements caused by rail testing at 10 mph. With planned disruptions, dispatchers will proceed to schedule trains to "work around" the disruption. However, network disruptions caused by accidents or power failures must be dealt with on an emergency basis. This may involve rerouting of trains, deadheading of power units, or changing the work schedule of a train en route. These decisions are made on an ad hoc basis as resources permit.

g. Train Monitoring and Control

Dispatchers are in direct radio contact with each train and can monitor and control train progress. Between Elsdon and Battle Creek the system is mainly double track; between Battle Creek and Port Huron the system is mainly centralized traffic control (CTC) single track. In the single track operation, the dispatchers directly control the switch settings.

If emergencies or unexpected events occur, the train crew can ask for and receive instructions from the appropriate dispatchers.

3. Improvements to the Dispatching Process

Based on observations and analysis of the dispatching operations, we conclude that information and procedures developed using the RAILS and the DMP provide dispatchers with information concerning the system-wide impacts of their decisions and could be used to improve the following aspects of the dispatching process:

- Power planning--Predictive information on traffic build-up in yards could be provided and yard congestion could be indicated.
- Train makeup--Predictive information on the size of the train and the number of cars to be picked up and set out along its route could be provided to determine whether "drags" should be made up.
- Car pickup and setout--Predicting the car counts of various blocks along the route would enable the dispatcher to determine what pickups and setouts should be made along a train's route. The DMP will allow the dispatcher to tradeoff the priorities of moving traffic and still maintain sufficient cars to run the train.

B. Yard Management

1. Introduction

The Battle Creek flat yard is located on the Chicago Division at approximately the midpoint of the main line between Elsdon and Port Huron (see Figure 9). Although the GT system has 12 primary flat switch-yards, the Battle Creek Yard is one of two which are mainly system classification yards. The other yards are mainly interchange industry yards. For this reason, Battle Creek Yard was chosen as the focus of our analysis.

The Battle Creek Yard is divided into two halves--the southern half (the East Yard) is for eastbound traffic and the northern half (the West Yard) is for westbound traffic. In fact, the yard is often run with two yardmasters. It also has nearby an associated industrial yard called City Yard, which deals mainly with industry switching activities and performs very little classification work per se.

The yard generally supports a switch engine working on each of the four leads. In addition to regular switching, crossover, and rip work, the switch engine in this yard must handle traffic flow to and from the City Yard, which includes interchange deliveries and pickups, industrial traffic, and special weighing functions. The lead layout permits switching to continue during departure and arrival of trains into the center long alleys. A CTC section of main line north of the yard provides a bypass for through trains. There is considerable inter-action between the East and West Yards. In particular, the long central tracks can be used by either side. Rip work must be crossed from the westbound side to the eastbound side.

All work for each switch crew is assigned by one yard master when traffic is light (e.g., less than 2,000 cars/day). When traffic is heavy, two yardmasters are assigned to the tower, one for each yard. Work is assigned to the switch crews by yardmasters instructing clerks to give appropriate lists to the yard conductor and by voice communi-cation between yard conductors and yardmaster over a speaker system. The yardmaster monitors operations from the tower during the shift.

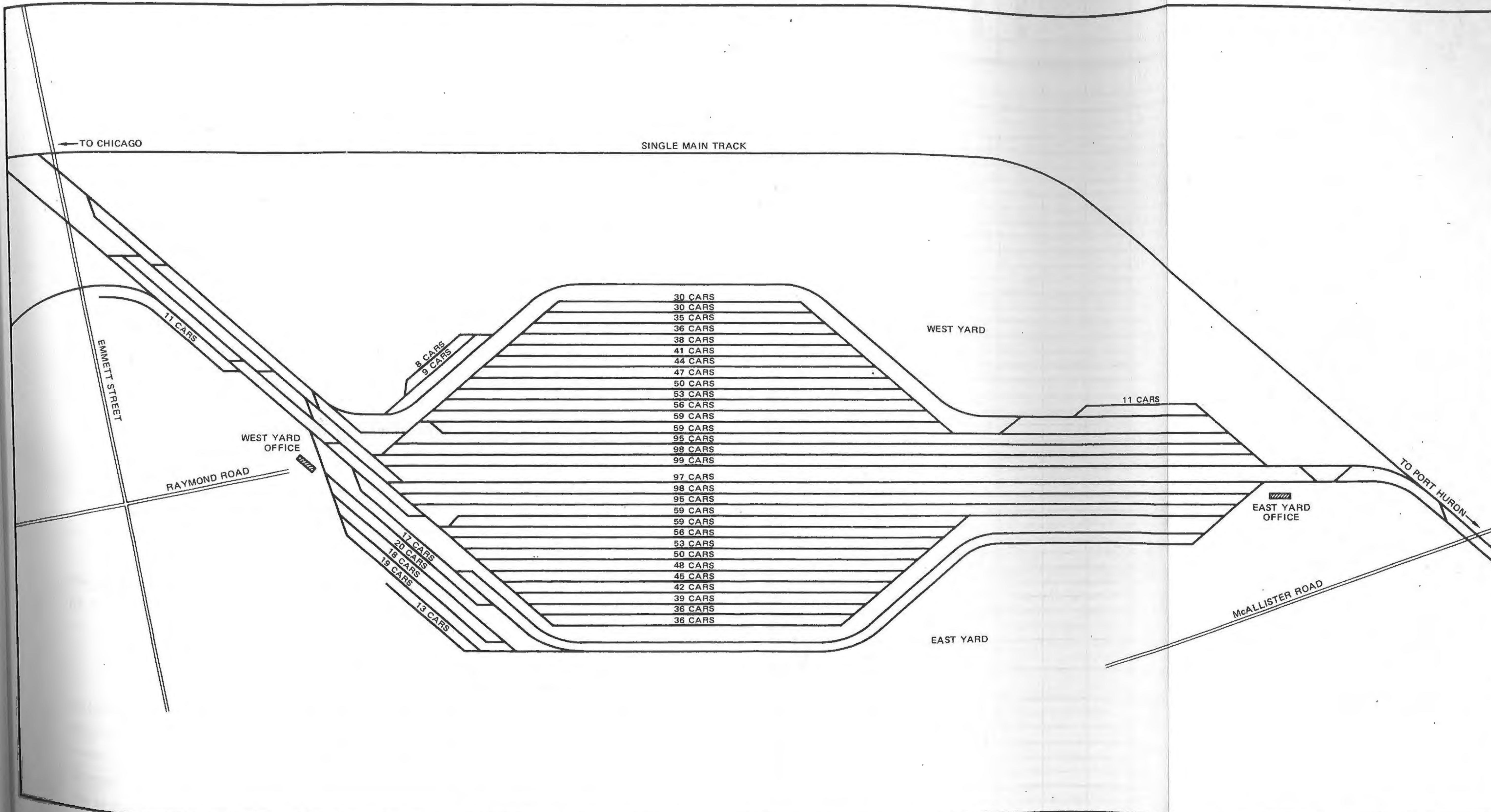

FIGURE 9 BATTLE CREEK MARSHALLING YARD

At Battle Creek Yard, inbound trains are bled by the switch crews after inspection by the car department. Occasionally the trainmaster calls in an extra yard man to assist with this task.

2. Yard Decision Making

To formalize yard operations it is necessary to identify key decision makers and key decision variables in a yard. It is especially important to point out the type of information available with which to make specific decisions. For example, it was found that the accuracy, timeliness, and form of such data as switch lists could have a profound effect on yard operations. In this section we summarize the key decision makers, their functions, and the information they use in performing those functions. A number of personnel are involved in making decisions that affect yard flow. These include:

- The trainmaster, who is in charge of yard personnel (including the yardmaster).
- The yardmaster, who makes decisions on track assignments, controls (in large part) the general order of switching, negotiates with with a dispatcher to alter call times, and runs additional trains.
- The dispatcher who plans and controls supervises the switch engine and crew line-haul movements.
- The yard conductor, who chooses where to make cuts in trains, and decide what cars to switch first..

The discussion below describes the personnel involved in the operations of the Battle Creek Yard.

a. Trainmaster

The trainmaster does not generally become involved in the detailed sequencing of switching work in the yard. He surveys a turnover sheet of standing inventory for each track at shift change times and a report of inbound trains. Furthermore, he is aware of critical traffic movement and receives telephone requests from many sources to expedite particular cars. He passes such information to a yardmaster via a "hot sheet."

b. Yardmaster

The yardmaster comes on duty 1/2 hour prior to the switch crew shift change and evaluates the turnover sheet giving the track standing inventory at shift change, a telegraphic report of inbound trains from the dispatching office, and a switching list of cars to be switched in the near term. Because much of this information flows in after the yardmaster has come on duty, the lead time for making decisions is reduced. Occasionally, a yardmaster going off duty annotates his turnover sheet to indicate where he would receive an inbound train arriving close to the shift changeover time or how he would handle other imminent events.

Using the above information, the yardmaster sends work to the switch crews. The type of work he assigns and the constraints under which he works are listed below. Based on experience and intuition, the yardmaster attempts to schedule clear tracks compatible with the switching order he has chosen.

ORDERS GIVEN BY YARDMASTER

- Switch standing traffic.
- Make local (e.g., city yard) moves.
- Pick up and deliver interchange from designated yard track.
- Assign open tracks to incoming trains and engine moves.
- Assemble ("build") classifications of cars to makeup outbound trains.
- Move repair traffic to and from rip tracks.
- Assign yard caboose and yard power moves.
- Designate when crews take lunch breaks.
- Miscellaneous (e.g., move a dangerous car so that it is a set number of cars from a train's end).

The pattern of trains arriving at and departing from a yard clearly affects yard efficiency. Because Battle Creek yard is a major originating point for trains, the yardmaster often negotiates alterations in the scheduled train makeup and departure with a dispatcher on the basis of projecting his ability to build a train given the current yard conditions.

Much of the yard master's work is based on experience and intuitive judgment. Yardmasters do not operate their yards on the basis of any formally defined, nominal set of conditions or any type of structural planning process. Little formal effort is required to schedule track and switcher usage to get the most utilization out of a yard's resources. In practice, about half of the trains yardmasters work with are unscheduled, and they have little time to experiment with alternative work plans for switch crews. Hence, the exact order of work carried out by the crews is often made by a yard conductor. There are important exceptions, however. For example, the yardmaster often builds trains against incoming car groups that are already properly blocked for outbound movement. In this case he must specify the place where a cut is to be made and the sequence in which work is to be switched.

As an aid to his decision-making process, the yardmaster may fill out a count sheet that summarizes the cars in his yard by outbound destination block. Accurate monitoring of the block situation and the ability to predict the status of blocks are critical to the yardmaster's function.

In exceptional cases a yardmaster may anticipate how he will handle an inbound group of cars that has not yet arrived at the yard. Information on such cars may come from an advanced consist or other sources and be forwarded by a trainmaster or clerk. Such planning, however, could be dangerous since errors in sources of data other than from advance consists enhanced by ACI scanners can be large. Yardmasters do not like to "gamble" and hence prefer to limit their projection of work to leaving empty tracks for receiving and making up trains*.

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*In one observed case, switching work was begun on the assumption that a large block of cars was on the head end of a train. Arrival on the rear end caused an hour or so loss in switching time.

c. Dispatcher

The dispatcher's influence on a yard is great because the sizing and time sequencing of inbound and outbound trains are critical to a yard's performance. For example, a long train (number 512 carrying 130 cars) was followed by a short train (carrying 35 cars or so). Both were held outside yard limits because (a) they arrived too close to preceding trains and (b) the yardmaster could not handle the long train immediately. Better sizing and time sequencing could have minimized this yard-related delay. In other cases, a yard could have been cleared by departing trains if line-haul power and/or crews were available at the best time for running a train.

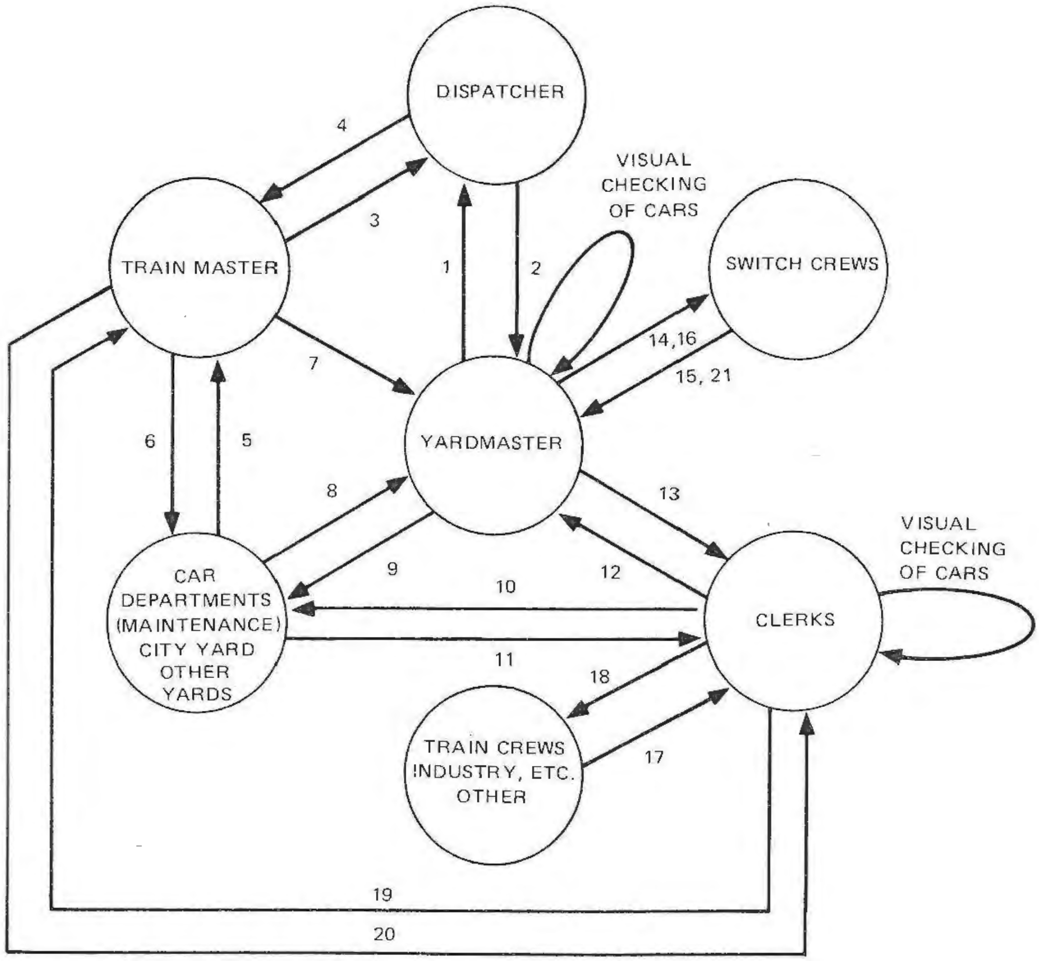
The dispatcher needs considerable lead time for decisions involving the deadheading of crews or the holding of crews at terminal pay at an away-from-home terminal. However, the information available to a dispatcher to make such decisions early is ofter minimal since yardmasters themselves do not assess outbound train requirements until inbound traffic has arrived and been inspected.

d. Yard Conductor

Yard conductors make some decisions during the switching process (e.g., where to make cuts in trains and what to switch first). It appears that it may be best for most of the decisions that are now made dynamically in the yard by the yard conductor to be made prior to the start of any switching effort--either by the yardmaster or the yardmaster and the conductor in concert. Experienced yard conductors exhibit great skill in planning, for example, how bleeding operations can be interfaced with switching, so it may be useful to incorporate their assistance in the decision-making process.

3. Overview of Yard Decision Makers and Their Interaction

Figure 10 shows a simplified picture of critical information paths and decision making among yard operations personnel during a shift.



NOTE: Table 4 gives flow parameters

FIGURE 10 CRITICAL INFORMATION PATHS IN CONVENTIONAL YARD OPERATIONS

Table 4

INFORMATION FLOW PARAMETERS FOR FIGURE 10

1.	Yardmaster to Dispatcher • Yard status--number of cars for given destinations switched and unswitched. • Expected sizes of called trains • Request for special train runs • Requests for position of trains or data on sizes of locals • Requests for altering call times
2.	Dispatcher to Yardmaster • Requests for yard status • Requests for status of trains being made up, size of blocks • Restrictions on train or block size • Call times for trains • Inbound train positions, estimated time of arrival, number of cars
3.	Special load or condition information
4.	Special load or condition information
5.	• Report flows--trainmaster is manager responsible • Special priority requests for yardmaster to assign
6.	Special priority requests
7.	Hot-car flow, special priorities
8.	Special back order moves to and from rips
9.	• Requests for inbound inspection • Ready cabooses or special repairs

Table 4 (Continued)

INFORMATION FLOW PARAMETERS FOR FIGURE 10

10.	• Pertinent car lists • Special location information for particular cars
11.	• Rip track conditions and requests • Lists of work coming from city yard
12.	• Lists of to-be-switched tracks with destinations and bad orders • Counts of other tracks and bad orders • Special lists or counts when errors suspected
13.	• Requests counts • Requests lists to be given to switch crews • Requests corrections to clerk lists
14.	• Class track assignments • Switching tasks • Lunch break permission • Special instructions or corrections for dangerous cars, etc. • When observed, corrections to erroneous switching
15.	Requests for work or special handling instructions
16.	Switch lists
17.	Inbound wheel lists
18.	Outbound lists for conductor
19.	Advance consists
20.	Special handling orders
21.	Information on portions of lists switched

In practice, two or more yardmasters can be in a tower during periods of high activity, one for each well-defined area of a yard. Also, an assistant trainmaster is on duty on each shift, and he frequently carries out the trainmaster tasks discussed above. Table 4 gives the flow parameters for each path shown in Figure 10.

4. Areas of Improvement Based on a Case Study

SRI interviewed and studied GT yard decision makers in their operating environment. Appendix A contains a description of an intensive, three-day study of yard operators at the Battle Creek East Yard. Sufficient data were recorded during the study to analyze, replay and experiment alternative ways of operating the yard. The results of our study demonstrated the potential for significant improvements in yard operations. There is room for improvement in the following areas:

- Transit times (detention times) of cars in yards can be reduced.
- Capacity of yard (its ability to keep blocking for a greater number of cars handled/day) can be improved.
- The amount and quality of blocking, given a certain number of cars to handle, can be increased.
- The switching effort required per car to move traffic properly can be reduced.

To realize these improvements in actual yard operations, the following steps must be taken:

- Improve the speed and accuracy with which data are delivered to and from the yard decision makers.
- Provide suitable formats for presenting current data to decision makers.
- Increase the time available for making decisions.
- Formalize the roles of the yardmaster, trainmaster, and others involved in the decision process.
- Tie yard personnel closer to the planning and scheduling process.
- Report yard conditions in a manner suitable for re-evaluation and review.

- Elongate the time horizon over which yardmasters plan.
- Provide the dispatcher with traffic flow projections that subsume predictable yard characteristics.

Our analysis indicate that a yard can be run "better" with accurate up-to-date, current and predictive information. In subsequent sections we describe a tactical operations planning procedure for Battle Creek Yard that takes advantage of the more accurate and up-to-date current and predictive information provided by RAILS and DMP.

IV NEW TACTICAL OPERATIONS PLANNING PROCEDURES

A. Introduction

In both the dispatching and yard management operations RAILS and DMP can provide accurate, up-to-date, current and predictive car inventory and train consists information. Without such information, dispatchers and yardmasters are prevented from effectively performing tactical (short-term on a shift-by-shift basis) operations planning. Presently, they use their accumulated experience to make operating decisions as the need arises; such ad-hoc decision making optimizes neither systemwide nor local operations.

Figure 11 shows an overview of the tactical planning process. At the beginning of each shift, the DMP simulation is run using inputs from the RAILS data base and a nominal systemwide operating plan for the shift. The DMP outputs predict the yard inventory for each yard in the system in the form of a yard summary report and train consists for all trains in the form of a train summary report which would result if the nominal operating plan were implemented. Both reports are presented to the dispatching and yard management planning personnel who attempt to develop a modified nominal operating plan within the first hour of the shift. Any exceptions to the nominal plan are negotiated and coordinated during this period of time.

The tactical planning process allows each dispatcher and yardmaster to develop a plan of his own local activities for the shift based on trying to implement the nominal operating plan, with the knowledge that others are trying to do the same thing. After the DMP predictions on yard inventory and train consists are examined, changes to the nominal operating plan are negotiated between the dispatchers and yardmasters as the need arises. In this manner, the nominal operating plan provides the central mechanism for insuring

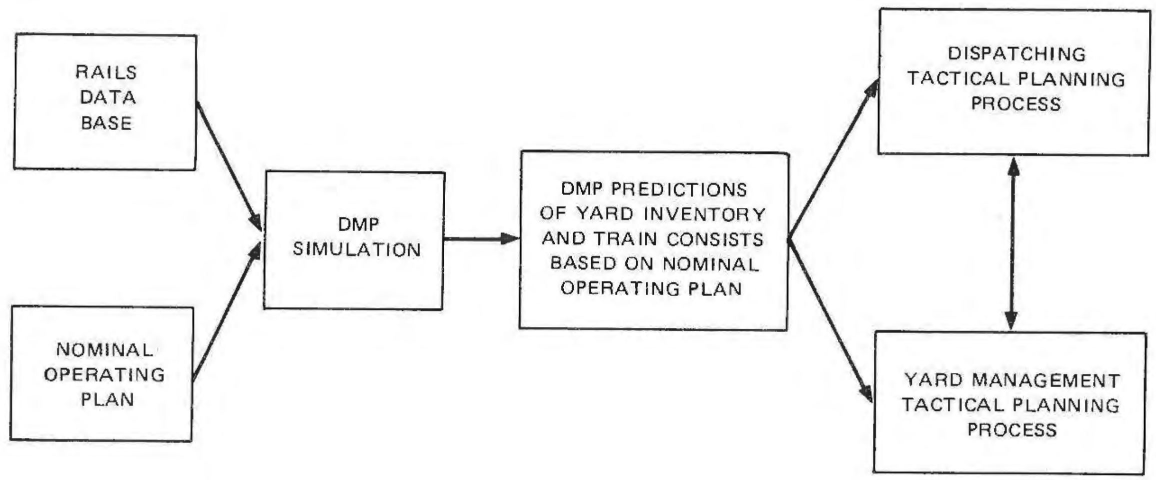


FIGURE 11 OVERVIEW OF TACTICAL PLANNING PROCESS

that local decisions are made with a systemwide perspective. Decisions to deviate from the nominal plan are efficiently communicated and coordinated as modifications or exceptions to the nominal plan. As a consequence, the planning process allows dispatchers and yardmasters to:

- Consider the systemwide consequence of decisions
- Coordinate more precisely the dispatching and yardmastering operations
- Consider the impact of current decisions on future events.

We discuss in detail below the dispatching and yard management tactical planning processes.

B. Dispatching Tactical Planning Procedure

1. Goals and Benefits

The main intent of the dispatching tactical planning procedures is to provide the dispatcher with an operating plan for the next shift that expedites the movement of traffic from a systemwide viewpoint, keeps yards from being congested, and allows efficient use of dispatching as well as yard resources (e.g., engines and crews).

As stated previously, the GT schedule has been designed for a nominal day. However, because most days are not monimal, the dispatcher must make daily modifications to the schedule. The magnitude and extent of the modifications depend on how far away the present day is from the nominal day. In general, the dispatcher can modify the nominal schedule by:

- Canceling trains, or adding extra trains
- Changing the start time of a train
- Adding or canceling scheduled stops of train
- Changing the blocks (classifications) picked up or set out at the stops.

For any specific division of the GT system, however, practical modifications to the schedule on a daily basis are fundamentally constrained by workrules, the 12-hour law, the nature of the train, terminal restrictions, and traffic priorities.

Because individual train decisions have an impact on other trains, these modifications must be orchestrated from a systemwide viewpoint. Presently, these modifications are made ad hoc based on the experience and judgment of the dispatcher. When the number of schedule modifications is small, it is likely that the experience and judgment of the dispatcher is effective. However, when the number of modifications is large, or when unusual circumstances arise, it is likely that the experience and judgment of the dispatcher can be aided by tactical planning.

Tactical planning can positively aid in dispatching in several situations. These include:

- Light traffic demand
- Heavy traffic demand
- Shortages of locomotives or crews
- Track repair or outages.

We discuss below each situation. However, because several are likely to occur on any given day the decision making for an actual day is usually more difficult than that discussed below.

a. Light Traffic Demand

In the case of light traffic demand, some trains must be canceled, and the work of these canceled trains must be reassigned to other trains (subject to the 12-hour law). The start time of trains whose work is reassigned may have to be rescheduled to accommodate the new traffic, and the systemwide impacts of the rescheduling, as well as the constraints on individual trains must be considered. Those trains which are eligible to be canceled have "pool" crews; certain trains can work at most one extra stop; trains designated "hotshot" must start on time; and trains designated "runthrough" normally do not stop at Battle Creek Yard except for a 10-minute crew change. Under light traffic conditions these "runthrough" trains can accept a "fill" at Battle Creek; however, this must be known sufficiently in advance to allow Battle Creek Yard to have the "fill" ready. Thus there are many options in moving traffic under light traffic conditions. The DMP can predict which trains will run light and thus can aid the dispatcher in deciding which trains to cancel and how to reorganize train consists taking into account individual train constraints.

b. Heavy Traffic Demand

In the case of heavy traffic demand, extra trains are likely to be added. These trains are likely to run heavy, thus slowing their speed. The work of these heavy trains may have to be reassigned so that they will carry fewer blocks, and certain yards are likely to become congested. The DMP can predict the effects of heavy traffic demand so that various actions can be implemented to relieve the system. For example, the traffic normally carried by train 386 can be projected by the DMP to be heavy enough for an extra train 2386. Alternatively, the DMP can predict when yards become congested and which blocks are unusually large. Scheduled trains or extra trains can be assigned to relieve congestion by picking up these blocks at the appropriate times indicated by the DMP. Thus, the DMP can be useful in predicting the occurrence and nature of unusually heavy traffic, and it can indicate ways to relieve congestion from a systemwide viewpoint.

c. Shortages of Locomotives or Crews

GT cannot instantaneously change the number of locomotives available for its operations. Therefore, if traffic increases unexpectedly, or if there is an unexpected number of locomotive failures, then GT could have in the short term a shortage of locomotives. In such a circumstance, trains are likely to run heavy and therefore slower than normal. This impacts the planned daily cycling of locomotives, since locomotives on trains going in one direction are cycled onto trains going in the opposite direction. Because the DMP can predict the altered running times of trains, more effective locomotive scheduling can be accomplished.

Arriving crews are required to rest for a certain number of hours before they can work again, and they must be notified or called two hours before their next departure. In certain situations, for example, when a train is unexpectedly late and there is a shortage of crews, a departing train must be delayed until the crew is ready. The effects of this delay have a systemwide impact on operations. If the delay is large, the dispatcher may have to reorder train priorities and schedule different work for each train. Because the DMP can predict altered arriving and departing times of trains, crew scheduling can be facilitated.

d. Track Repair or Outages

Frequently, portions of track are "out" or have "slow orders" for varying amounts of time due to track repairs. These track disruptions can significantly affect the running time of trains and severely impact operations under conditions of heavy traffic and locomotive crew shortages. In such circumstances, the network characteristics input to the DMP can be altered, and the DMP can predict the effect of track disruptions, thus allowing the dispatcher to make more effective modifications to the schedule from a systemwide viewpoint.

2. Overview

The new dispatching tactical operations planning procedure and how it fits into the overall dispatching operation is shown in Figure 12. RAILS is the primary information source for the procedure; it provides current information on yard inventory and train consists and predictive interchange and industry data. This RAILS information is

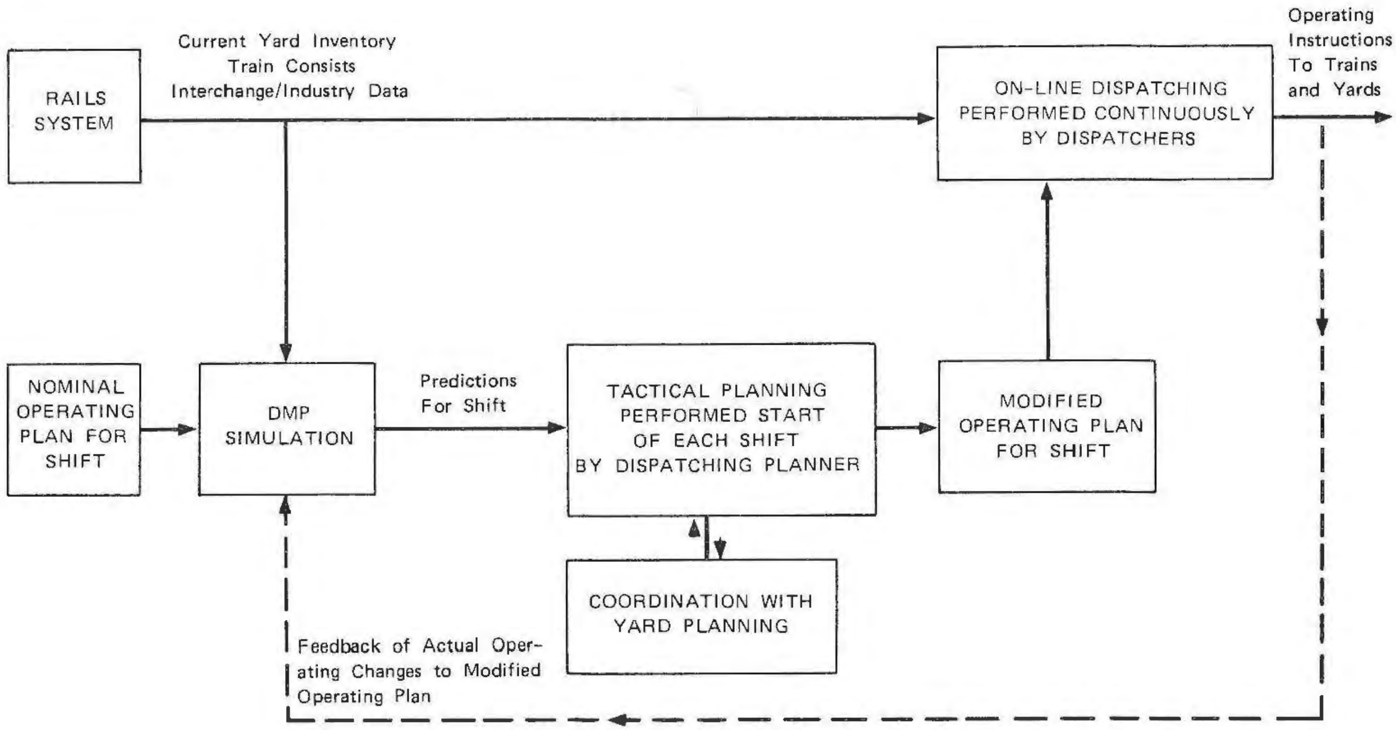


FIGURE 12 OVERVIEW OF NEW DISPATCHING PROCESS

input to the DMP simulation along with a nominal operating plan, and the DMP is run at the end of each shift. The outputs of the DMP are then available for evaluation at the beginning of each shift. These DMP outputs predict train movements and consists as well as yard loadings for a shift, assuming that the nominal operating plan were implemented.

At the beginning of each shift, the DMP predictions for the shift are analyzed and evaluated by a dispatching planner (perhaps the chief dispatcher). This dispatching planning process involves coordination with the yard planning process and results in a modified operating plan (game plan) for the shift. This modified operating plan is then given to the dispatchers to guide their decisions. It is envisioned that this dispatching planning process can be accomplished in less than an hour.

In parallel with the dispatching planning process, normal on-line dispatching operations are continuously taking place. This on-line dispatching process continuously monitors and performs the minute-by-minute decisions to run the railroad; the outputs of this process are train and yard instructions. The on-line dispatching process is aided by direct access to the RAILS data base and by the modified operating plan provided by the dispatching planner near the beginning of each shift.* This modified operating plan is used by the on-line dispatching process as a guide; depending on the "real-time" contingencies which arise, the plan will be further modified and adapted to the "on-line" situation. The main purpose of the plan is to aid the dispatcher in making decisions that take into account present and future systemwide impacts.

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*The tactical planning process takes an hour before a modified operating plan is produced. During that hour, the on-going dispatching process utilizes the "tail-end" of the modified operating plan produced from the previous shift.

At the end of each shift, the actual changes made by the on-line dispatching process to the modified operating plan and the reasons for these changes are "fed back" to the DMP simulation in preparation for the tactical planning process of the next shift.

3. Detailed Description

The DMP simulation is run at the end of each shift so that the DMP outputs can be ready for evaluation at the beginning of the next shift (see Figure 13). This requires that at the end of each shift the following information be input to the DMP:

- RAILS data on current yard inventory and train consists, and predictive interchange and industry data.
- Decisions and operating situations from current shift.
- Nominal schedule of operations for the next shift.

Much of the RAILS data will be automatically input to DMP; a large amount of the interchange and industry data will be obtained manually via telephone calls to appropriate yards or foreign roads. The DMP simulation requires information on the current operation of trains that will still be in operation during the next shift and on any abnormal system problems (e.g., track outages and slow orders). The DMP also requires a nominal schedule of operations for the next shift. The nominal schedule is essentially a "guess" on how the next shift should be run.

The DMP simulation will process the above inputs and produce the train summary and yard summary as outputs. These outputs which will be ready for tactical planning at the beginning of the next shift, predict yard inventories and train consists if the nominal operating plan were actually implemented. The result of this tactical planning process is a new, more accurate, operating plan which can be considered

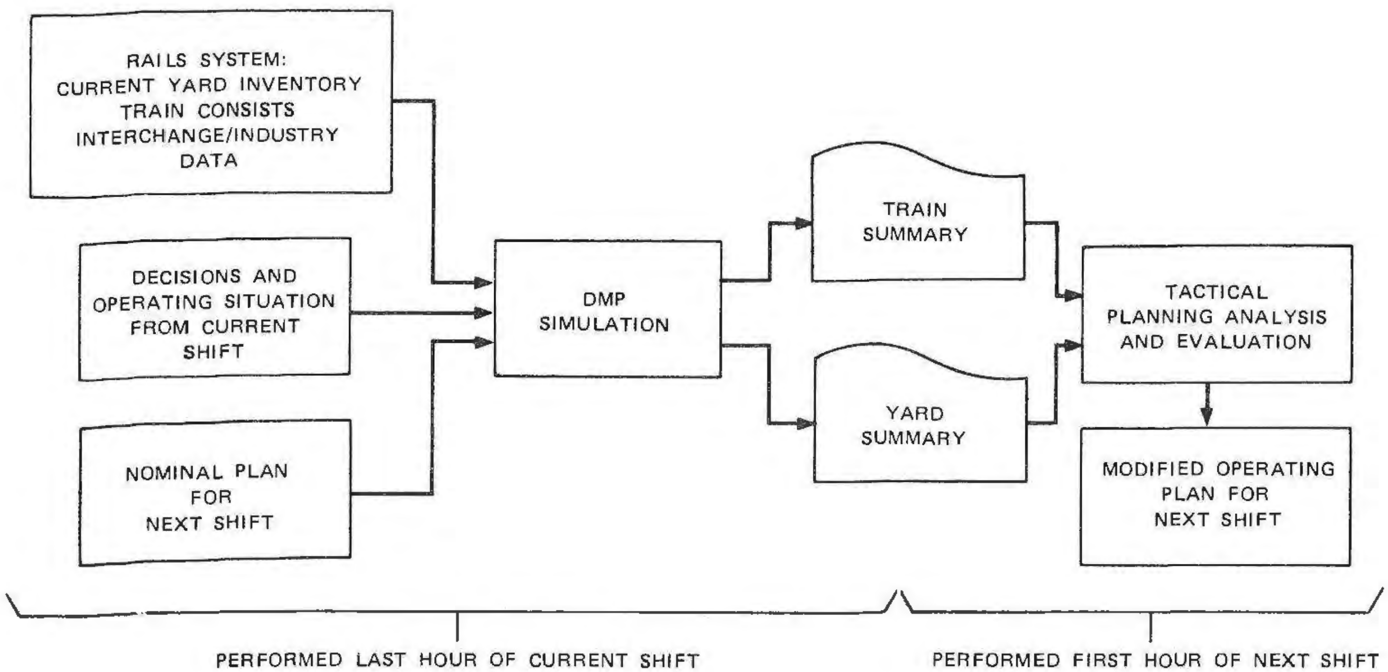

FIGURE 13 DISPATCHING TACTICAL PLANNING PROCESS

a modification to the nominal plan originally input to the DMP. The modifications to the nominal plan result from traffic conditions, operating constraints, and plant conditions not accounted for in the nominal plan.

The following scenario illustrates the manner in which the tactical planning procedure analyzes and evaluates the DMP train and yard summary outputs and produces a modified operating plan (refer to Figures 6 and 7):*

a. For each yard in the yard summary, the time at which priority blocks become exceptionally large is circled, and the time at which the yard is expected to be congested is marked.

b. Trains predicted to be either light, heavy, or late are circled and noted on the train summary.

c. Trains identified as running light are reviewed to see if they can carry some of the large blocks in congested yards identified in (a). If so, these light trains are reassigned to pick up extra traffic. The start time of reassigned trains may have to change in order to pick up the extra traffic; the expected time at which this reassigned block is ready for pickup can be estimated using the yard summary. In particular, the yard summary indicates for each block the net change in size of the block and the block size as a function of time. By noting when cars enter the yard for the block and estimating the time necessary to switch the cars, estimates of when the block is ready for pickup can be made.

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*This scenario should be considered a guide to training. Each tactical planner will develop his own method for effectively using the DMP outputs.

d. If there are no more trains available to relieve congested yards identified in (a), then extra trains must be scheduled; their start time is rescheduled to relieve yard congestion before the predicted congestion time identified in (a).

e. For those trains predicted to be both heavy and late [identified in (b)], a scheduled pickup of a block can be canceled and rescheduled for pick-up by a light train. The train summary can indicate candidate blocks (and their size) to be canceled from heavy trains and potential light trains to pick up the block. If a suitable light train is identified, then work is reassigned. The start time of reassigned trains may have to change to wait for reassigned traffic; the expected time at which this reassigned block is ready for pickup can be estimated using the yard summary and the process discussed in (c).

f. If yards are uncongested and a substantial number of trains are running light [as identified in (a) and (b)], then the "pool" trains in the train summary can be canceled one at a time and their work reassigned to the "preferred" trains until all the trains are at capacity. Some trains with reassigned work may have to have their start time set back in order to wait for traffic; the expected time at which this reassignment is ready for pickup can be estimated using the yard summary and the process discussed in (c).

In the process of analyzing the train summary and yard summary, any decisions to deviate from the nominal operating plan are communicated and coordinated with the affected yards.

The output of the tactical planning process is a modified operating plan which is used to aide the on-line dispatching process. This operating plan is recorded on a worksheet similar to that shown in Figure 14. In particular, for each train the planned call time and departure time is noted. Next, the planned stops for the train are specified. For each stop, the number of cars of each classification to be picked up or setout is noted.

C. Yard Tactical Planning Procedure

1. Goals and Benefits

The purpose of the new yard tactical planning procedure described in this section is to provide yard managers with an operating methodology that improves yard performance within the context of a systemwide operating plan. Measures of yard operating performance include:

- Transit time of cars through a yard.
- Amount of "handling" required to process each car.
- Number of blocks or classifications that can be made.
- Efficiency with which a yard can receive scheduled inbound trains and depart scheduled outbound trains with the proper classifications and tonnage.
- Speed and efficiency with which "special" functions are handled (e.g., processing wide loads or "hot" priority cars).

Yardmasters affect the performance of yard operations by the way in which they sequence tasks for switch engine crews, classification track assignments, and negotiate with the dispatcher the departure time, the classification, and the size of outbound trains to be madeup at the yard. However, the quality of yard performance varies from day to day because of many factors, including:

DATE: ____________

TIME: ____________

TRAIN	CALL TIME	PICKUPS (NO. CARS)	SETOUTS (NO. CARS)	COMMENTS AND DEVIATIONS

FIGURE 14 TRAIN INSTRUCTION SHEET

- Variability of inbound traffic in terms of:
  - Total number of inbound cars
  - Variations in the destination of inbound cars
  - Arrival times of inbound cars
  - Ordering of cars within inbound consists
- Variability in the quality and quantity of both local and systemwide information available to yard managers
- Lack of formal systemwide guidelines or procedures for tactical yard planning
- Experiences, personalities, and difference among yard personnel
- Need to process special customer requests
- Occurrence of such phenomena as equipment failure and labor relations problems.

The analysis of yard operations discussed in Appendix A indicates that the proper use of RAILS and DMP information combined with new formalized planning procedures would have an impact on the performance areas discussed below.

a. Transit Times

The yard tactical planning procedure requires that explicit tradeoffs be made on the order in which cuts of cars are switched so that the maximum number of cars can meet their connections, thus minimizing car detention time. For example, switching inbound trains in the sequence in which they arrive in the yard may not be the optimum strategy to insure that the maximum number of cars meet their earliest connection. Also, the planning procedure requires that the impact of modifying train schedules so that more cars can make a connection (thereby reducing transit times) be explicitly considered.

b. Handling of Cars

A poorly planned sequence of switching activities may require that cars be reswitched more often than necessary. Excessive reswitching can reduce yard throughput and increase transit times in yards; a second-order effect of excessive reswitching is wear and tear on equipment and a lowered crew morale. The yard planning procedure has been designed to enhance the ability of the yardmaster to plan his activities for the shift and to organize his switching activities so that a minimum amount of reswitching is required.

c. Quality of Blocking

Each yard has specified classifications into which outbound trains should be separated. In many cases, several classifications may be going to the same yard. At Battle Creek, for example, eastbound traffic classifications to Port Huron include Port Huron "boat" traffic, which is destined for CN interchange but cannot fit in the tunnel underneath a river between GT's Port Huron yard and CN's Sarnia yard and must be ferried by boat, Port Huron "mainline" traffic, which is destined for CN interchange and can go through the tunnel, and Port Huron "propers", which are destined to be delivered locally within the Port Huron terminal district. Under saturation or high workload conditions, these traffic classifications might be aggregated at Battle Creek, thereby requiring reswitching at Port Huron. This means increased car handling on a systemwide basis. Proper yard planning procedures should maximize a yard's ability to efficiently switch the classifications necessary for outbound trains.

d. Train Receiving and Makeup

Cars can be delayed if an inbound train must be held outside yard limits because of congestion of the yard receiving tracks. Avoidance of such delays depends on careful coordination between dispatcher and yardmaster and on the ability of the yardmaster to efficiently switch cars thus keeping the receiving tracks open.

Similarly, outbound trains can be delayed or be poorly sized if this coordination is poor or if the yard is not carefully managed. The yard planning process will allow the yardmaster to plan a more efficient operation and will provide sufficient warning of future problems so that early coordination between yardmaster and dispatcher can mitigate these problems. This will enhance a yard's ability to receive, makeup, and depart trains.

e. Special Activities

It is important that special yard duties such as pulling and spotting riptracks be performed promptly. Wide loads and "hot" cars often must be specially handled. The improper sequencing of this type of work can cause excessive cost, delay to all cars in the yard, and a reduction of yard throughput. The yard planning procedures require the yardmaster to look into the future and assign these special activities so that they interfere minimally with the switching activities necessary to allow cars to make their earliest connection.

2. Overview

The new yard tactical planning procedure is designed to enhance the yardmaster's ability to plan his activities for the entire shift at the beginning of the shift. By properly organizing and presenting RAILS/DMP data, more planning time will be available to make better sequencing decisions on work assignments. In the new procedure, a worksheet has been designed that contains data showing which connections all cars in the yard and cars projected to be in the yard must make. This procedure makes the effect of alternative sequences of work more transparent to yard managers than it has been in the past. The new procedure is designed to anticipate line-haul power and crew availability and to smooth shift turnover transition by providing an orderly transfer of knowledge to the next shift. The yard tactical planning process also serves as a training process for imparting the knowledge of more skilled yardmasters to less skilled yardmasters.

Figure 15 shows an overview of the new yard tactical planning process. The process begins toward the end of a shift when a yardmaster assistant, after consultation with the yardmaster, fills in a portion of the yard planning worksheet. This worksheet organizes the inbound traffic demand in a yard from RAILS advanced consists and DMP projections so that it can be scanned by a trainmaster who can detect major trends or special problems readily. The trainmaster can then assign nominal connections of blocks of cars to scheduled trains and anticipate the need for any additional trains far in advance of their required call times. When the yardmaster comes on duty for the next shift he can then scan the worksheet, discuss it with the trainmaster if necessary, and then look at the specific standing inventory lists of cars presently in the yard as provided from RAILS. Using these data, the yardmaster can annotate his worksheet with actual connections and assign work to the switch crews to balance transit time considerations and car handling factors. The worksheet can be continually annotated throughout a shift and then used as an evaluation and planning device.

3. Detailed Description

A detailed outline of the yard tactical planning procedure is presented below. It is anticipated that the process will be refined with long-term usage and that some of the counts and tabulations of the yard planning worksheet can eventually be filled in automatically by RAILS computers.

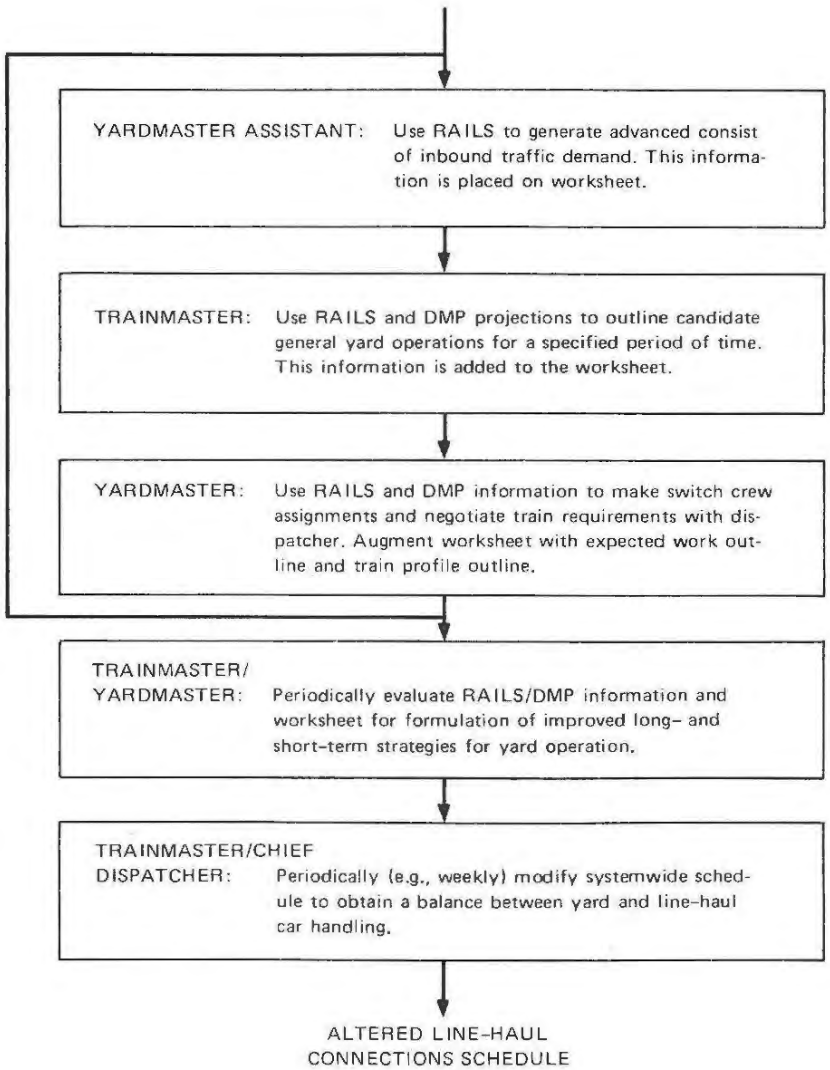


FIGURE 15 OVERVIEW OF YARD TACTICAL PLANNING PROCESS

a. Worksheet Description

The details of the yard tactical planning procedure are centered about the worksheet shown in Figure 16. We describe below the format of the worksheet.

Left Side of Worksheet -- The information on the left side of the worksheet is as follows:

- Upper-left column "Battle Creek East Yard" -- contains information on the yard's turnover. This turnover information details the status of the yard at the end of the previous shift for the new yardmaster at the beginning of the next shift. In particular, what is on the track and the number of cars are listed for each track. For example, a received train that is unswitched such as Train 512 with 73 cars to be switched may be on Track 1; Tracks 4, 5, and 6 may contain blocks of cars that have already been switched, such as 9 Flints, 20 Pontiacs, and 14 Mainlines, respectively. This information is obtained from the Yardmaster's Turnover Sheet.
- Lower-left column, "Engine Delays and Failures" -- contains the factors and times the switch engines were unavailable for work. This information is useful for an expost facto evaluation of why certain things were or were not done.

Right Side of Worksheet -- The information on the right side of the worksheet is as follows:

- Upper-right columns, "Estimated Train and Blocks Outbound" -- list the outbound trains expected to run, their expected call times, the expected blocks to be put on the train, and the expected number of cars in each block. An initial estimate of this information is provided by the nominal operating plan. The information is continually refined during the yard planning process and through negotiation with the dispatcher.

BATTLE CREEK EAST YARD

SHIFT/DATE ______
CLERK ______
TRAINMASTER ______
YARDMASTER ______

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
I-T	
O-T	
Rip	

ENGINE DELAYS AND FAILURES

		PORT HURON	BOATS	TUNNEL (Mainline)	FLINT	DURAND	TOLEDO	DETROIT	PONTIAC	LANSING	SHORTS	CITIES	WESTBD	BAD ORDERS	NO BILLS				
		801	801-CNB	801-CN	819	823	516-DTS	603	610	830		837							
1	TOTAL READY TO MOVE (SWITCHED)																		
	OVERAGE CARS																		
IN YARD TO BE SWITCHED																			
2	TOTAL TO BE SWITCHED																		
INBOUND THIS SHIFT																			
3	TOTAL INBOUND THIS SHIFT																		
4	TOTAL INVENTORY HANDLED THIS SHIFT (1+2+3)																		
5	EXPECTED OUTBOUND MOVEMENT																		
6	PROJECTED TURNOVER																		
LATER INBOUND																			

ESTIMATED TRAIN AND BLOCKS OUTBOUND

TRAIN		TRAIN	
NUMBER	DESTINATION	NUMBER	DESTINATION

DANGEROUS CARS

CAR No.	LOCATION	REPORTED TO:

HOT CARS, TRANSFER, SPECIAL MOVES

FIGURE 16 YARD PLANNING WORKSHEET

- The middle right column, "Dangerous Cars" -- provide information on the location of dangerous cars in the yard and on which crews have been notified of this fact before moving the dangerous cars.

- Lower right column, "Hot Cars, Transfer, Special Moves" -- contain special instructions for priority movement of cars, blocks, or trains. Hot cars are a group of cars which must make certain connections. This information comes from the yard hot sheet.

Middle of Worksheet -- The various outbound classifications and their station numbers are listed along the top of the middle portion of the worksheet. The following information can be entered in the rows:

- "Total Ready to Move (Switched)" -- lists the total number of cars that have already been switched. Within this first row the number of cars already switched which are considered "overaged" are noted. This information is obtained from the yard count sheet.

- "In Yard to be Switched" -- list for each received train in the yard not yet switched the number of cars for each classification. This information is obtained from switch lists.

- "Total to be Switched" -- totals the cars in the yard to be switched (i.e., the sum of entries in "In Yard to be Switched").

- "Inbound this Shift" -- list for each future train to be received in the yard during the shift, the expected number of cars. Advanced consist information from RAILS is used for trains that have already departed a neighboring yard and are to arrive in the near future. DMP projections are used for trains not yet made up and departed.

- "Total Inbound this Shift" -- totals the cars not presently in the yard that are expected to be switched during the shift (i.e., the sum of entries in "Inbound this Shift").

- "Total Inventory Handled This Shift" is the total number of cars already switched plus the cars expected to be switched during the shift (i.e., the sum of rows labeled 1, 2, and 3).
- "Expected Outbound Movements" -- gives the totals for each classification expected to leave the yard during the shift. This information is obtained from the number in "Estimated Train and Blocks Outbound" in the upper-right column of the worksheet.
- "Projected Turnover" -- gives the number of cars by classification expected to be in the yard (i.e., row labeled 5 subtracted from row labled 4).
- "Later Inbounds" -- lists for trains expected to arrive in subsequent shifts (not this shift) the expected number of cars for each classification. This information would come from DMP projections and is mainly advisory for the present shift.

b. Steps in the Tactical Planning Procedure

We describe below the detailed yard tactical planning procedure in terms of the steps involved in using the worksheet in Figure 16.

Step 1 -- A yardmaster assistant uses a RAILS terminal and yardmaster work assignments (delivered verbally to the assistant by the yardmaster) to fill out data required for yard planning on the worksheet. These data are as follows:

- A projected yard turnover consisting of the content of each track in the form of either number of cars and their classification or an inbound or outbound train number and number of cars. This turnover information is placed in the upper-left columns: "Battle Creek East Yard."

- The number of classified cars for each block that is already switched is entered into "Total Ready to be Moved." This is obtained from RAILS adjusted for the cars that will be added or deleted to the track by switching assigned by the yardmaster via switch lists that he has issued through RAILS.
- The number of unswitched cars for each block for each unswitched received train is entered in "In Yard to be Switched." Each grouping is identified by train number, interchange source, or other grouping, such as crossovers or industrial movements. These block counts will be available from previous planning sheets for long-standing trains, from advanced consist summary reports transmitted by RAILS, and from counts off the RAILS "list" report.
- The number of cars for each block on each known inbound train is listed by train number, interchange, or industrial connection and entered in "Inbound This Shift." Advanced consist summaries and lists from RAILS are required to get these data. Occasionally critical data must be obtained by telephone or estimated. Estimated data should be followed by "est."

Step 2 -- A yardmaster fills in upper-right columns, "Estimated Train and Blocks Outbound," the scheduled outbound train numbers (including any specials or extras) called by the dispatcher. He fills in times and the preferred classifications for those trains. He then does a preliminary assignment of blocks to those trains. He notes any particularly short connection times or train sizing problems. The number of cars for each destination would not be filled in initially. However, during the process, the sum for each classification on each train would be estimated and noted beside each outbound train; these estimates would continually be refined.

Step 3 -- The oncoming yardmaster reviews the planning sheet for reasonableness. If he spots potential schedule or connection problems, he immediately notes and contacts the dispatcher and/or trainmaster to negotiate possible changes or anticipated problems.

Step 4 -- The yardmaster makes switching assignment to his crews by annotating the worksheet. As estimates of the classifications and numbers of cars making outbound trains become clear, he writes the estimates in the upper-right columns labeled "Estimated Train and Blocks Outbound" for each outbound train. Also, the number of cars either switched or to be switched for each classification specified in the middle rows is annotated with the connecting outbound train number, when this decision is made.

Step 5 -- The yardmaster continues to annotate the worksheet throughout his shift in the manner described in Step 4. Information on later inbounds is added throughout the day from RAILS advanced consist summaries.

Step 6 -- The yardmaster continually projects train and other requirements for 12 hours or so in advance and notifies the trainmaster/dispatcher of the desirability of potential operating changes to the nominal plan. Factors that could modify the nominal plan from the yard's viewpoint include:

- Unacceptable bunching of inbound trains.
- Unacceptable (e.g., too large) sizing of inbound train.
- Unusual block buildups (e.g., too few or too many of a given classification for a train or track).
- Unusual car distributions in a train (e.g., 20 Flints already blocked on a train can leave on thoroughfare and build against Flints immediately).
- Desirability of running extra trains or cancelling scheduled trains.
- Desirability of mine-running certain traffic from or through the yard.

Step 7 -- The yardmaster assistant continues to monitor and update the worksheet. Actual connections and train compositions should be annotated when a train leaves.

Step 8 -- A yardmaster assistant can use the worksheet for the next shift by extrapolating turnovers and copying over unswitched inventory information.

Step 9 -- The sheets will be stored and saved for evaluation of schedule and operating policy on a regular basis.

Step 10 -- Yardmasters will compare DMP yard projections with actual. Dispatcher/yardmaster discussions can center around exceptions to the nominal plan.

Preliminary experience with yard operations has shown that it will be necessary to iterate experimentally on the best times and persons for the performance of individual tasks in the planning procedure. Yardmasters and trainmasters who are not used to operating with formal planning tools must alter their whole modus operandi to accommodate the procedures. The natural tendency of yard personnel is to continue operating with classical procedures, while regarding the planning form as additional recording that must be done over and above their old job.

With the planning worksheet it is anticipated that switch engine work assignments can be made faster than previously has been possible. In a busy situation in the East Yard (e.g., over 1,000 cars per day inbound), an experienced yardmaster handling a shift can generally take one to two hours to assign four hours of work to two switch engines working both ends of the yard. This includes the time required to evaluate yard conditions, mark lists, read a turnover list to each of his switch engine crews, make lists, and cut points to the crews. Actual assignment of work will take less time with the worksheet since switching priorities should be easier to determine than in the past.

V EXPERIMENTAL EXAMINATION OF TACTICAL OPERATIONS PLANNING PROCEDURES

A. Goals and Experiment Organization

The on-line experiments of the tactical planning procedures were implemented during the week of July 25, 1977. The goals of the experiment were to assess the viability of the procedures in a real operating environment and to evaluate improvements to railroad operations. The assessment and evaluation were predicated on using a quantitative MOE (measure of effectiveness) statistical analysis and obtaining the subjective judgments of GT personnel involved in the experiment.

Detailed preparation for the on-line experiments began in January 1977, when a preliminary experiment plan was agreed on. This plan involved establishing the logistics, communications, and staffing needed to run the DMP simulation at GT Detroit headquarters and teleprocessing the DMP outputs to the Battle Creek dispatching and yard offices. A list of MOEs to be monitored before the on-line experiments and the means to obtain them from existing GT data sources were devised; SRI started collecting some of these MOEs in February 1977. In March 1977, the main portions of the DMP simulation were debugged and installed on GT's IBM 370/135 computer at Detroit headquarters. In May 1977, the remainder of the DMP simulation concerned with the RAILS and teleprocessing interfaces were installed on GT. At this time, Mr. N. Lay, Manager--Operations Planning at GT, was completely trained to run the DMP simulation, and selected GT staff began in-house training in the tactical planning procedures developed by SRI. During the week of June 13, 1977, a complete "dress-rehearsal" was staged; GT staff used the tactical planning procedures and made "paper decisions." (These decisions were not actually implemented to run the railroad.) Further training of GT staff and certain refinements to the procedures were implemented in June and July 1977.

The operations of the experiment involved three locations: Detroit headquarters, Battle Creek dispatching office, and Battle Creek yard office (see Figure 17). At Detroit, the DMP simulation was run just prior to the beginning of each shift, and the DMP outputs were teleprocessed via RAILS to printers located in the dispatching and yard offices. However, before a DMP simulation could be run, operations status data for the shift on traffic, train, locomotives, and track conditions were obtained over the telephone from the Battle Creek dispatching and yard offices and other field sites. The experiment team consisted of SRI personnel who ran the simulation (i.e., "DMP operators") and GT personnel who obtained operations status data by telephone (i.e., "DMP input analysts").

The Battle Creek dispatching office performed the dispatching tactical planning functions, provided operations status data for the DMP in Detroit, and implemented dispatching decisions (see Figure 17). The experiment team at the Battle Creek dispatching office consisted of GT/SRI personnel who performed the planning functions and phoned operations status data to Detroit (i.e., "dispatching planners"), and the actual dispatcher who made dispatching decisions (i.e., "real dispatcher"). Prior to the beginning of a shift the dispatching planners would phone operations status data to Detroit; when the DMP outputs were received, the dispatching planners would perform the tactical planning functions. The outputs of this planning process would then be available early in the shift to assist the real dispatcher in his decision making throughout the entire shift.

The Battle Creek yard office performed the yard tactical planning functions, provided operations status data for the DMP in Detroit, and implemented yard operating decisions (see Figure 17). The experiment team at the Battle Creek yard office consisted of GT/SRI personnel who performed the planning functions and telephoned operations status information to Detroit (i.e., "yard planners"), and the actual yardmaster who made yard operations decisions (i.e., "real yardmaster"). Prior to the beginning of a shift, the yard planners would telephone operations status data to Detroit; when the DMP outputs were received, the yard planners would perform the tactical planning functions. The

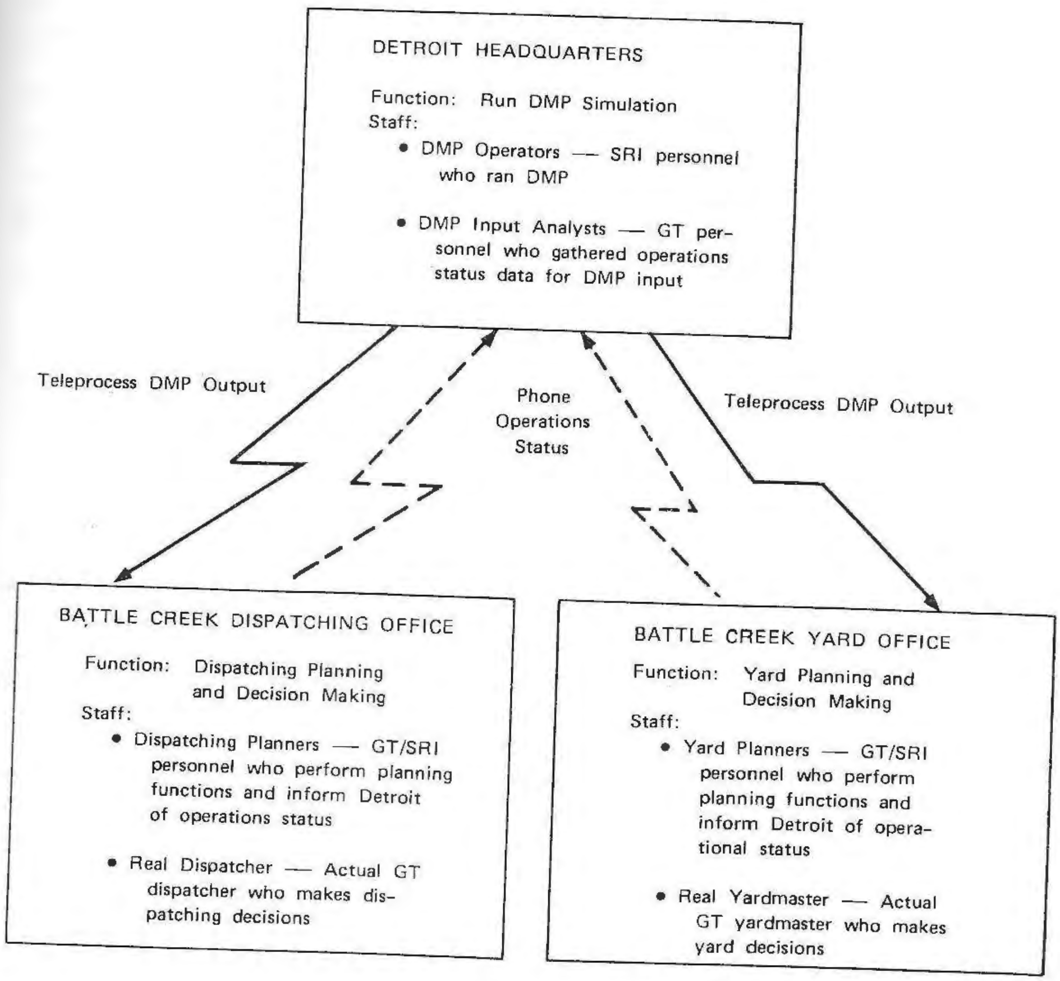


FIGURE 17 EXPERIMENT LOGISTICS AND STAFFING

outputs of this planning process would then be available early in the shift to assist the real yardmaster in his decision making throughout the entire shift.

B. Operational Scenario

During the week of July 25, 1977, the Chicago Division line-haul trains and the eastbound operation at Battle Creek yard were operated for approximately 48 consecutive hours using the tactical planning procedures developed during this project. All three shifts were manned by a GT/SRI experiment tean at Detroit (four people per shift), Battle Creek Dispatching office (two people per shift) and Battle Creek yard office (two people per shift). The team did not include the normal operations people at these locations. The DMP simulation was run so that output reports would be ready for transmission three times per day at approximately 0700, 1400, and 2200 hours. At these times the outputs were teleprocessed from Detroit to the Battle Creek dispatching and yard offices.

The General Manager of GT operations issued instructions to all operating personnel that the train schedule and marshalling instructions developed for each shift by the tactical planning procedures should be followed explicitly during the experiment period. This insured that the entire system would be run according to a central plan and that deviations from the plan would occur only after being communicated and coordinated with the experiment team.

The typical experiment events for a shift at each of the three locations are briefly described below.

1. Events at Detroit

Although the tasks of the DMP operators and the DMP input analysts were performed simultaneously, we describe their activities separately

The DMP input data acquisition needed to supplement the RAILS data base was done via telephone by two members of the GT staff (DMP input analysts). These two analysts were selected because they were knowledgeable of GT train operations, the GT physical plant, and the GT RAILS data processing system.

For each shift, one hour before report transmission to the dispatching and yard offices at Battle Creek, the two input analysts tested GT data processing and communications systems. This entailed testing the operational status of the front-end processor and the three operating node computers, and checking on the state of the DCOL system. It also entailed examining systems control devised and the concentrator that governs the CRT and printer functions. The analysts also determined whether the field printers in Battle Creek were tested prior to transmission to insure proper data transmission at DMP report time.

The most important task of the DMP input analysts was to obtain advance consists of traffic from industry and interchange. GT yardmasters and clerks at Elsdon, Blue Island, Flint, and Port Huron were contacted by telephone to get the latest information and counts on actual and expected car arrivals. If, at DMP run time, such information was not available through GT channels, foreign roads were consulted by telephone.

The analysts collected railroad systems status data as well. For each shift, calls were made to the dispatcher at Battle Creek to inquire about known operational changes to the network and the train schedule. Network modifications often included delays in one direction over a certain stretch of the road to account for track maintenance, either for the entire simulation period or for a shorter time interval. Train schedule changes, for the most part, consisted of canceling trains, changing block pickups and setouts, altering train makeup time, or changing a train's final destination.

Input anlaysts had from 30 minutes to 50 minutes each shift to acquire and evaluate operational changes, advance consist, and industrial and interchange traffic data.

During the experiment, preparation of input cards and DMP program execution were handled by two DMP operators. As exactly one hour before scheduled DMP report transmission time, one of the operators would "freeze" the RAILS data base, and a program was initiated to scan the data base for pertinent yard and train car records. Scanning the data base can take from 15 minutes to 30 minutes, depending on the load of the computer system.

While the scan of the RAILS data base was going on, the other DMP operator would discuss with the analysts industrial and interchange data and changes to the network and train schedule. Input cards were prepared by the DMP operator as necessary.

Upon completion of the scan of the RAILS data base, the DMP operator executed the DMP car record processing programs. These programs produce the DMP compatible input files from the RAILS data base. With all DMP input files estabished, the simulation was run and upon its completion yard summary and train summary reports were generated. The DMP simulation itself took about 10 minutes to run.

DMP analysts would then examine and evaluate the yard and train reports and check them for data consistency. If these reports met with their approval, they were teleprocessed by one of the DMP operators to the yard and dispatching offices in Battle Creek.

The amount of time and effort required per shift for processing the RAILS data base, obtaining additional inputs via telephone calls, and executing the various DMP programs fluctuated from 55 minutes to 75 minutes. These times include data and report evaluations.

2. Events at Battle Creek Dispatching Office

About two hours before DMP report transmission from Detroit, the dispatching planner gathered information about the state of the railroad network; this information included which tracks were out of service or had slow orders (e.g., for track maintenance), and for what periods of time. The dispatching planner also determined what deviations from the previous shift's tactical plan had taken place. He discussed with the dispatchers whether any special constraints (e.g., hot cars or special movements) might determine what trains would or would not run.

At approximately one and one half hours before DMP report transmission, the dispatching planner discussed with the yard planner the status of the Battle Creek yard and dispatching operations. Approximately one hour before DMP report transmission, the dispatching planner called the DMP input analyst at Detroit to provide information for the current shift's DMP run. After this call was made, a test message was sent over the teleprocessing network to ensure that the field printers and communication lines were properly operating.

After the teleprocessing of the DMP reports began, it took approximately 30 minutes to completely print out the DMP train summary and yard summary reports. During the next 45 minutes to 60 minutes, the dispatching planner analyzed the reports in a manner similar to that described in Section IV. During this process the dispatching planner found out from the dispatchers the availability of power and crews. Decisions on what trains would run, when they would run, what they would carry, and what pickups and/or setouts would be made were recorded on the train instruction sheet (see Figure 14).

After the train instruction sheets were filled out, another telephone call was made to the yard planner. The dispatching plan as represented by the train instruction sheet was negotiated and modified as necessary based on yard capabilities. After this was done the train instruction sheets were given to the dispatchers who ran the railroad according to the developed plan.

The dispatching planner retained a copy of the train instruction sheet on which he recorded observations during the remainder of the shift on how well the plan was followed and why deviations, if any, occurred. A train's actual load was recorded for later comparison with a train's predicted load.

3. Events at Battle Creek Yard Office

The yard plan preparation period generally started about three hours before DMP report transmission. At that time, the yard planner (with the assistance of the yardmaster) began to gather the necessary information to fill out the yard planning worksheet (see Section IV.C and Figure 16). This information was obtained from turn-over sheets, constant updates of yard inventories from the yardmaster, advance consist block summaries, and interchange data.

Approximately one and one half hours before DMP report transmission, the worksheet was filled out as completely as possible without DMP predictive information. At that time the yard planners had a pretty good idea of the state of the yard. A telephone call was then made to the dispatching planner at the dispatching office to share information. After this telephone call the field printer was tested.

Until DMP reports were received, the yard planner continuously modified and updated the yard worksheet as new information was obtained. When the DMP reports were received, those portions of the worksheet dealing with planning operations further ahead in time could be completed.

A new yardmaster normally arrived for the next yardmaster shift at approximately the time the DMP reports were received. As soon as possible the new yardmaster received a copy of the worksheet started by the yard planners and the departing yardmaster. This worksheet contained yard turnover information as well as outbound train projections and status information on standing or known inbound trains. Outbound train projections specified desired scheduled departure times and their preferred classifications.

Upon receipt of this worksheet, the new yardmaster assessed the yard condition and ascertained whether he could make the necessary connections to meet the projected outbound train schedules. This initial assessment took approximately 10 minutes.

After the initial assessment, the yardmaster scanned the switch lists to make work assignments. Initial work assignments to the switch crews normally took about 30 minutes to 40 minutes, including switch list inspection and reading work instructions to the crews. Occasionally, switch list generation was late, which delayed the work assignment task and forced the yardmaster to speculate on the connections for the unlisted inbound traffic since the exact distribution of the train's cars by outbound destination was not known.

After handing out the switching work, the yardmaster then updated his worksheet with new information on any inbound trains. (The updating of the worksheet is a continuing process.) Next the yardmaster updated his projection of outbound train sizes. This took about 15 minutes to 30 minutes.

Approximately one and one half hours after the receipt of the DMP reports, the yard planner telephoned the dispatching planner to indicate changes he wanted to make in the schedule. The dispatching planner indicated agreement or disagreement with the changes and any other useful data he might have. This telephone call generally took less than 5 minutes.

Toward the end of the shift the yardmaster and the yard planner projected a fairly accurate turnover and started a new worksheet that would be turned over to the next yardmaster.

C. Evaluation of Results

The evaluation of the results of the experiment is discussed below in terms of dispatching (i.e., line-haul) and yard management.

1. Dispatching

a. Evaluation Plan

To determine the effect of tactical operations planning on improving dispatching and line-haul operations, the following plan was devised:

- Monitor the effect of the tactical planning procedures on a selected set of MOEs
- Determine accuracy of predictions of the planning procedures
- Obtain the subjective judgments of operational personnel

A preliminary set of MOEs was developed assuming no practical difficulties in obtaining the data. This preliminary set of MOEs was refined and modified based on a study of what data are currently available and could be processed from the existing GT recordkeeping and reporting system. For those MOEs that were considered important yet not easily available, special provision was made to obtain the data. The eight MOEs selected are listed and defined in Table 5. Most of them were monitored both for the six-month period prior to the experiment and during the experiment. The plan was to determine whether the procedures used during the experiment period improved the performance of the railroad as measured by the MOEs.

Critical to the success of the tactical planning procedures was the accuracy of the predictions. If the predictions of DMP were sufficiently accurate for 8 to 12 hours in advance, then the planning procedures were likely to be useful and effective. For this reason, the second part of the evaluation plan was to determine quantitatively the accuracy of the predictions.

In many ways, the acceptance by operations personnel who implement new railroad procedures, is the true test of whether these procedures are useful and effective. Operations personnel can provide the "gut-level" evaluation, which in many cases is more important than any quantitative evaluation. If operations personnel do not think the new procedures will work, then they will not work, since ultimately they

Table 5

RAILROAD OPERATIONS MEASURES OF EFFECTIVENESS

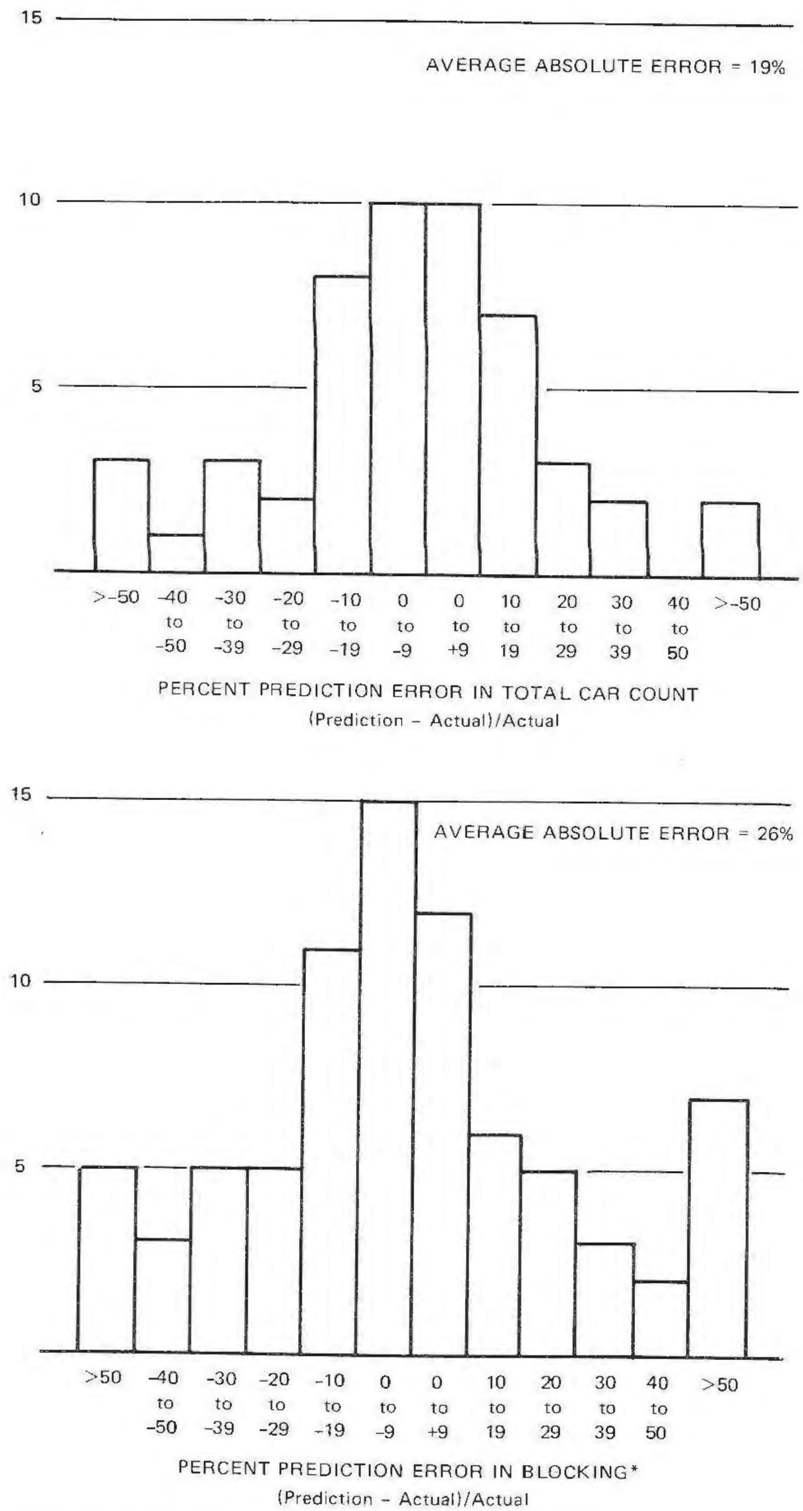
Measure of Effectiveness	Definition
Terminal detention time	Difference between actual and ordered train departure times
Average train speed	Total train miles/total transit time
Gross ton miles per train hr	Total gross ton miles/total transit time
On-time record at destination	Difference between actual and scheduled train arrival time
Gross tons handles per engine	Total gross tons/total engine horsepower
Cars handled per train	Total number of cars either pickup or setout
Cars handled per yard engine	Total cars handled/total yard engine hours
Yard detention time for specific pool cars	Difference between time in and out of Battle Creek yard for specific pool cars

determine the success or failure of any new operational procedures. For these reasons the subjective judgments of the dispatchers and yard masters were considered an important part of the evaluation plan.

b. Results

The results of the MOE analysis is provided in Appendix B. In summary, it was found that the MOEs exhibited a wide range of variabilities in the six-month period before the experiment, that is, the statistical variance was large. These large day-to-day variabilities were caused by variations in traffic conditions, weather, power and crew availability, and network disruptions, which are outside the control of the experiment. Because of such variabilities the effect of the planning procedures of the MOEs monitored during the experiment were completely masked and undetectable. A further statistical analysis was conducted to determine the number of experiment days necessary to detect a 10% change in each of the MOEs. In some cases, the number of days ranged from approximately 30 days to 150 days; and in other cases the MOE data were so random that an excessively large number of experiment days would be required to show statistically significant results.

During the experiment, the tactical planning was done routinely 8 to 12 hours in advance (which was the goal of the project) and in some cases 16 to 20 hours in advance. For dispatching, the major factor in prediction accuracy was the ability to predict far enough the total train size and the block counts on the trains. Figure 18 shows a histogram of the prediction errors for total train size and train block counts where the average value of the absolute prediction error for train size 19% and for block counts is 26%. For purposes of planning 8 to 12 hours in advance whether a train will or will not run and what blocks will be on it, these accuracies were considered satisfactory. Most of the trains had accuracies better than these averages; the average errors were increased by a small set of trains whose errors were large. The large errors for these small set of trains were caused by imperfect



*Prediction error calculated for blocks with actual count >10.

FIGURE 18 PREDICTION ERRORS

interchange and industry information. Because the dispatching planner knew which interchange and industry data were likely to be bad, in the planning process he knew which trains were likely to have larger uncertainties in their predictions. Consequently, the dispatching planner could make contingency plans for these trains, in the planning process, that is, he could make provisions to add extra "fill" cars. Because the dispatching planner knew which trains were likely to have predictions inaccuracies, he was able to compensate so that the planning process was viable.

On last day of the experiment, a debriefing meeting was held to obtain the opinions of all those who participated in the experiment. The GT dispatchers and yardmasters on the experiment team who were skeptical at the beginning of the project, were uniformly positive during the debriefing. Their main points are summarized as follows:

- The experiment proved the feasibility of tactical planning and systemwide coordination.
- The experiments showed the importance of having dispatchers and yardmasters work from a common manifest schedule or "game plan."
- The planning procedures coordinated dispatching and yard operations so that counterproductive activities were minimized and thus made a more efficient operation from a cost and resource viewpoint.
- The planning procedures should provide more consistent service for customers since everyone is working from a central plan and deviations are coordinated.

c. Concluding Remarks

The experiments were successful in the sense that they proved the feasibility of implementing the tactical planning procedures developed during the project. Although we were not able to demonstrate conclusively through a statistical MOE analysis that railroad operations improved, operational personnel felt that if dispatching and yard operations were planned and coordinated, more consistent service could be provided with more effective utilization of railroad resources.

The experiment and the associated "before" and "during" MOE analysis (see Appendix B) indicate that more research needs to be done in selecting an appropriate set of MOEs that is reasonably obtainable using existing railroad reporting procedures and data bases, and in performing a statistical experiment design analysis to ensure that the cause of the day-to-day variations can be factored out and that the experiment sample size is sufficiently large.

2. Yard Management

a. Evaluation Plan

The yard-related activities associated with the tactical planning experiments carried out during the week of 25 July 1977, were centered on using the yard worksheet planning procedures (see Section IV and Appendix A) to make yard operations more efficient and to coordinate systemwide decisions being made at the chief dispatcher's office. To do this well, the yard planning process had to meet its initial design objectives, which were to:

- Consolidate the planning information available to yard personnel.
- Formalize the shift-to-shift transfer of yard planning information.
- Formalize yard-dispatcher negotiations.
- Use RAILS and DMP to extend yard planning capabilities up to 20 hours ahead of a given shift changeover. This includes listing information on (1) inbounds up to 8 hours in advance of their expected arrivals, (2) yard tracks and block inventories, (3) outbounds planned from Battle Creek up to 20 hours ahead of their forecast call times.

The experiment lasted slightly over two days and included seven consecutive 8-hour shifts of yard operations. A 4-hour plan preparation period preceded that start of each shift, during which a planning worksheet was prepared for the incoming yardmaster by the GT/SRI yard planner. The worksheets included available inbound and yard inventory information, certain block connections that appeared obvious to the experiment controller team, and the outbound lineup prepared during the previous shift. The worksheets were numbered to correspond to each planning period and the shift during which the plan was to be deployed. Table 6 lists the planning periods and their corresponding preparation and deployment periods by meeting time and date.

b. Results

Excution of Planning Process--The description of the typical events at the Battle Creek yard office during the experiment (Section V. B.3) documented several significant changes in the execution of the planning process discussed in Section IV. C.2. These included:

- The execution of the trainmaster role by GT yard controllers and yardmasters.
- The execution of most yardmaster assistant tasks by SRI/GT controller teams.
- The entering of DMP inputs to the yard planning procedure indirectly (through dispatcher inputs) with RAILS and telephone contacts supplying most inbound block information.
- The deletion of certain calculation features of the yard planning worksheet.
- The use of nominal schedule information to anticipate the need for trains beyond the yard's immediate planning horizon as determined through RAILS, DMP, and dispatcher input.

These changes evolved somewhat naturally during the first couple of shifts of the experiment.

Yardmaster participation in the overall planning process ranged from perfunctory to enthusiastic. However, all yardmaster participants were willing and able to perform thoughtful and deliberate block connection and outbound train forecasts from whatever inbound, yard inventory, and outbound information was available during each planning period. The relatively inexperienced yardmasters tended to revert rather quickly to their usual lists and count sheets for block and track information when traffic became heavy or moved in an unorthodox manner. Experienced yardmasters generally attempted to "run the yard" from the worksheet in addition to performing the required planning tasks.

Table 6

YARD PLANNING PERIODS

Planning Period	Yard Planner Preparation Period (hr)	Plan Development Shift (hr)	Date (1977)
1	1200 - 1500	1500 - 2300	25 July
2	1900 - 2300	2300 - 0700	25-26 July
3	0300 - 0700	0700 - 1500	26 July
4	1100 - 1500	1500 - 2300	26 July
5	1900 - 2300	2300 - 0700	26-27 July
6	0300 - 0700	0700 - 1500	27 July
7	1100 - 1500	1500 - 2300	27 July

Yardmasters and dispatchers were in general agreement that the planning process did, in fact, consolidate yard planning information and formalize the transfer of such information between shifts, although it was felt that the presence of experienced yardmasters as "yard controllers" contributed greatly to the latter objective. They were most enthusiastic about the opportunity to establish communication between yard and dispatching functions in a more structured, streamlined manner and felt that the ultimate success of a production version of the planning process would hinge on retaining this capability.

Inbound Information--In order to extend the outbound train planning capabilities of the yard up to 16 hours from a given shift changeover, it is necessary to provide yard planners with complete and accurate advance consist information on all major inbound blocks expected during the shift. These data are listed in the "Inbound This Shift" section of the yard planning worksheet (Figure 16). Yard switching requirements can then be estimated 8 to 16 hours in advance, which is 8 hours longer than current yard procedures allow. Inbound block information during the experiment came primarily from RAILS advance consists forwarded by GT's Chicago area yards and telephone calls made to local industry and interchange sources and to nearby nonmechanized GT stations. Other, limited, block information came from the Chicago Railroad Terminal Information System (CRTIS) and DMP. Two sets of information came in sufficiently far in advance to be listed in the "Later Inbound" section of the planning sheet (Figure 16); one of these a CRTIS report on a "run-through" train coming from the ICG--was over 90% accurate and nearly 20 hours early.

A summary of the amount of inbound train information available for each planning period is shown in Table 7. Local and industrial interchange movements are not shown. The "Inbound Planning Horizon" is defined as the amount of time after the start of a shift for which the identity and size of all major line-haul blocks entering the yard are known with reasonable (60%-70%) accuracy. (It can also be defined as the earliest expected train arrival at the yard after the start of the shift for which advance consist is missing.) In period 3, for

Table 7

INBOUND TRAIN INFORMATION SUMMARY

	Planning Period						
	1	2	3	4	5	6	7
Line-haul trains arriving during shift	2	2	3	3	2	2	2
Trains without advance inbound block information	1*	1†	0	3‡	0	0	1§
Later inbounds--very advanced information	0	1	0	0	1	0	0
Actual inbound planning horizon	5+hr	8+hr	7 hr	0 hr	5+hr	7+hr	4+hr
Ideal planning horizon	8 hr	8+hr	8 hr	8 hr	8+hr	8 hr	8 hr

*No advance consist was received via CRTIS on 386, a runthrough train from the MoPac.

†Train 522, a Kalamazoo local had not departed its originating station at the end of the planning period, and therefore, advance consist information was not available through RAILS.

‡No advance consist information was received via CRTIS on trains 370 and 386. Furthermore, a clerical mix-up in forwarding the list of 432 occurred. This mix-up may have been due to a restaffing of the yardmaster position at the last moment.

§No list was received for the "extra" 432 at Battle Creek although computer records show that a list for this train was transmitted.

example, the horizon contains all three inbounds during the shift, with the latest of these arriving seven hours after the shift started. However, at the beginning of period 2 there were only two trains inbound toward the East yard: 398 and 522. Only information for 398, the first train, due at 0200, was available before 2300, making the planning horizon three hours. Train 522 was a local from Kalamazoo (approximately 25 miles from Battle Creek) carrying a significant amount of traffic. However, the train has not departed the originating station at the beginning of the shift and therefore the data were not yet entered into RAILS.

Occasionally, data on trains were available more than one shift in advance of actual arrival. These trains are labeled "later inbounds" in Table 7. Such advance consist information may be more readily available if railroad-to-railroad data exchange mechanisms, such as CRTIS, are more effectively used.

The inbound planning horizons shown in Table 7 are those actually achieved during the experiment. The missing train information in period 1 was expected because of the transition period at experiment start-up time. The missing train information in period 4, however, appears to be due primarily to difficulties in communication and coordination among the experiment personnel. The CNW interchange train 370 was a relatively new train during the experiment period. The CNW was not yet providing input via CRTIS for this train, and the experiment team was not able to provide timely, alternate procedures to obtain the necessary advance consist information from CNW. Also, the MoPac interchange train 386 was operated without advance information furnished through CRTIS as GT had expected. Consequently, throughout the experiment, advance consist information on trains 370 and 386 was missing or delayed, and thus the planning accuracy was less than it should have been. On one day, however, advance consist information on 386 was entered at Blue Island by GT personnel in sufficient time to be of use for planning purposes.

Periods 1-3 and 5-7 are representative of currently achievable planning horizons; no special alterations to the procedures used in operating RAILS are necessary. Table 8 contains additional estimates of the accuracy with which the sizes of each inbound block could be estimated during the planning period.

Table 8

INBOUND PLANNING ACCURACY SUMMARY

Block	Planning Period (Planned Arrivals/Actual Arrivals)						
	1	2	3	4*	5	6	7
Mainlines	15/51	0/9	12/28	0/48	19/31	19/36	18/25
Flints	1/22	31/33	63/63	0/46	23/23	45/45	15/21
Durands	3/16	0/4	29/29	0/13	7/7	3/6	2/10
Lansings	4/27	22/20	8/10	0/12	14/14	0/0	14/14
Detroits	1/22	18/28	7/13	0/18	5/5	1/4	4/15
Pontiac	3/12	11/14	8/13	0/13	8/8	1/1	7/7
Total	27/150	82/108	127/156	0/150	76/88	69/92	60/92
Percentage	18%	76%	81%	0%†	86%	75%	65%

*Period 4 had some disturbance due to a track outage that was not communicated to experiment personnel.

†One list was mishandled during period 4, probably as a result of a staffing change. A new CNW interchange train began operation prior to the experiment without procedures to obtain advance information being operational. Also, the MoPac interchange train advance information was not furnished via CRTIS.

The planning process was able to provide up to 8 hours of inbound block information during periods 3, 5, and 6--that is those periods in which block information was on hand for all inbounds expected that shift. Inbound data in periods 2 and 7 were sufficient for outbound planning and for forecasting the probability of certain trains, given normal city, local, and interchange delivery. However, the three missing consists in period 4 seriously impaired the planning capability of the yard team and served to divide the experiment into two separate parts that included periods 1-4 and 5-7.

Yard Inventory Information--Yardmaster or yard controller estimates of the yard inventory after each switching shift were used to fill out the "Ready to Move" data for the planning sheet about two hours before each shift changeover. This presented no significant problems in the execution of the planning process and did not adversely affect the timing or accuracy of the plans formulated by the yard team.

Outbound Activity--As an input to the systemwide power, crew, and train status decisions, required of dispatching personnel during the tactical planning process, it was important for yard planners to be able to forecast the need for outbounds from Battle Creek from 12 hours to 20 hours after a given plan preparation period. All initial outbound block size estimates should be available within a 16-hour horizon; trains leaving within a 12-hour horizon should require only block size corrections by the yardmaster. Explicit block connection forecasts should therefore be available for outbound movements planned up to 12 hours after each shift changeover time.

Table 9 summarizes the planning horizons available for initial estimates of outbound train size and departure time for each period; Table 10 shows the train size and departure time accuracy of the initial estimate for each major eastbound train leaving during the experiment. Certain trains, such as 432, were turnaround trains and hence could be anticipated without making accurate block estimates. Other trains, such as 388 on July 26, 1977, were projected on the basis of an exact prediction and a yardmaster's experience that he would have more traffic for the train later.

Table 9

OUTBOUND ACTIVITY

	Planning Period						
	1	2	3	4	5	6	7
Actual outbound horizon*	9	13	14	11	15	16	12
Ideal outbound horizon	16	16	16	16	16	16	16

*Refers to hours in advance of time when initial outbound consist sizes can be estimated.

Table 10

TRAIN-SPECIFIC OUTBOUND ACTIVITY

Departure Day	Train Number	Initial Plan Preparation Time	Estimated Order Time	Estimated Size	Order Time of Actual Consist	Actual Size
July 25, 1977	392	1330	1700	71	1700	76
	430*	1330	1745	45	1745	48
	394	1330	2000	100	1930	102
July 26, 1977	384	2130	0200	77	0330	95
	386	2130	1000	44	1000	79
	432*	0500	1200	79	1200	80
	430	0500	1745	39+	0025	49
	384	0500	1200	80	1430	76
	388*	0500	1800	46+	1930	79
	394	1330	2340	81	2340	85
July 27, 1977	386	2130	1000	90	0800	90
	432*	2130	1200	61	1200	72
	384	2130	1200	90	1200	91
	430*	0500	1745	26+	1830	53
	388*	0500	1800	86	2000	85
July 28, 1977	384	0500	2000	41+	0145	89

*The "need" for this train was actually known up to 8 hours before the initial plan preparation time. Planners felt the initially estimated consist size was virtually certain to increase--usually by 30 or more cars.

Not surprisingly, the outbound planning horizons were found to vary directly with the inbound planning horizons for each period (Table 7), which in turn were related to the amount of advance inbound information on hand during the planning period. The desired planning horizon (i.e., 12 hours to 20 hours in advance) for outbound train departure times and outbound block sizes were attained in periods 5 and 6 and were very nearly approached in period 2. In period 5, it was possible to forecast a need for a train (388 ordered at 2000 on July 27) nearly 20 hours before its estimated order time; an accurate initial estimate of the block composition and size of the train was available about 15 hours in advance. Railroad personnel indicated that on this occasion, sufficient advance information was available to enable a crew to deadhead from elsewhere on the GT system in time to meet the ordered departure time had a crew not been available in Battle Creek. Thus, train 388 was planned far enough in advance so that crew and power resources could be arranged for the train without unduly straining systemwide operations, and it was forecast from information normally available through RAILS.

The accuracy of initial train size estimates was highest during periods 5, 6, and 7. Furthermore, in these periods some trains were predicted further in advance than they were in earlier periods. Improved experimental procedures developed as the experiment progressed and the consistent availability of inbound information were critical to the ability to forecast outbound activity far enough in advance to meet the design objectives of the experiment. From this it was learned that the yard tactical planning process can only function with a continuous stream of good RAILS data and a mechanism for feeding that data to the yardmaster.

The planning accuracy of outbound block activity is shown in Table 11 for blocks expected to depart during the seven, two-shift, 16-hour planning horizons defined by each planning period. The top entry in each cell denotes the ratio of planned to actual departures

Table 11

OUTBOUND PLANNING ACCURACY

Planning Period		Flints	Block Mainlines	DTSL/ Detroits	Period Error Ratio	Period Error Percentages
1	Current Period	100/76	26/26	0/0	24/102	23.5
	Next Period	-/0	-/68	0/0	-/68	N/A
2	Current Period	22/0	55/68	0/0	35/68	51.4
	Next Period	0/30	0/12	52/80	70/122	57.4
3	Current Period	25/30	14/12	79/80	8/122	6.6
	Next Period	41/47	0/42	0/0	48/89	53.9
4	Current Period	47/47	47/42	0/0	5/89	5.6
	Next Period	0/0	0/0	0/0	0/0	0
5	Current Period	0/0	0/0	0/0	0/0	0
	Next Period	71/82	62/46	61/70	34/198	17.2
6	Current Period	84/82	60/46	72/70	18/198	9.0
	Next Period	42/49	24/72	0/0	55/122	45.1
7	Current Period	48/49	72/72	0/0	1/122	0 8
	Next Period	N/A	N/A	N/A	N/A	N/A
Average Error Ratios	Current Period	54/276	34/266	3/150		
	Next Period	54/208	172/240	37/150		
Average Error Percentages		19.6	12.8	2		
		26.0	71.7	24.6		

A dash(-) indicates no blocks planned.

N/A = Not applicable.

for each block during the indicated planning period; the bottom entry denotes the value for the period immediately following. The ratios of the number of erroneous planned departures to the actual departures summed over all seven planning periods for both "current period" and "next period" outbounds are also given. This was done to eliminate the possibility of high and low estimates for a block cancelling each other. The period error ratios and percentages were aggregated over all three blocks for each of the seven periods.

Overall, current period error percentages were found to be good, except for the Flint block, which had to be unexpectedly rescheduled out of Battle Creek during periods 1 and 2 to accommodate track maintenance in the Flint area. However, for the last four periods of the experiment, yard planners were regularly within ± five cars in forecasting outbound block sizes during the "current period," which extended from 2 hours to 12 hours after the planning was actually performed. The only exception was the Mainline block estimate of period 6, which was 14 cars high due to a missed connection with an inbound local delivery.

Historically, yardmasters have only tried to switch everything standing in their receiving yard at the beginning of their shift. Hence, given a procedure for estimating outbound block sizes, their estimates can be fairly accurate. The process of making these estimates, however, is new to the yardmaster.

In the past it would have been virtually impossible for yard personnel to predict consistently and accurately the next-shift (8 to 20 hours in advance) outbound movements since the RAILS/DMP data and planning process described herein is critical to such predictions. The Flint and Detroit blocks were predicted with a good overall error percentage. A sustained next-shift error percentage of less than 30% appeared acceptable and attainable.

Mainline error percentages were higher than desired because of the following factors: (1) one consist list was mishandled in period 4; (2) trains had to be rescheduled around maintenance in the Flint area;

(3) a new CNW interchange train began operation a relatively short time before the experiment; and (4) advance consist information was not available via CRTIS from MoPac. The maintenance problem in the Flint area was not communicated to the experiment team during preexperiment meetings. This affected the second planning period but was accommodated by the planning process on subsequent shifts. Maintenance essentially closed off a section of mainline track for six hours or so in the early morning. A lengthy, indirect routing was used on at least one occasion to run around this section of track.

Table 12 shows how yardmaster connection forecasts during periods 5, 6, and 7 progressed through consecutive planning periods to their actual departures. The last three periods were chosen because inbound lists were available for all but one train, and departures could therefore be forecast 12 hours to 20 hours (or two periods) in advance. Accurate data were also available through railroad sources on actual connections made in Battle Creek that day. The table shows how blocks were switched between planning periods to meet yard/system realities that shifted between planning periods. Note, for example, how the block of Flints inbound on 386 were initially assigned to move out on 384 but switched during period 6 to move out on 386. The block size estimate also changed between planning periods; the block size estimate closest to the actual departure was less accurate than the initial period 5 estimates. (This was due to the appearance of a group of cars which Battle Creek Yard determined to be No Bills, but which were assigned to a destination point by the originating stations in the RAILS advance consist.) The Flints inbound on 432 were initially distributed between 386 and 384 during period 5 but were forecast to move exclusively on 384 during period 6, as they actually did. The Flints were "bumped" from 386 outbound to make room for higher priority Mainline and Lansing traffic that would fill out the train to its 90-car maximum. The 10 Mainline cars originating from the City Yard that were planned for 386 but failed to make the train are also indicated in Table 12.

Table 12

PLANNED VERSUS ACTUAL CONNECTIONS:
Periods 5, 6, and 7

Date Train Arrival Time	Period	Flints 386 1145	Flints 384 1615	Flints 388 2145	Mainlines 386 1145	Mainlines 384 1615	Mainlines 388 2145	Mainlines 384 0145 Th
July 26	5	0	12		24			
386	6	24	0		24			
2115	7	--	--					
	Actual	12	0		19			
July 26	5	20	16		23			
432	6	0	37		23		0	
2230	7	--	--				0	
	Actual	1	36		28		3	
July 27	5		22			19	0	
398	6		22			0	19	
0500	7		--			0	19	
	Actual		22			0	18	
July 27	5		12					
512	6		12				19	
1200	7		17				0	32
	Actual		17				4	30
July 27	5		0					
CR Delivery	6		30					
1330	7		28					
	Actual		28					
July 27	5		--					
510	6		--					
1540	7		3			2		
	Actual		3			4		
July 26	5			10				
City Yard	6			10				
Delivery								
2330	7			0				
	Actual							

A dash (--) indicates a period after the actual connection.

Table 12 illustrates the ability of yard personnel to forecast connections more accurately as the actual departure time approaches. The table also shows how most cars inbound to Battle Creek from line-haul destinations can be in the "planning process" for at least two planning periods before inbound data are available through the normal channels, as they were for most of periods 5, 6, and 7. The table also illustrates how connection forecasts tend to be refined as more data enter the yard as, for example, when advance consists are replaced with switch lists after the train is yarded, when city industrial traffic appears in the yard and is listed, or when trains such as 512 inbound pick up traffic at nearby, nonmechanized stations. The latter situation is shown for the 512 and 384 connection for Mainline traffic.

c. Concluding Remarks

The ultimate success of planning outbound movements from Battle Creek to meet the 16-20 hour design requirements of the yard tactical planning experiment rests mainly in the ability to obtain accurate inbound block information on trains within eight hours of arriving at Battle Creek. This depends on accurate and timely advance consists produced by RAILS, including accurate input from CRTIS, and an effective, auxiliary telephone communication capability where RAILS and CRTIS are not applicable. To the extent possible, advance consist information should be extended with DMP predictive information. The consistent and timely transmission of these data to Battle Creek must necessarily be the first step toward a production version of the yard planning process.

The results of the experiment successfully demonstrate the feasibility and desirability of performing tactical planning of yard operations using the worksheet concept developed in this research. It was the judgment of the yardmasters that the planning process:

- Enabled the yardmaster to better organize his activities, foresee potential problems, and take early corrective action.
- Afforded the yardmaster a means to better schedule yard engine work.
- Provided a foundation for reacting to "emergency" problems.
- Provided a means for better communicating the "state" of the yard to the dispatcher.

Ultimately the planning procedures revolving around the worksheet should be implemented on a CRT display using interactive graphics techniques to minimize clerical operations and to enhance the usefulness of the procedures to the yardmaster.

VI CONCLUSIONS AND RECOMMENDATIONS

The tools and procedures necessary to enhance tactical operations planning at the local dispatching and yard operations level have been developed during this project. The feasibility of the concepts and approaches was demonstrated by having GT personnel use the procedures in "live" experiments on the GT system during the week of July 25, 1977.

During the experiment, tactical planning of train and yard operations 8 to 12 hours in advance was routinely accomplished; for certain trains the planning horizon was extended to 16 to 20 hours. The average values of the absolute prediction errors for total train size and train block counts were 19% and 26%, respectively, This accuracy was considered satisfactory for planning 8 to 12 hours in advance what trains should run, when they should depart, what blocks they should carry, and what pickups and setouts should be made. Based on this plan, dispatching and yard operations, power scheduling, and crew assignments could be coordinated.

GT operating personnel were uniformly positive about the experiment. They viewed the new procedures as an effective means of planning dispatching and yard operations in advance on a systemwide basis and of imposing an operating discipline on dispatchers and yardmasters at the local level. Attempts on the part of higher-level operating officers to "decree" or "legislate" better local tactical planning and system wide coordination will be thwarted without new tactical planning tools and procedures.

A statistical analysis of the experiment using a selected set of MOEs was inconclusive because of the shortness of the experimental period. Since each operating day of a railroad has unique operating contingencies and constraints (i.e., every day is different), in order to conduct a meaningful "before" and "during" statistical analysis--that is, in order to let the day-to-day operating variabilities even themselves out over the long run--test periods in excess of several months must be used.

Otherwise the daily variations of the MOEs completely mask the effect of the experiment on the MOEs.

Within the next ten years it is likely that tactical operations planning procedures will be seen as necessary for the efficient conduct of a railroad and will be implemented on a routine basis on a number of railroads, albeit perhaps using other tools and procedures than those developed during this project. Ultimately the problems of trip unreliability, poor car utilization, excessive car transit times, and low labor productivity on railroads must be solved at the local operations level. Presently, the dispatchers who control the running of trains and the yardmasters who control the switching of cars need better tools and procedures to perform their jobs more effectively.

Based on both the results of our research and the insights gained during the project, we make the following recommendations:

- Install a permanent "production" version of the tactical operations planning procedures on GT.
- Modify the procedures and tools developed herein to interface with a manually input data base on another railroad.
- Automate the yard planning process by using interactive graphics.
- Develop a practical (i.e., obtainable at low cost) set of measures of effectiveness for measuring the performance of railroad operations and statistically valid experimental design procedures to measure performance changes.

Appendix A

BATTLE CREEK YARD OPERATIONS: THREE CASE STUDIES

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BATTLE CREEK YARD OPERATIONS: THREE CASE STUDIES

A. Introduction

This appendix contains an analysis of the operations data obtained by SRI in the GT Battle Creek East Yard between 12 and 14, October 1976. Our primary goal was to gather sufficient yard operating data in order to develop a realistic manual simulation of at least three consecutive days of yard operations. The simulation period of yard operations was used to make preliminary, in-house tests of various yardmaster pre-planning concepts.

Upon reduction of the data gathered in October, one of our first tasks was to identify situations in which the yard could have operated more efficiently than it actually did. In this appendix we identify three such situations that involved either the improper sequencing of switch-engine tasks or the building of trains well before crews were available to operate them. For each situation, alternative operating tactics are suggested that would facilitate a more efficient yard operation using DMP, RAILS, and revised yard planning procedures within the fixed operational constraints existing at the time the situations occurred.

The analysis is presented in a case-study format so that no strict statistical inferences can or should be drawn from the results. Our intent here is simply to illustrate the types of operational problems occurring in the yard, the consequences or impacts of these problems on yard efficiency, and the ways in which these problems could be solved. GT personnel can draw their own conclusions regarding the frequency with which the problem types analyzed herein occur and hence the savings realizable over longer, fixed periods of time by circumventing or eliminating these situations.

Furthermore, this analysis has been conducted with all the benefits of perfect hindsight at our disposal. Many weeks were available to formulate successful alternative resource (crew) task allocations in response to conditions in which the actual yardmaster had but seconds or minutes to react. We were also postulating the use of information from DMP and RAILS that was unavailable in the Battle Creek yard in October. And finally, although every effort was made to gather and record all the information available to the yardmaster during each analysis shift, it is possible that the yardmaster made certain decisions and moves based on information and knowledge unavailable to us in our restrospective posture.

B. Data Collection and Reduction

Data were taken during nine continuous shifts of operations at the yard during our three-day visit in October. SRI personnel were present in the tower at all times during this period to record the times taken to switch and build trains in the East Yard and to observe and record other extraneous events that may have affected switch-engine and yard master activity. Other data were gathered during each shift. These included:

- Yardmaster's incoming train lineups
- Switch lists
- Turnover sheets and track lists
- Hot sheets
- Outbound wheel lists.

Copies of the dispatcher's inbound and outbound summaries at Battle Creek for the five days before, during, and after our yard activities were also obtained.

Our data were reduced to appear in the form shown in Figures A-1 through A-9, which show the actual buildup and decline of the yard's car inventory as a function of switch-engine activity. Track inventories and classification labels are shown on the vertical areas; time of day

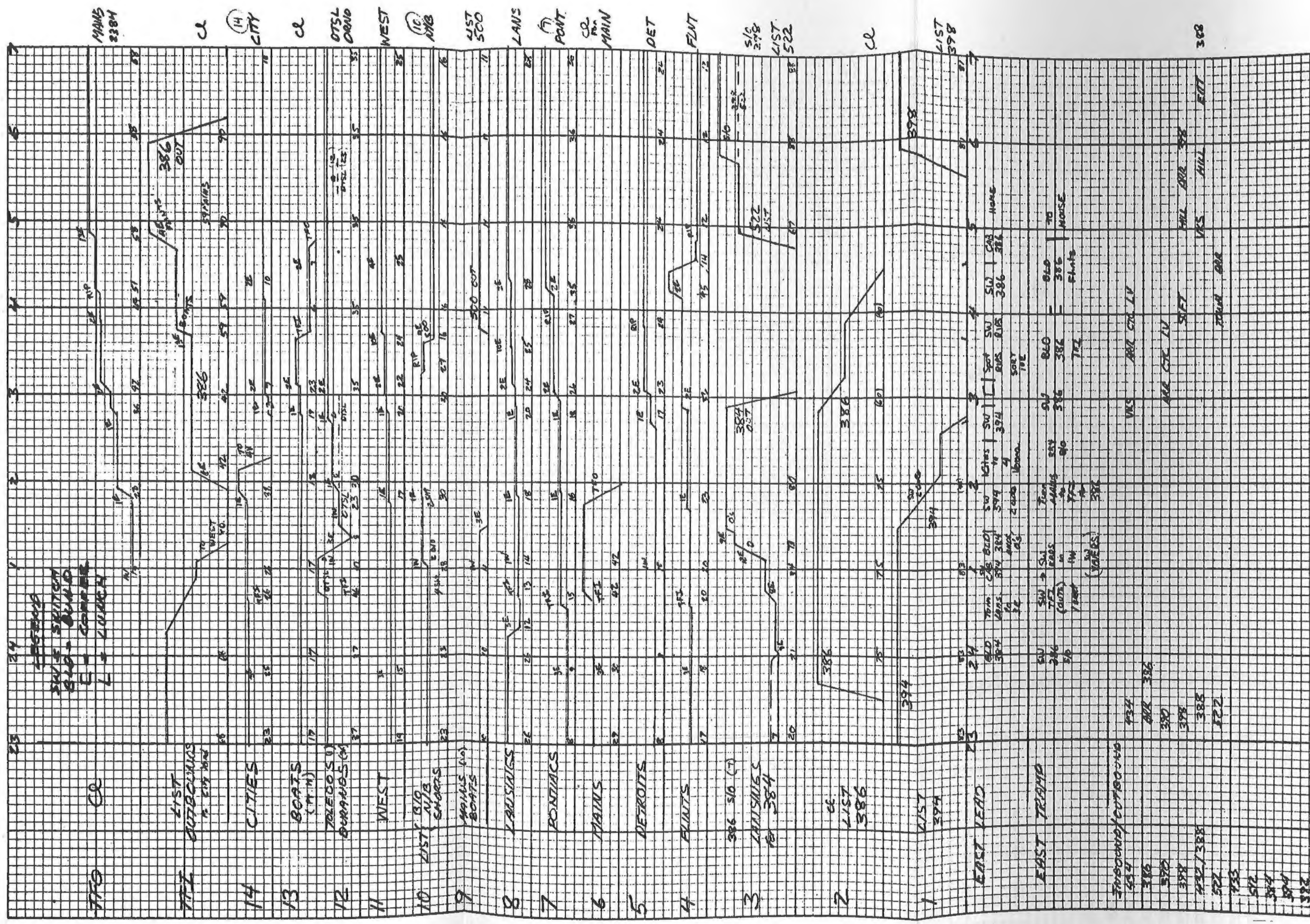

FIGURE A-1 BATTLE CREEK EAST YARD: TUESDAY NIGHT SHIFT

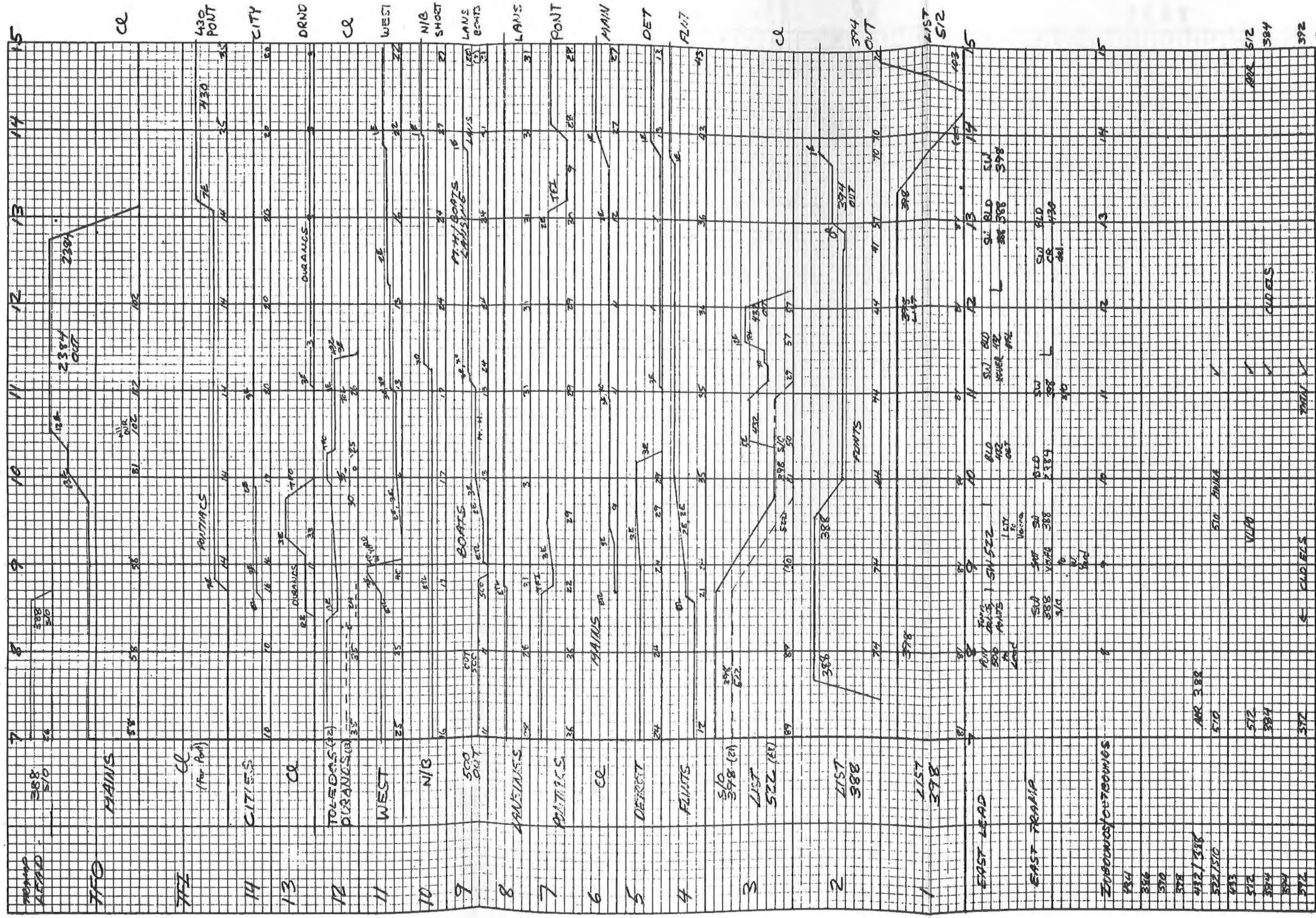

FIGURE A-2 BATTLE CREEK EAST YARD: TUESDAY DAY SHIFT

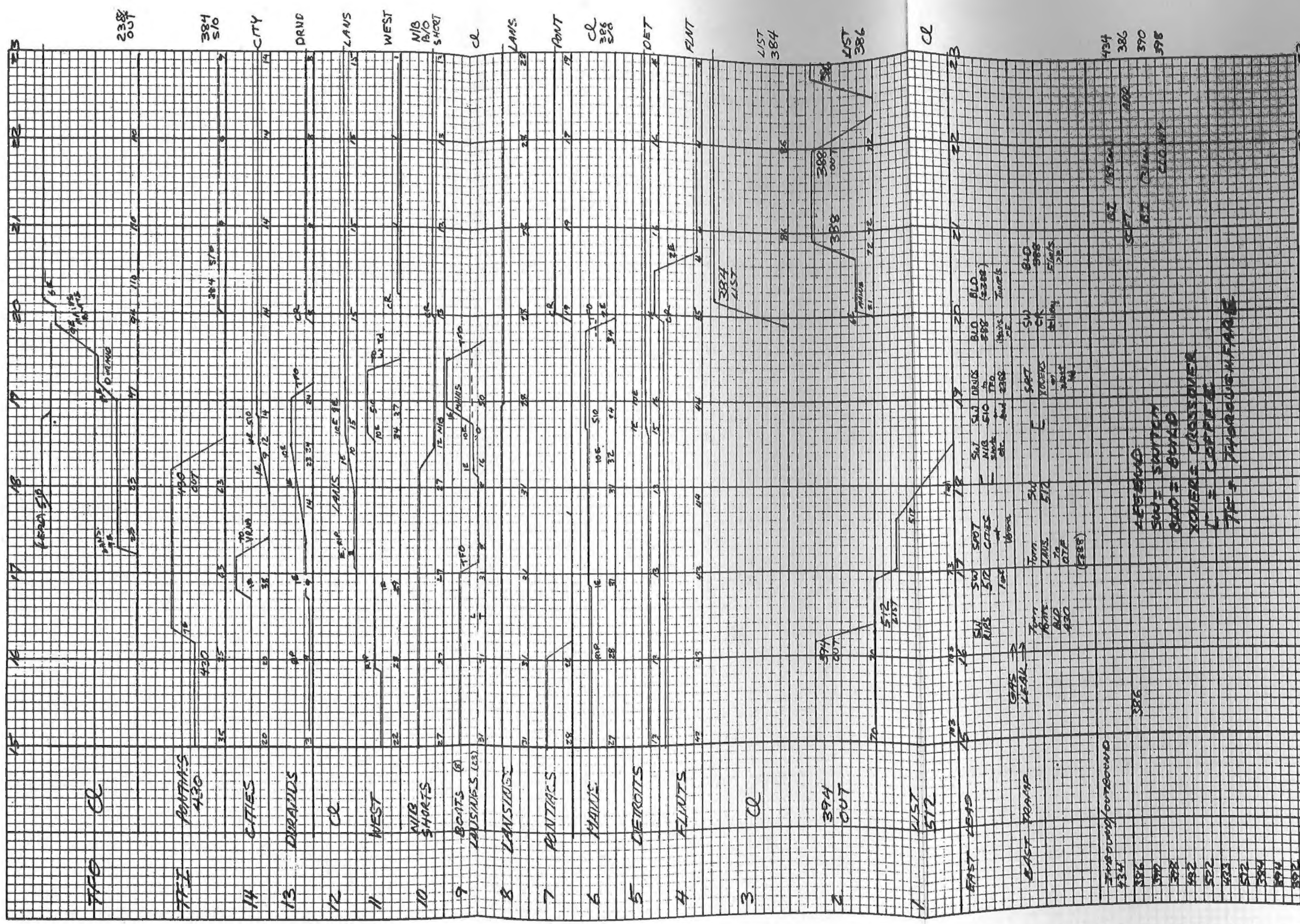

FIGURE A-3 BATTLE CREEK EAST YARD: TUESDAY AFTERNOON SHIFT

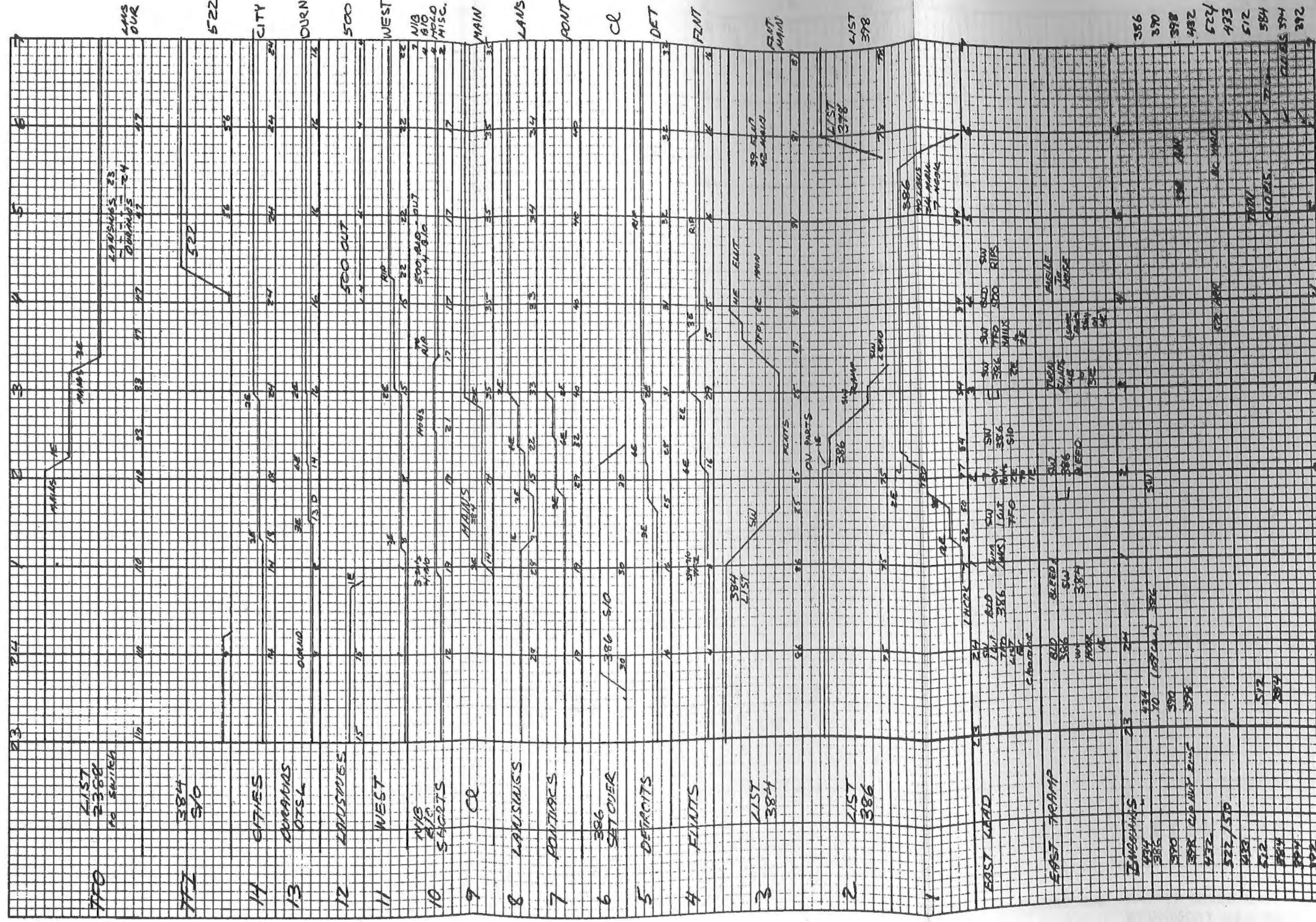

FIGURE A-4 BATTLE CREEK EAST YARD
WEDNES

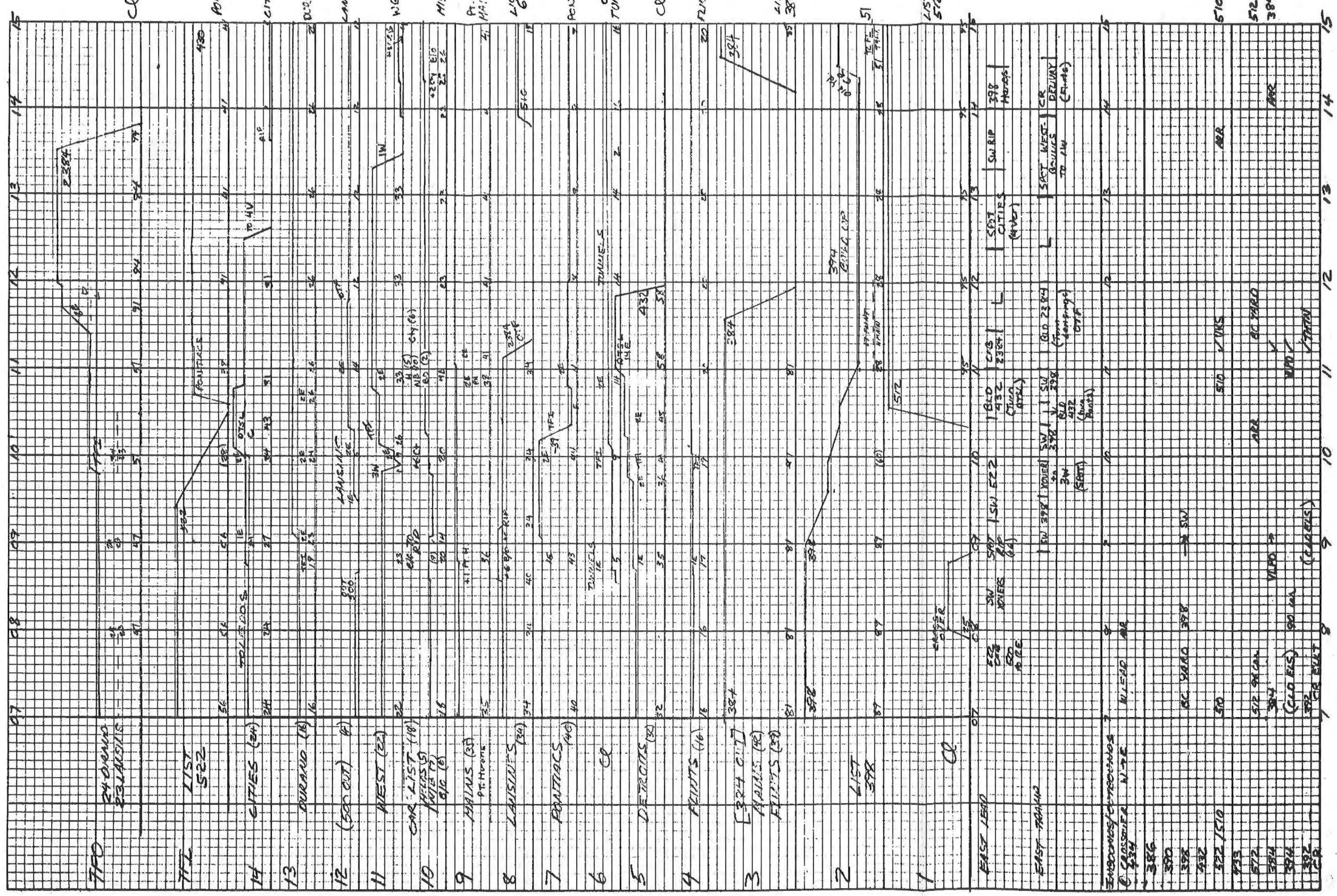

FIGURE A-5 BATTLE CREEK EAST YARD: WEDNESDAY DAY SHIFT

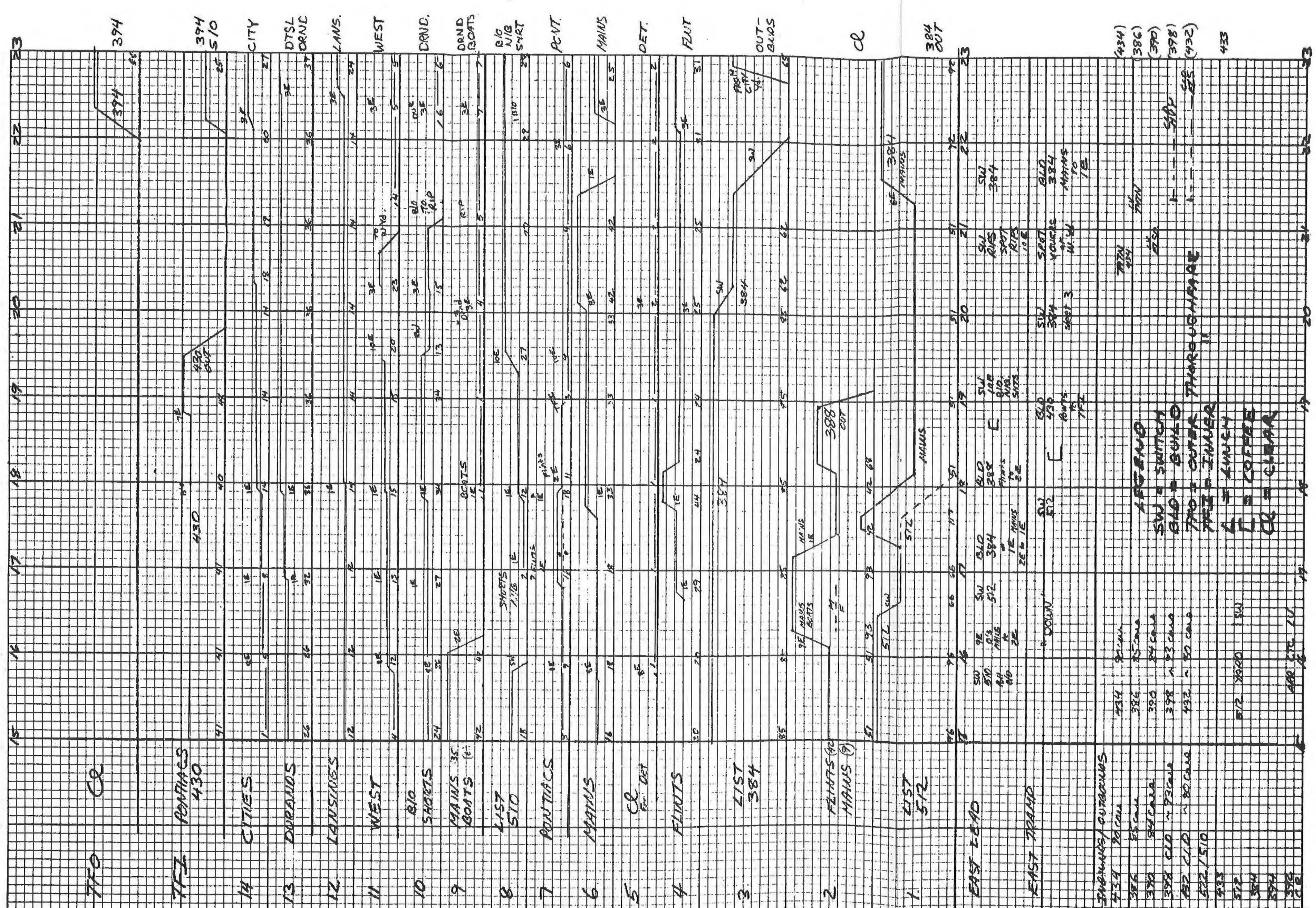

FIGURE A–6 BATTLE CREEK EAST YARD: WEDNESDAY AFTERNOON SHIFT

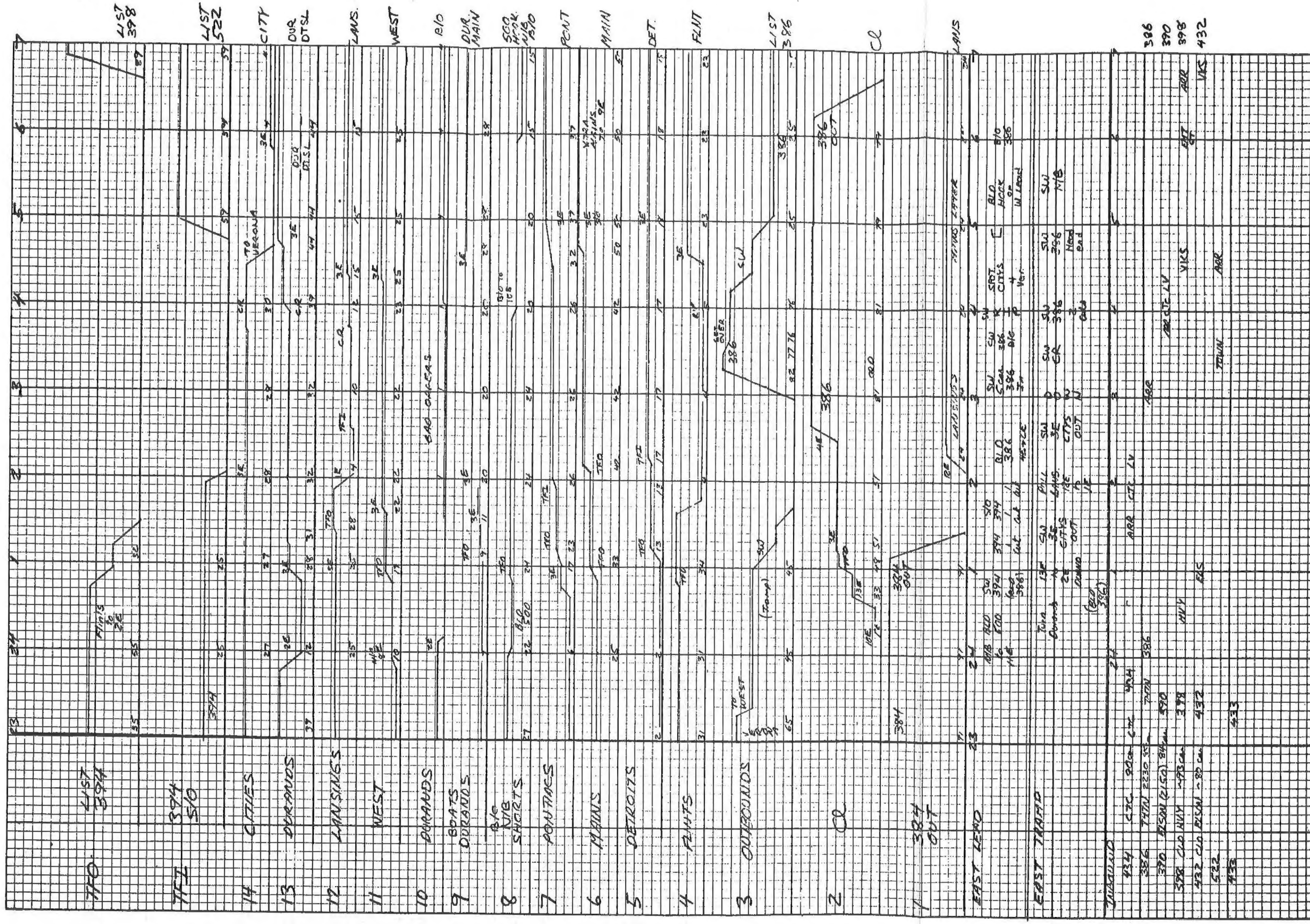

FIGURE A-7 BATTLE CREEK EAST YARD: THURSDAY NIGHT SHIFT

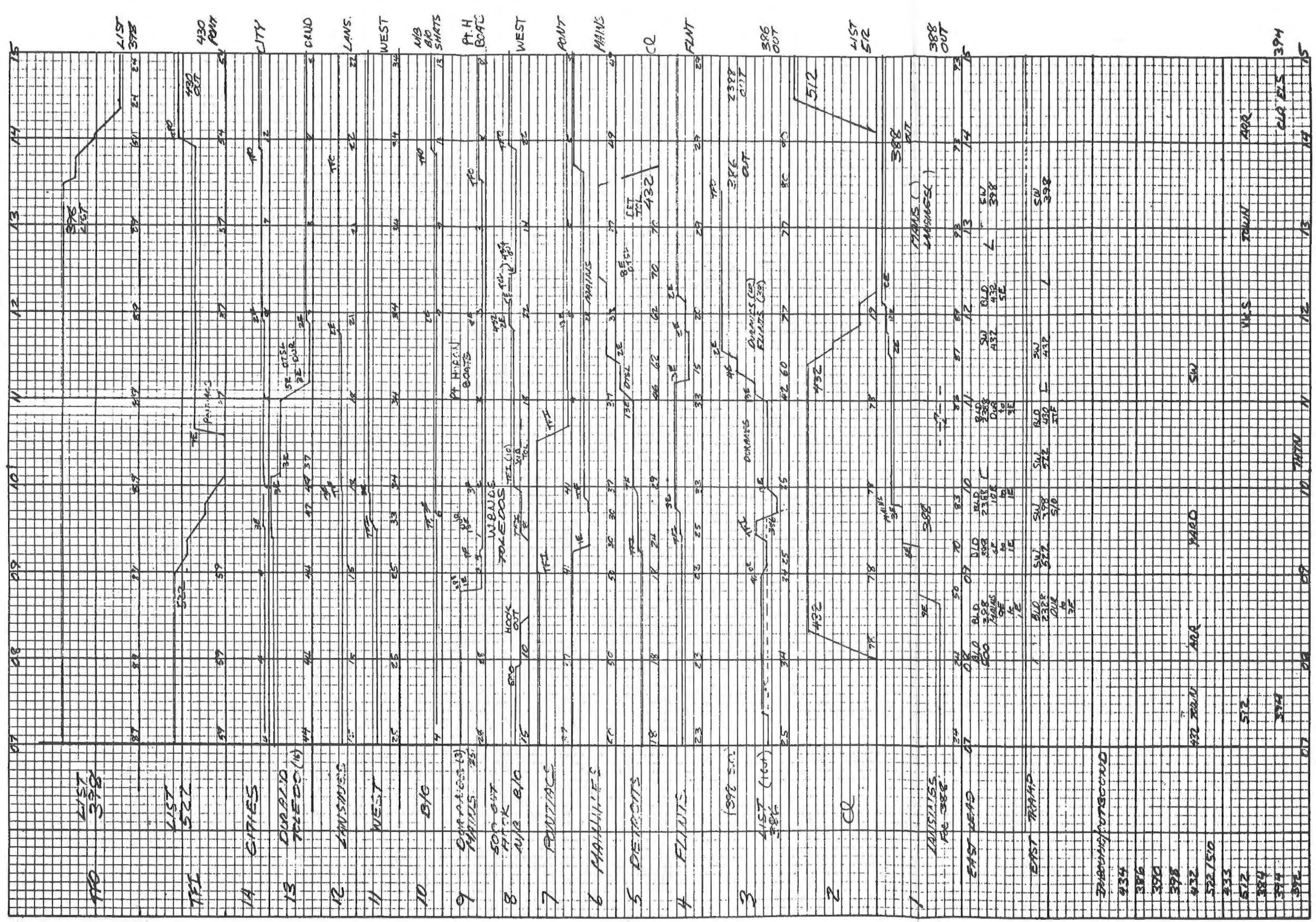

FIGURE A-8 BATTLE CREEK EAST YARD: THURSDAY DAY SHIFT

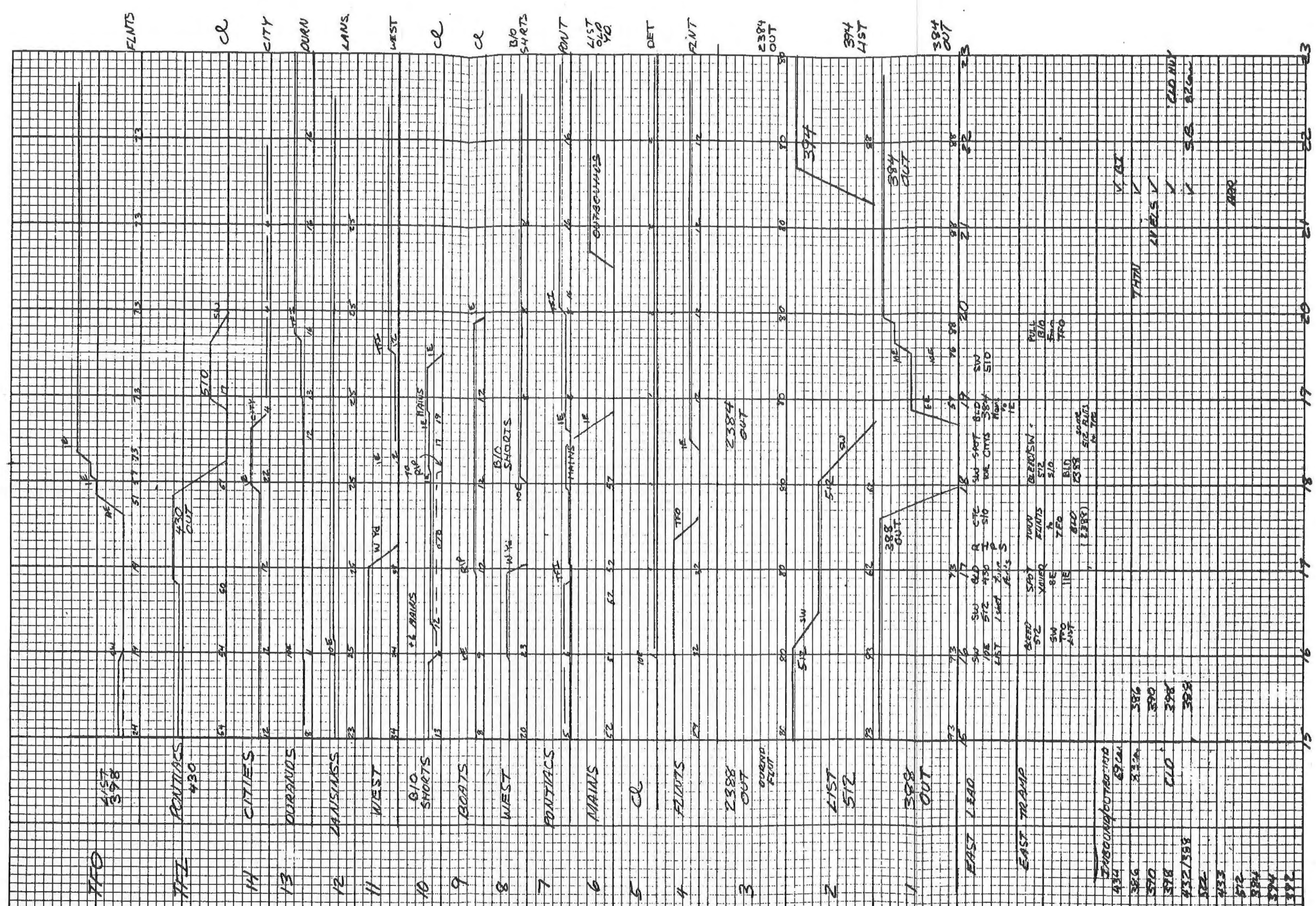

FIGURE A-9 BATTLE CREEK EAST YARD: THURSDAY AFTERNOON SHIFT is shown on the horizontal scale. Each figure contains an eight-hour yardmaster shift of work.

The switch-engine activities are also laid out as a function of time of day, and beneath that the status of trains enroute to the East Yard is shown by an abbreviated location identifier for the train as reported on the yardmaster's lineup or through telephone information. The car inventory of each track is shown at hourly intervals, and multiple classifications in a single track are indicated where appropriate. The movement of cars between class tracks is indicated by showing the destination track for cars leaving a track and the originating track in the row entry for cars entering, accumulating, or switched to a class track. For trains on receiving tracks being switched, an "SW" is shown on the receiving track at the time switching is carried out, with the receiving track number, say 1E for Track 1, East Yard, shown at the appropriate time in which cars accumulate in the classification track(s) reserved for their respective block designations.*

With the assistance of a qualified Battle Creek yardmaster, Figures A-1 through A-9 were examined and circumstances were identified under which the yard operated in a less-than-optimum manner. We postulated realistic events and conditions (consistent with the Battle Creek environment) that would have facilitated a more efficient yard operation and then proceeded to evaluate how yard efficiency under those events could have improved (see Figures A-10 through A-18). We used standard measures of yard performance, including:

- Accumulation delay in car-hours.
- Yard throughput in cars entering or leaving per unit time interval.
- Overage cars by block designation.

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*A more vivid, dynamic picture of the yard can be viewed by simply detaching the sheets and overlaying them in chronological order, left to right, so that only the 1/2 inch margin on the right of each sheet separates a continuous, 72-hour time scale. The margin contains abbreviated turnover information which is shown in more detail on the left-hand vertical area of the next shift's sheet.

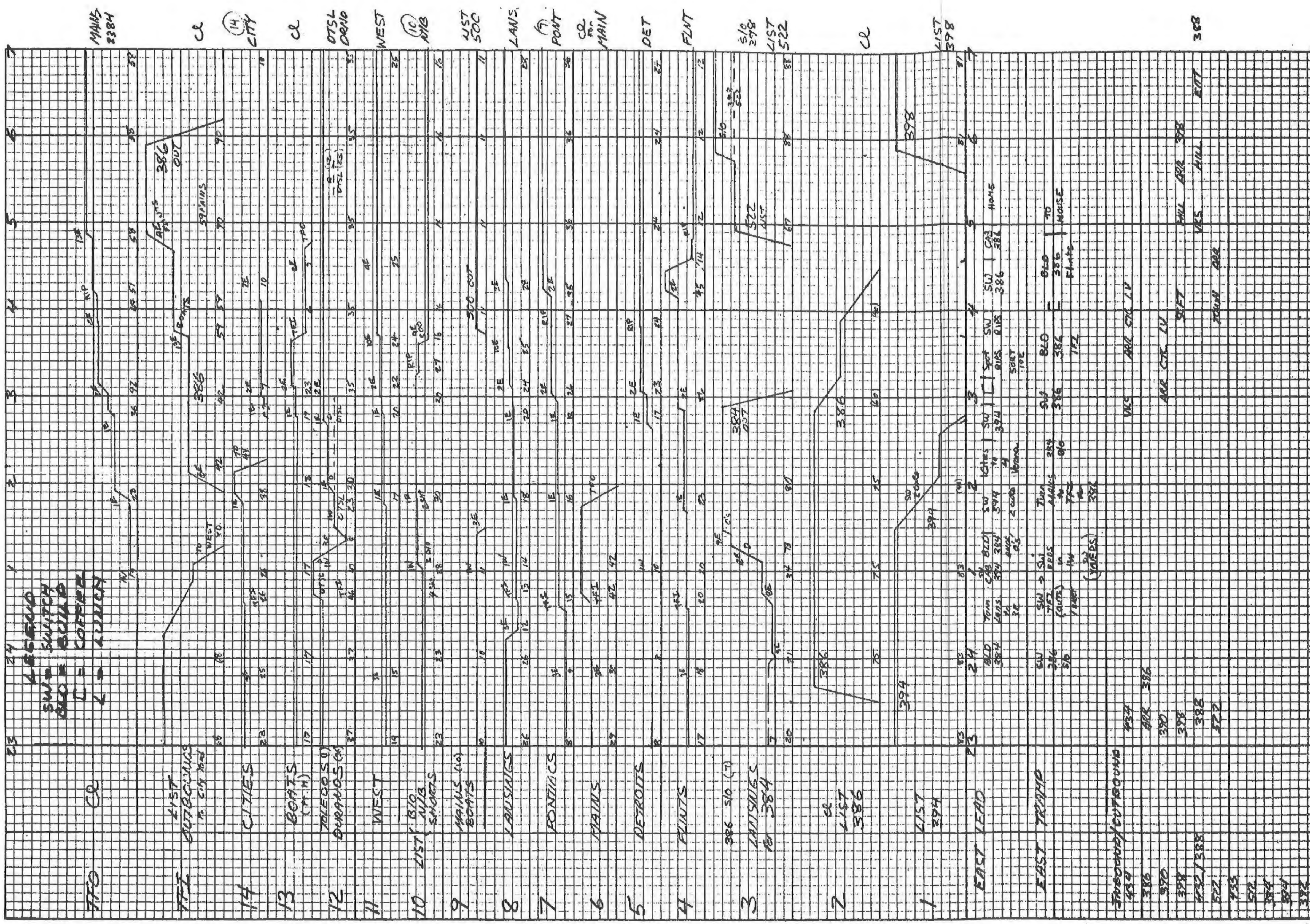

FIGURE A-10 BATTLE CREEK EAST YARD: TUESDAY NIGHT SHIFT

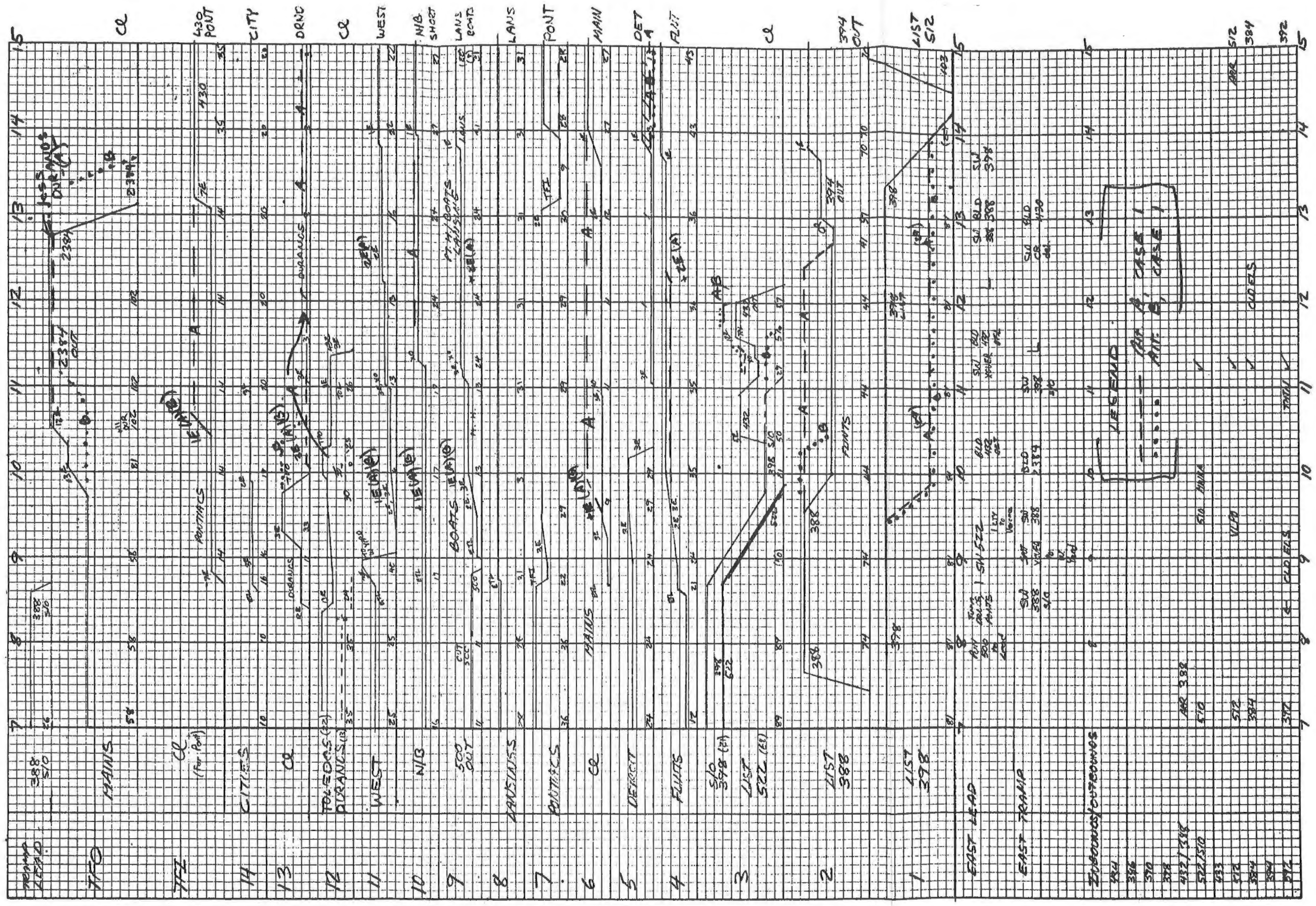

FIGURE A-11 BATTLE CREEK EAST YARD: TUESDAY DAY SHIFT

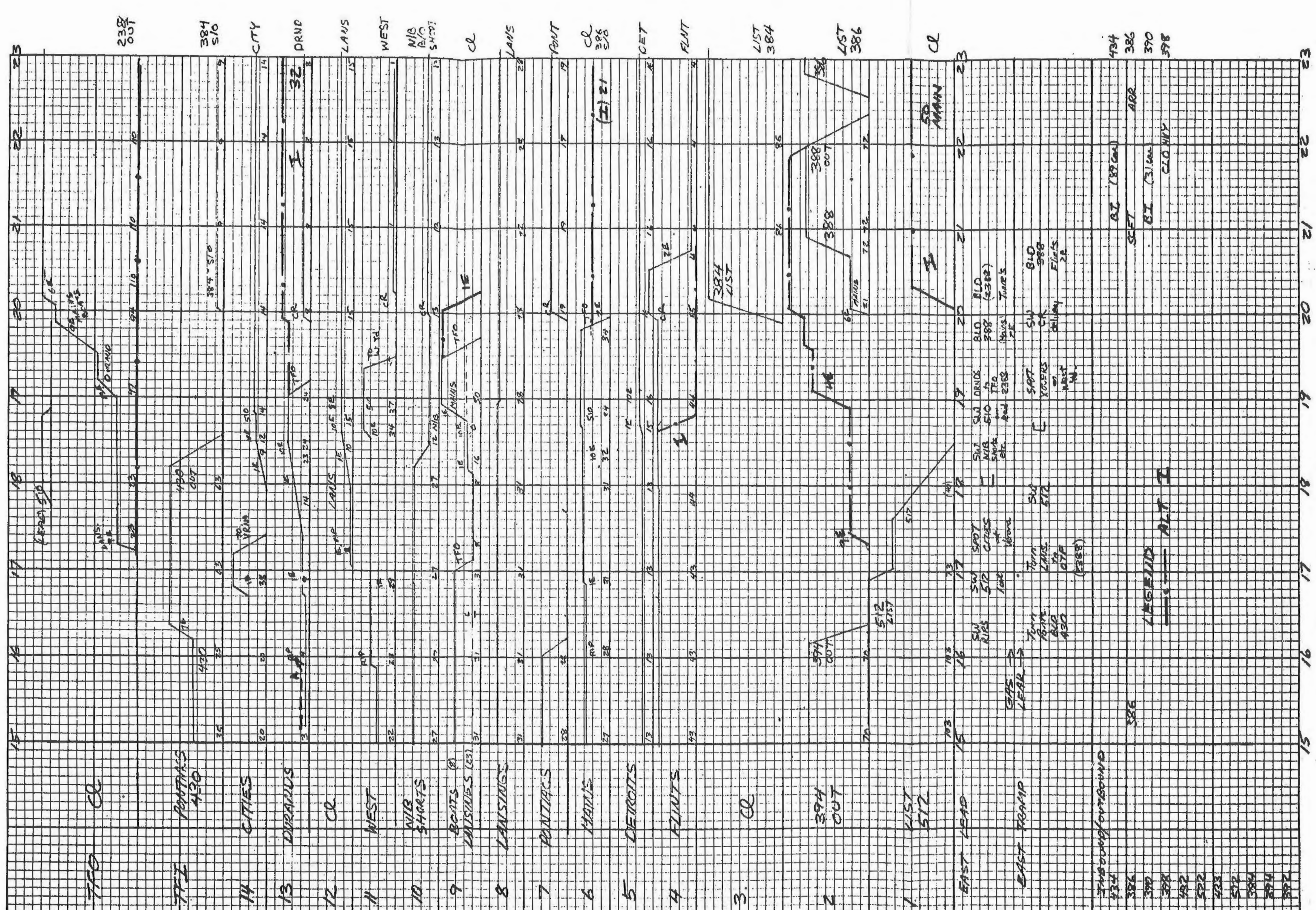

FIGURE A-12 BATTLE CREEK EAST YARD: TUESDAY AFTERNOON SHIFT

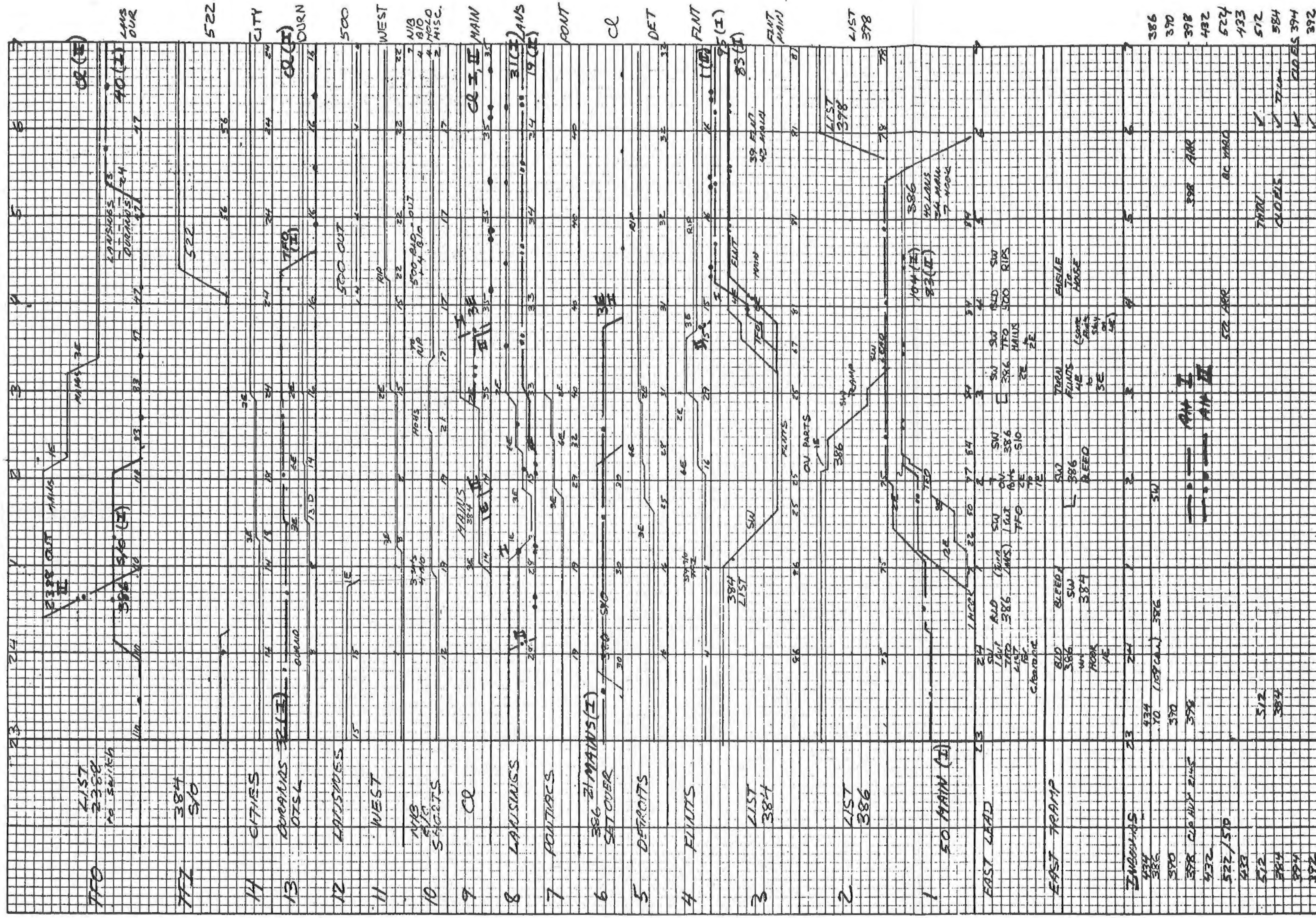

FIGURE A-13 BATTLE CREEK EAST YARD: WEDNESDAY NIGHT SHIFT

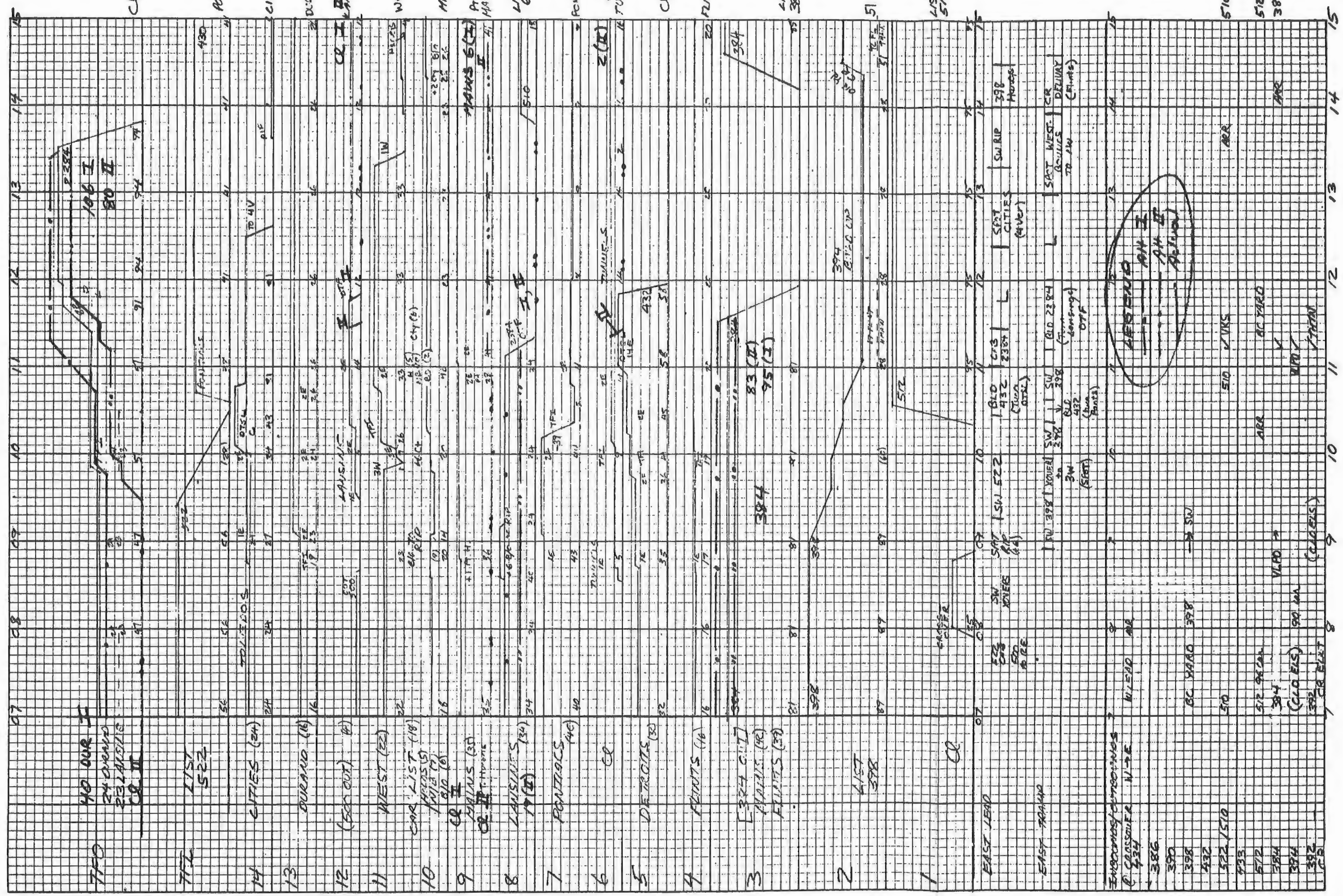

FIGURE A-14 BATTLE CREEK EAST YARD: WEDNESDAY DAY SHIFT

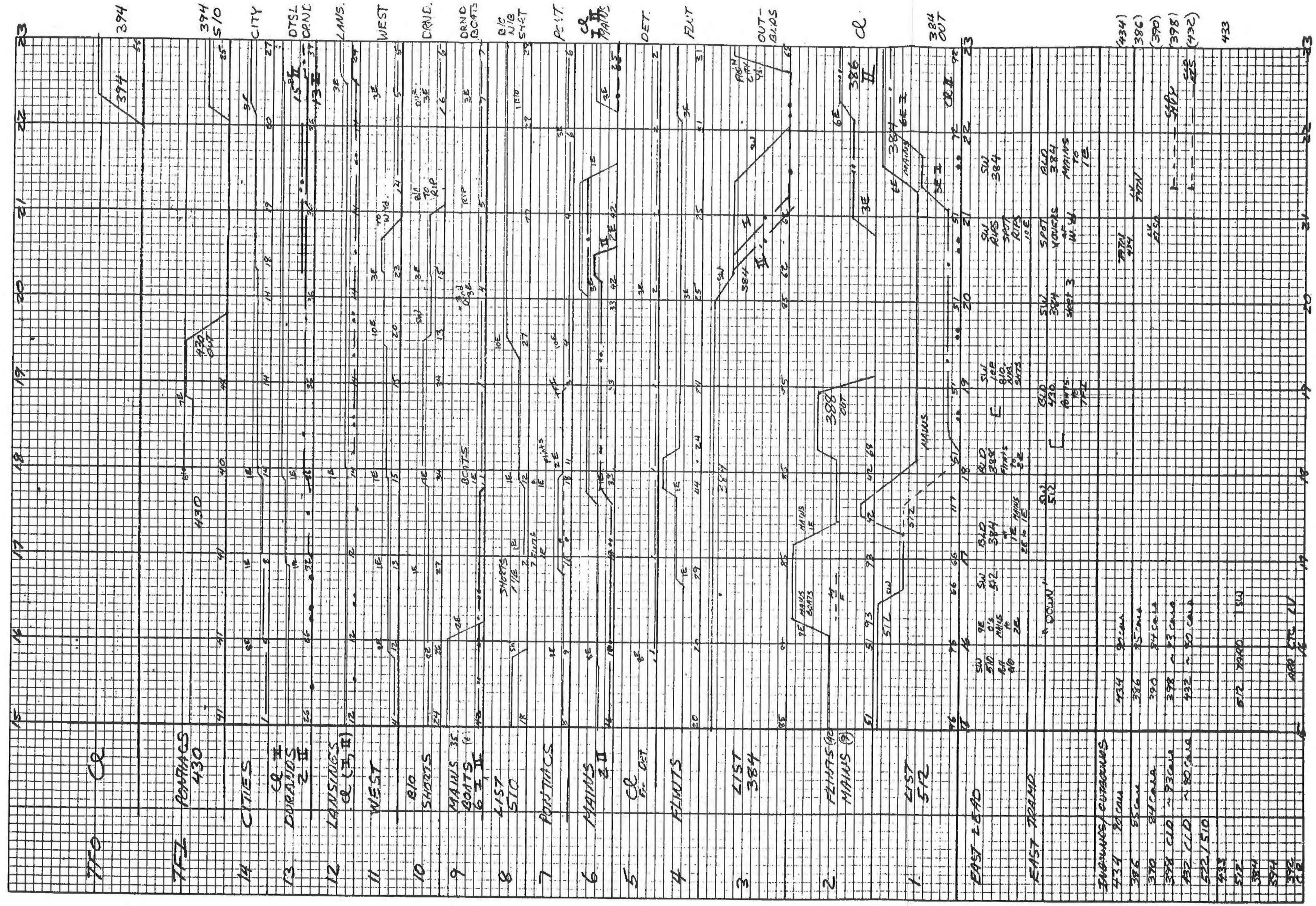

FIGURE A-15 BATTLE CREEK EAST YARD: WEDNESDAY AFTERNOON SHIFT

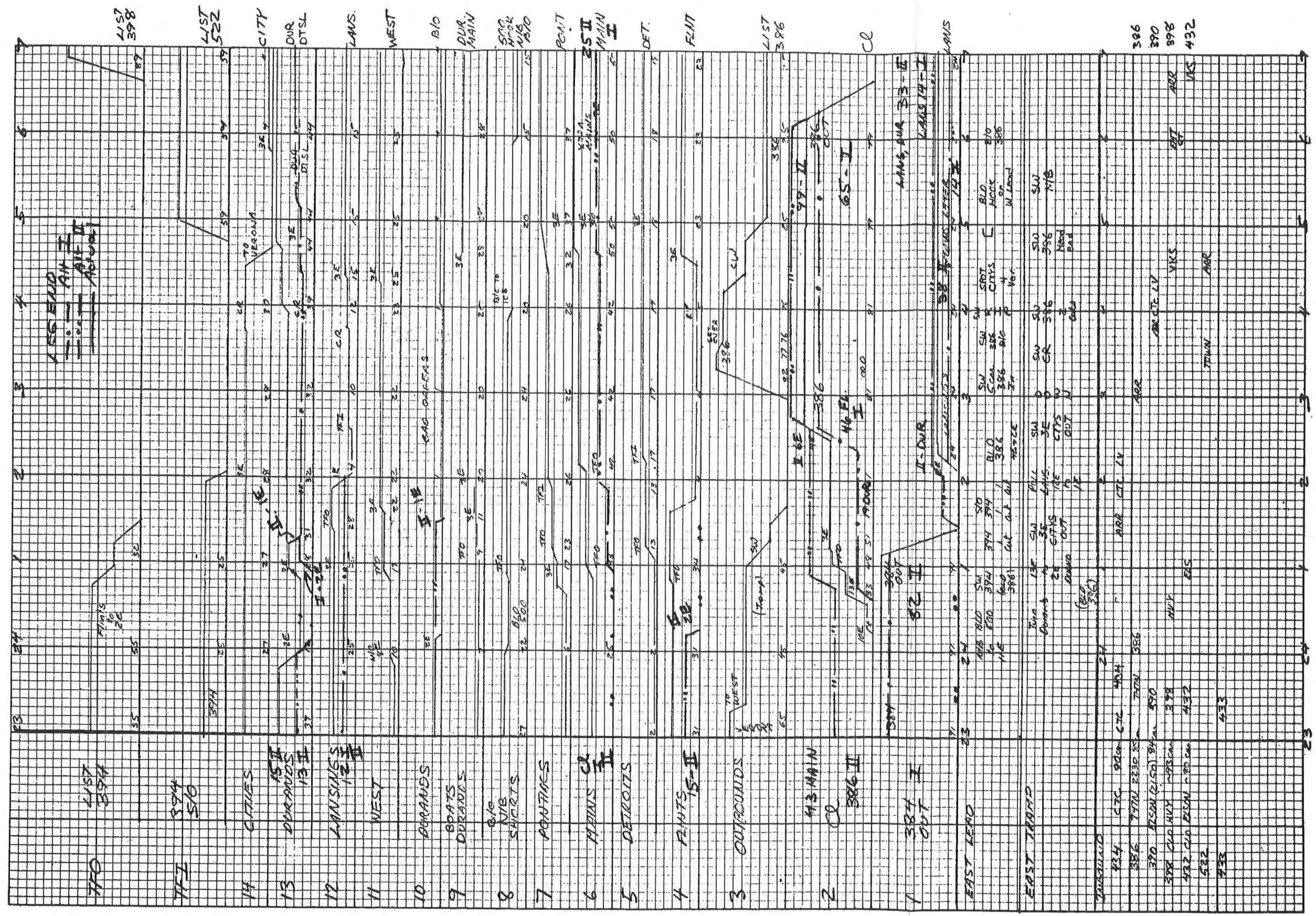

FIGURE A-16 BATTLE CREEK EAST YARD: THURSDAY NIGHT SHIFT

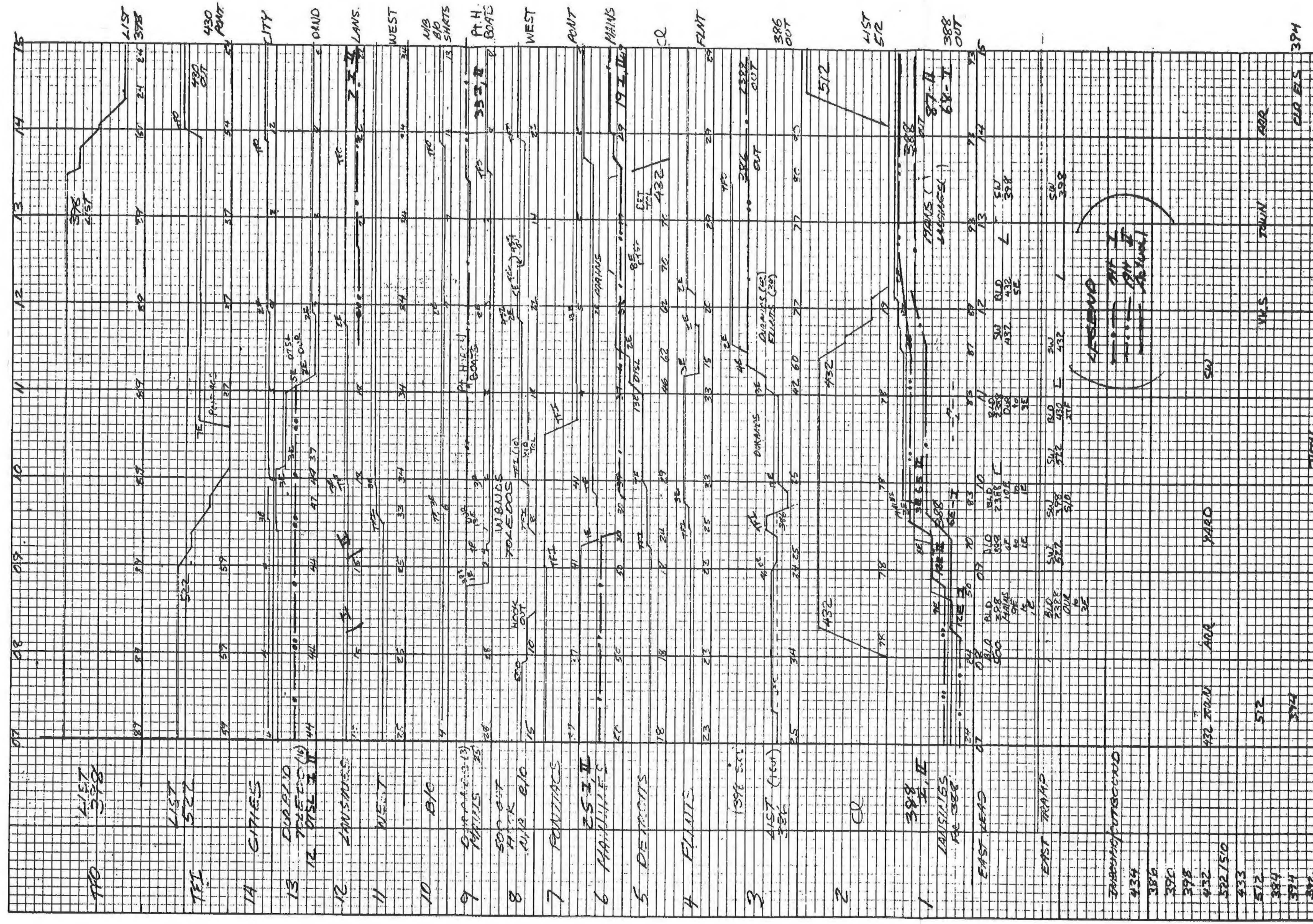

FIGURE A-17 BATTLE CREEK EAST YARD: THURSDAY DAY SHIFT

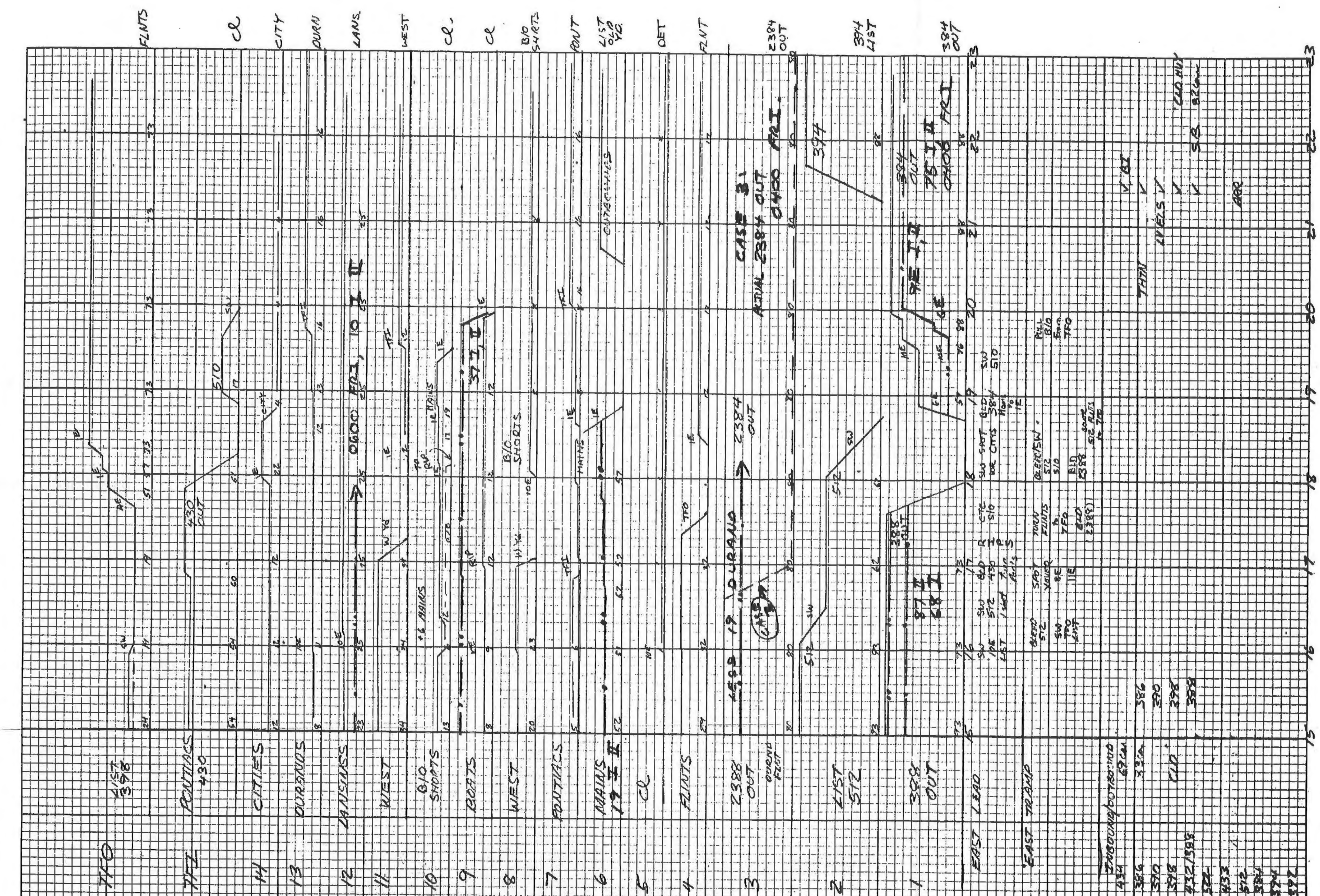

FIGURE A-18 BATTLE CREEK EAST YARD: THRUSDAY AFTERNOON SHIFT

- Connection efficiency as expressed in the percentage of cars making reasonable first connections out of the yard.
- The above measures expressed in terms of per-switch-engine hours of crew utilization or engine work to achieve the work.

Dollar costs associated with yard delays, extra crew deadheading, and the like can be calculated by GT management on a per-incident basis. Their insight into the frequencies of the situations described herein can be used to gain rough estimates of the monthly or yearly potential dollar savings realizable.

C. Case Studies

1. Case 1

The first case we wish to analyze is contained in Figure A-2, which shows the East Yard activities and inventories for the day shift (7 a.m. to 3 p.m.) on Tuesday, October 12. On this shift, 12 cars bound for Detroit on train 398, which arrived in Battle Creek at 0600 that day, were switched into the Detroit classification track (Track 5E) after 432 was assembled and called for Detroit at 1200. These cars remained in the yard approximately 24 hours, leaving on 432 the next day, having missed the once-a-day connection to Detroit from Battle Creek on Tuesday.

The 12 cars could have left Detroit on the first possible 432 connection on Tuesday if only part of 398 had been switched before 1100, when 432 was built. This would have involved the exchange of the 398 switching task with a less "urgent" task performed earlier in the day.

Figure A-19 shows a plausible alternative sequence of lead and tramp crew tasks that would allow two cuts of the 398 containing Detroit traffic to be switched by the tramp engine while postponing the switching of 388 by the tramp crew (on 2E) until 1200 hours that day. One cut of 398 will remain for the lead engine to switch at the end of the shift. In essence, this alternative calls for a three-hour delay in switching 388 and half-hour delays in switching the CR delivery and building 430 in exchange for switching two sheets of 398 four hours earlier. The total work performed by the two crews remains the same under the alternative yard operating scheme, although the switching of 398 at 0900 is transferred from the lead to the tramp, causing this crew to finish work later than it actually did.

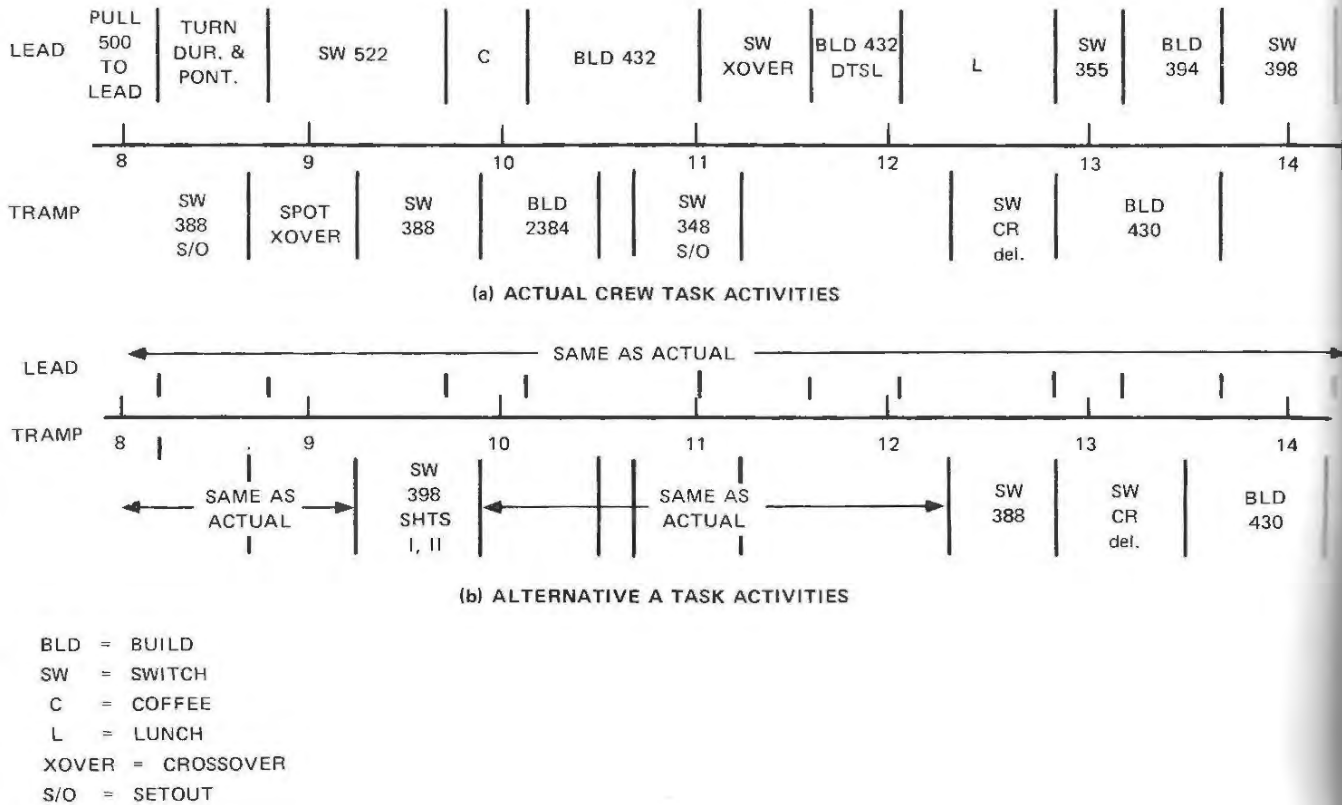

FIGURE A-19 ALTERNATIVE SEQUENCES OF LEAD AND TRAMP CREW TASKS

Figure A-11 shows how the yard inventory would have appeared under the alternative crew task-ordering sequence. The solid lines show the actual yard inventory as in Figure A-2, while the broken lines show the car inventories on each track if a change in that track's inventory occurred due to the Alternative A sequence. The revised alternative numerical entries are shown in parentheses next to the actual hourly counts where applicable. Note that at the end of the shift, the yard looks almost the same under both task sequences except for the six additional Durands on 13E, the single additional DTSL on 13E, and the 12 less Detroits on 5E. The Durands would have moved out at 2400 that day on another 2384 (Figure A-12) train built on the outer thoroughfare. (In reality, a crew scheduling problem postponed the 2384 departure until 1400 Wednesday, but at 0700, when these switching decisions were made, it would have been reasonable to assume the Durands to move again in 12 to 18 hours. We will assume, for simplicity, a delay of 15 hours for the 6 Durands missing the 388 connection.)

In sum, this alternative yard operation would have resulted in the following changes in yard performance:

- 174 car-hours saved in delay
  (12 Detroit 24 hr) - [(6 Durand x 15 hr) + 1 DTSL x 24 hr)].
- Five more cars leaving the yard this shift by switching 398 earlier. Note that 432 goes out with 12 more Detroits, but 2384 leaves with 6 less Durands under the alternative.
- Five more cars (net) make their first connections.
- Twelve 24-hour cars avoided.

This small gain in yard efficiency is commendable, but it would be desirable to find a way to switch 388 so that its Durand traffic can also make its first reasonable connection--2384 leaving Battle Creek at 1300 Tuesday. This can be accomplished under Alternative B, in which the tramp crew's work tasks can be rearranged so that the 398 Detroits and 388 Durands can be switched before building 432 and 2384, respectively. This sequence is shown in Figure A-20.

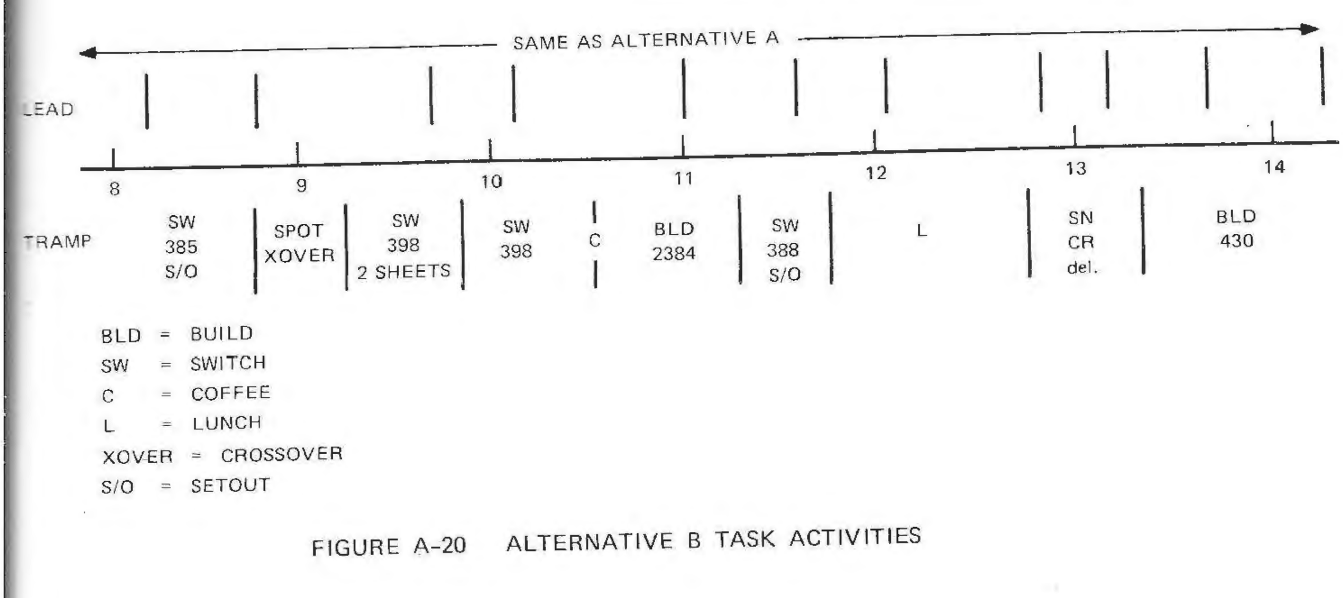

FIGURE A-20 ALTERNATIVE B TASK ACTIVITIES

The effects of Alternative B on yard inventories are indicated by the dotted lines in Figure A-11. Note specifically the half-hour delay to 92 cars of 2384 waiting for 388 to be switched. This delay is essentially the "tradeoff" that must be made to gain the benefits of 398 and 388 being switched before building 2384. The net effect on the yard at the end of the shift, however, is to reduce only the inventory of the Detroit track (5E) from 13 under actual conditions to 1 under Alternative B. The changes in yard performance over actual conditions would be:

- 242 car-hours saved in delay (288 Detroit car-hours less 92 cars in 2384 delayed an additional 1/2 hour). Note that the 1/2 hour delay to the 92 cars on 2384 will probably never be noticed by that train's customers, but a day's delay to the Detroit traffic can have significant consequences.
- Twelve more cars make their first reasonable connection. This is an especially important measure of effective for once-a-day connections.

Alternative B is clearly the most desirable way to allocate yard crew resources according to the above measures of effectiveness (MOEs), especially since total work performed by the engine crews remained constant; only their task orders were changed. Moreover, in both alternatives, 432 was built and called at the same "actual" time so as to comply with the work-rule constraints on the crew that arrived in Battle Creek on 433.

Both Alternatives A and B represent only modest, incremental improvements in yard efficiency, and if they represented solutions to unique, isolated operating conditions, it would hardly pay to propose wholesale revisions in the Battle Creek yard operations. However, if yardmaster planning and decision aids using RAILS and DMP can be developed that will enable the block connection situation portrayed in this example to be spotted and properly analyzed on a routine basis, significant, long-run cost savings could be realized by GT, in addition to certain nonquantifiable benefits in areas such as customer relations and employee morale.

We are currently experimenting with planning techniques that specifically isolate sparse, once-a-day connections, like those executed with 432, by requiring yard personnel to estimate potential car-hours of delay resulting from missed connections. For other, more frequent connections (Mains, Flints, etc.), these planning techniques require yardmasters (and dispatchers) to use advance yard inventory information available through DMP to determine the combination of destination blocks on each outbound train that optimizes some objective function, such as connection efficiency of yard throughput. A typical situation that would occur here would involve the proper assignment of blocks to, say, 384, so that blocks arriving on later trains can be accommodated by designated yard classification tracks. For example, if a large block of Durands was forecast to arrive in the yard in eight hours, and the Lansing inventory was expected to remain constant, it may be desirable to run a 384 out with the existing Durand inventory combined with Mains. The Lansings could go out on a later train, while the incoming Durands can be accommodated on a single, designated classification track that will have been "cleared" by the departure of those Durands on 384.

2. Case 2

The second, and by far the most complex, case actually occurred on Tuesday afternoon (Figure (A-12) and involved the building of an "extra" 2388 train, for which it was discovered during the next shift that no pool crew was available. As a result, the "train" (as shown on the outer thoroughfare track, TFO) was stripped of its Mainline traffic early the next morning, which moved out on 386 (Figure A-13) and 384 (Figure A-14), while the 47 Durand and Lansing cars remained on the track and became part of an extra 2384 train that eventually went out at 1330 Wednesday afternoon (Figure A-14).

We have conservatively estimated that this incident resulted in nearly 1,100 car-hours of delay to the original consist, assuming an 0100 leave time for the would-be 2388 train. If we account for the cars presumably denied places on later trains that had to accommodate the

Mains, Durands, and Lansings from 2388, we could estimate an additional 200% to 300% delay to all cars due to these "higher-order" effects.

However, we are not really interested in conducting a thorough postmortem restricted to what actually happened, since the problem seemed to boil down to a simple lack of communication between an inexperienced yardmaster and a crew dispatcher regarding the availability of a pool train crew. We would rather speculate on the feasibility of deadheading a train crew from Port Huron to Battle Creek in time to take 2388 out at 0100 Wednesday without violating work rules (see Alternative II below) and compare it with not building 2388 at all and instead logically placing its consist on other regularly scheduled trains leaving the yard within 12 hours of 2388's assumed call time (see Alternative I below). Of course, doing this analysis correctly involves "adding" and "bumping" cars onto or off trains that actually went out for several shifts after 2388's call time, at which time the yard would presumably "settle down."

We did this very thing in analyzing Case 2 and found that to properly account for the effects of both alternatives on the yard it was necessary to make strong assumptions regarding both the blocking combinations of some outbound trains and the ex-post-facto rearrangement of switch-engine tasks so that we could hypothetically build and switch trains in a logical, realistic manner. In doing so, however, we have tried our utmost to keep total crew switching time constant and to keep the tasks performed during each shift unchanged from the actual events documented in Figures A-1 through A-9, although an obvious exception to this is the crew time saved by not building 2388 in Alternative I and, as discussed below, not building 384 in Alternative II (see Figure A-6). We have also tried to keep individual task times constant, thereby making the ordering of engine tasks the only real independent variable employed in both alternatives of Case 2.

In the following paragraphs, we have summarized the events comprising each alternative and have shown in the time domain how switch-engine tasks would have to be rearranged to facilitate the hypothetical operations shown in Figures A-11 through A-18. Alternatives I and II are then compared and evaluated, and the applicability of DMP and RAILS to this situation is discussed.

a. Alternative I

Under this sequence of events, a pool crew was not available and 2388 was not assembled. Instead, 2388's would-be consist, which included 24 Durands, 23 Lansings, and 63 Mainlines* was distributed as follows:

- The 23 Lansings were assumed to go out at 2230 on 388, which increased that train's consist from 72 to 95 cars (see 1E, Figure A-11).
- 50 Mains were turned to 1E and went out on train 386 at 0600 Wednesday with 104 cars.
- 13 Mains, originally on 6E during the afternoon shift, were turned instead to 3E at 0300 Wednesday and went out at 1200 as part of a 94-car 384.
- The 24 Durands remained in the yard (on 13E), going out, as they actually did, at 1400 as part of a 106-car consist on 2384.

These, and the subsequent hypothetical moves defined for Alternative I, are shown on the time graphs in Figures A-11 through A-18 by the ---●--- notation. Where a train or block has been deleted, as 2388 was in this alternative, the notation will appear on the baseline, or zero-car, position, on the appropriate track over the time interval during which the cars actually appeared on the track (see TFO between 1700 and 2300 in Figure A-12). The revised consists for all relevant outbound trains in Alternative I are listed in Table A-1, where the train number and leave time are shown along with the size of each block, the originating yard classification track (the "switched from" track), and explanatory notes where applicable. These entries are listed along with the actual outbound consists for each train and the hypothetical, Alternative II, consists as described below.

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*Mainlines (492) and Boats (0) were not being blocked when the October data was taken.

Table A-1

TRAIN CONSIST COMPARION: CASE 2

Train Leave Time	Alternative I Consist	Class Track	Alternative II Consist	Class Track	Actual	Class Track
388 2200 Tues.	21 Main 51 Flint 23 Lansing 95 cars	6E 4E 7E	21 Main 51 Flint 72 cars	6E 4E	21 Main 51 Flint 72 cars	6E 4E
2388 0100 Wed.	--None--		63 Main 23 Lansing 24 Durand 110 cars	9E,6E 9E 13E	--None--	
386 0600 Wed.	50 Main 40 Lansing 7 O.V. Parts 7 Hook 104 cars*	9E 12E 2E	14 Main 55 Lansing 7 O.V. Parts 7 Hook 83 cars	9E 12E,8E 2E	30 Main 40 Lansing 7 O.V. 7 Hook 84 cars	TFO 12E 2E
384 1200 Wed.	56 Main 39 Fling 95 cars	9E,6E 3E,4E	29 Main 54 Flint 83 cars	9E,TFO 3E,4E	42 Main 39 Flint 81 cars	TFO 3E,4E
2384 1400 Wed.	48 Lansing 58 Durand 106 cars	6E,12E 13E	32 Lansing 34 Durand 14 Main (boats) 80 cars	6E,12E 13E 6E	57 Lansing 37 Durand 94 cars	8E,TFO TFO
384 0100 Thurs.	57 Main† 25 Main 82 cars	6E,2E 6E,(384)	--None--		91 Main 91 cars	9E,6E
386 0600 Thurs.	19 Durand 46 Flint 65 cars	13E 4E,TFO	43 Main 25 Main 31 Flint 99 cars	6E 6E 4E,TFO	33 Durand 46 Flint 79 cars	13E 4E,TFO
388 1800 Thurs.	14 Lansing 15 Lansing 39 Main 68 cars	12E 12E 6E	19 Durand 14 Lansing 15 Lansing 39 Main 87 cars	13E 12E 12E 6E	24 Lansing 69 Main 93 cars	12E 9E,6E,3E
0400 Fri.					7 Durands leave yard	
0600 Fri.					Assume 18 Lansings	(12E)

*Includes all but 13 Mains from Alternative II - 2388 consist.

†Nine Mains from 388 inbound.

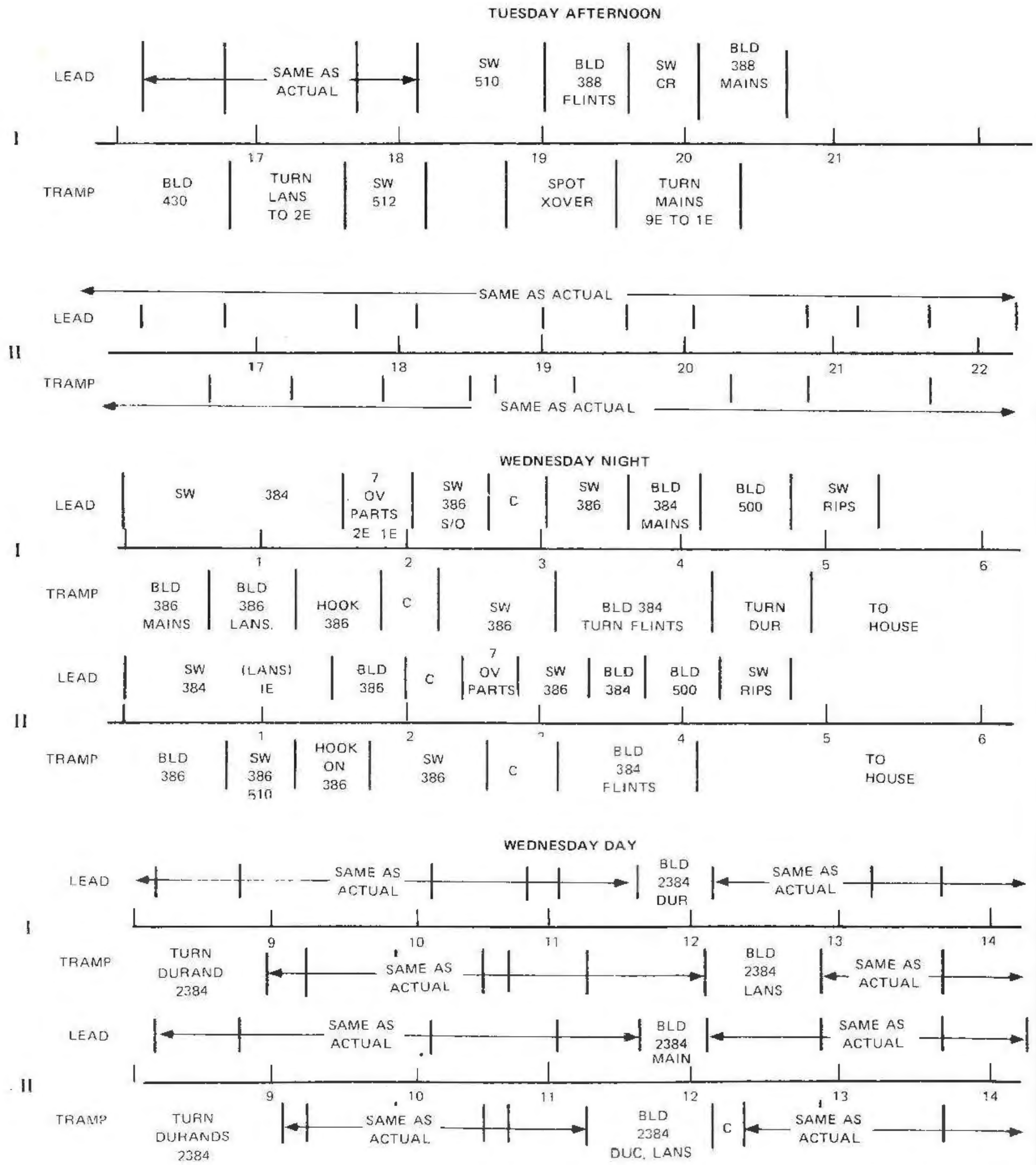
Inspection of the Alternative I consists will reveal that trains leaving the Battle Creek yard from 2100 Tuesday until 0100 Thursday with Mains, Durands, and Lansings are generally longer than their actual sizes, as we would expect. This is the case for the first four outbound trains affected by the assumptions of Alternative I. The exceptions are 386, out 0600 Thursday with 14 fewer Durands than actual, which were instead assumed to go out as part of a 106-car 2384 about 16 hours earlier, 384 out 0100 Thursday with fewer Mains, and 388 out 180 Thursday. We have also had to assume several important changes in switching tasks as shown in Figure A-21 for Tuesday afternoon through Thursday night shifts. Note that by not building 2388, the Tuesday afternoon crews do a little less work than actual even though we have assigned them the additional task of turning Mains from 9E to 1E, and that most other shifts must perform slightly more work per relevant task in order to build the longer trains.

b. Alternative II

Under this hypothetical sequence of events, we assume that somehow the buildup in yard inventory was anticipated sufficiently far in advance so that a pool crew would have been deadheaded from Port Huron, rested, and then taken 2388 out of Battle Creek at approximately 0100 Wednesday. A chronology of the events and decision necessary to get the train out at the assumed time is shown below:

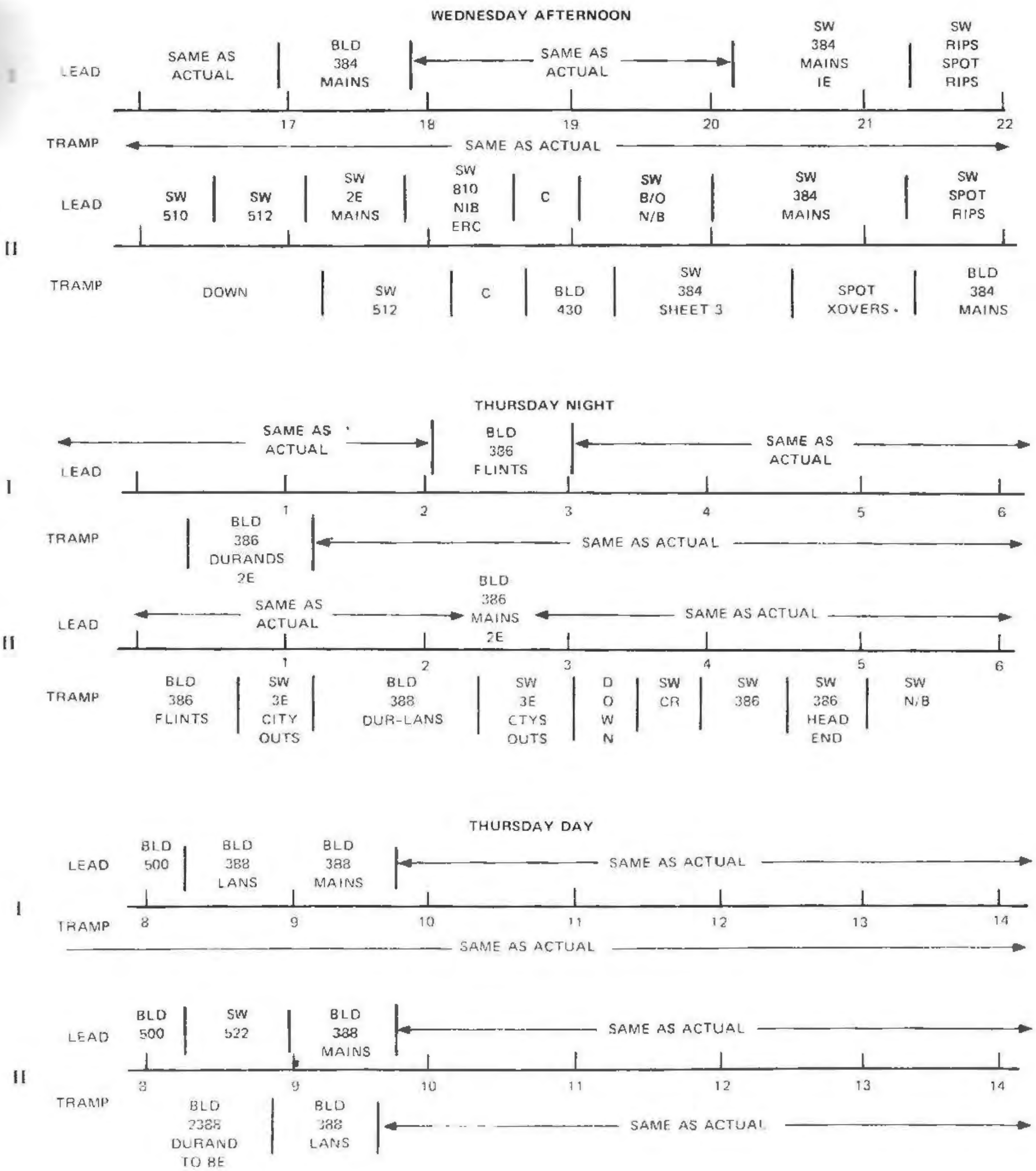
2400 Tuesday--The Battle Creek dispatched notes the progress of three eastbound trains toward Battle Creek and expects that 522 with 67 cars, 398 with 102 cars, and 388 with 100 cars will arrive at the yard between 0500 and 0800. He must continue to monitor the situation closely for the next several hours, both on the line and in the yard, and correlate that with the current and projected availability of power and crews. He should be thinking of having the wherewithal on hand to build an extra train if the arrival date of cars in the yard over the next 12 hours is significant compared to the service rate, the rate at which trains can be built in the yard.

0500 Tuesday--522 is in the yard, 398 in town, and 388 in Vicksburg. The dispatched, using DMP and consulting with the yardmaster of assistant trainmaster, should be able to estimate how many cars will be moved the next shift and how many will



BLD BUILD
SW SWITCH
C COFFEE
L LUNCH
XOVER CROSSOVER
S O SETOUT

FIGURE A-21 SWITCHING TASK COMPARISON: CASE 2



BLD	BUILD	L	LUNCH
SW	SWITCH	XOVER	CROSSOVER
C	COFFEE	S O	SETOUT

FIGURE A-21 SWITCHING TASK COMPARISON: CASE 2 (Concluded) arrive during the next 12 hours. He should know what 512 will carry, how the consist of 384 is shaping up in the Elsdon yard, what the day's ConRail delivery will be like, and how many trains and cars the dayshift yardmaster is likely to move during his shift. He must then anticipate a loaded yard that will require crew and power for an extra train (2388, 2384, or 2386) that will most likely have to be built during the afternoon shift to handle the Mains brought in by 512 and 398 and the Durands inbound on 512. Consulting the crew and power boards, and noting that no pool crew will be available in Battle Creek for over 24 hours, he must arrange for a crew to be deadheaded from Port Huron to take the anticipated extra train out sometime Wednesday morning. This means getting them on a westbound train before noon that day so as to meet crew work-rule constraints.

0600 Tuesday--After negotiating with yardmasters, chief dispatchers, trainmaster, etc., the dispatcher decides to deadhead a train crew from Port Huron on 393 westbound, called later that morning in Port Huron and slated to arrive in Battle Creek Tuesday afternoon. He should know that his only presently available crew must take some hot Flints out on 394 that afternoon.

0700 Tuesday--The extra crew must be called so that it can deadhead in on 393.

0800 Tuesday--393 arrives in Battle Creek with the extra crews. 512 has arrived with 103 cars as anticipated, and the need for an extra 388 is obvious, as the yardmaster begins turning Durands and Lansings onto the outer thoroughfare (see Figure A-12).

2400 Tuesday--The train is called and leaves Battle Creek within the hour with 110 cars.

The impact of 2388's scheduled departure on subsequent yard operation is shown graphically by the —••— entries in Figures A-12 - A-18. As in Alternative I, we have estimated a good 24 hours for the yard to "settle down" after the 2388 move in Alternative II. The Alternative II trains will naturally tend to run shorter than either their actual consists or their Alternative I counterparts.

The Alternative II consists are also listed and described in Table A-1. Of particular interest here is the fact that we could not fint enough cars to run a 384 out at 0100 Thursday, so we arbitrarily held 44 Mains scheduled for that train until 386 could take them out at

0600 as part of a 94-car consist. It would appar, then, that building the 2388 on Tuesday ultimately spared us the necessity of building 384 on Wednesday afternoon, so that between Tuesday and Thursday the Battle Creek yard assembled an equivalent number of trains under both Alternatives I and II. This means that the additional crew cost of Alternative II should be restricted only to the cost of deadheading 2388's crew from Port Huron and not to the cost of running the train, since the train really "takes the place" of 384. We must, however, account for the additional five-hour delay incurred by the 44 Mainlines going out on 386. As in Alternative I, we have estimated the impact of 2388 to attenuate by the time 388 goes out at 1800 Thursday.

We have also rearranged some switching tasks and, of course, deleted the 384 task from Wednesday afternoon's work. The workload reallocation is shown along with Alternative I in Figure A-21.

c. Evaluation by Alternatives

Tables A-1 through A-4 show how blocks are transferred between trains for each of three hypothetical situations. One can develop an appreciation of the block delays involved with each combination by simply noting the concentration and steepness of the lines connecting blocks assigned to trains under both alternatives and actual movements. In Table A-3, for example, 30 Mains are shown by the connecting line as being transferred from their actual 386 train on Wednesday to 2388 leaving five hours earlier that day, under Alternative II. We can then attribute 150 car-hours of delay to that block of Mains relative to their status in Alternative II. Occasionally, a downward pointing connector is used to show blocks actually moving to the less efficient alternative or "against" the predominant flow of blocks backward in time. This, for example, will follow from not building a Wednesday 384 in Alternative II.

Relative delays for each combination have been calculated from these tables and are shown in conjunction with other MOEs in Table A-5. The delay statistics are particularly insightful in that they

Table A-2

BLOCK TRANSFERS BETWEEN ALTERNATIVES I AND II

Time Leave Time	Alternative I Consist	Class Track	Alternative II Consist	Class Track
388	21 Main	6E	21 Main	6E
2200 Tues.	51 Flint	4E	51 Flint	4E
	23 Lansing	7E		
	95 cars		72 cars	
2388			63 Main	9E,6E
0100 Wed.	--None--		23 Lansing	9E
			24 Durand	13E
			110 cars	
386	50 Main	9E	14 Main	9E
0600 Wed.	40 Lansing	12E	55 Lansing	12E,8E
	7 O.V. Parts	2E	7 O.V. Parts	2E
	7 Hook		7 Hook	
	104 cars*		83 cars	
384	56 Main	9E,6E	29 Main	9E,TFO
1200 Wed.	39 Flint	3E,4E	54 Flint	3E,4E
	95 cars		83 cars	
2384	48 Lansing	6E,12E	32 Lansing	6E,12E
1400 Wed.	58 Durand	13E	34 Durand	13E
			14 Main (boats)	6E
	106 cars		80 cars	
384	57 Main†	6E,2E		
0100 Thurs.	25 Main	6E,(384)	--None--	
	82 cars			
386	19 Durand	13E	43 Main	6E
0600 Thurs.	46 Flint	4E,TFO	25 Main	6E
			31 Flint	4E,TFO
	65 cars		99 cars	
388	14 Lansing	12E	19 Durand	13E
1800 Thurs.	15 Lansing	12E	14 Lansing	12E
	39 Main	6E	15 Lansing	12E
			39 Main	6E
	68 cars		87 cars	
0400 Fri.				
0600 Fri.				

Note: Arrows point to most efficient alternative.

*Includes all but 13 Mains from Alternative II - 2388 consist.

†Nine Mains from 388 inbound.

Table A-3

BLOCK TRANSFERS BETWEEN ACTUAL AND ALTERNATIVE II

Train Leave Time	Alternative II Consist	Class Track	Actual	Class Track
388 2200 Tues.	21 Main 51 Flint 72 cars	6E 4E	21 Main 51 Flint 72 cars	6E 4E
2388 0100 Wed.	63 Main 23 Lansing 24 Durand 110 cars	9E,6E 9E 13E	--None--	
386 0600 Wed.	14 Main 55 Lansing 7 O.V. Parts 7 Hook 83 cars	9E 12E,8E 2E	30 Main 40 Lansing 7 O.V. 7 Hook 84 cars	TFO 12E 2E
384 1200 Wed.	29 Main 54 Flint 83 cars	9E,TFO 3E,4E	42 Main 39 Flint 81 cars	TFO 3E,4E
2384 1400 Wed.	32 Lansing 34 Durand 14 Main (boats) 80 cars	6E,12E 13E 6E	57 Lansing 37 Durand 94 cars	8E,TFO TFO
384 0100 Thurs.	--None--		91 Main 91 cars	9E,6E
386 0600 Thurs.	43 Main 25 Main 31 Flint 99 cars	6E 6E 4E,TFO	33 Durand 46 Flint 79 cars	13E 4E,TFO
388 1800 Thurs.	19 Durand 14 Lansing 15 Lansing 39 Main 87 cars	13E 12E 12E 6E	24 Lansing 69 Main 93 cars	12E 9E,6E,3E
0400 Fri.			7 Durands leave yard	
0600 Fri.			Assume 18 Lansings (12) leave yard	

Note: Arrows indicate how blocks could have gone out.

Table A-4

BLOCK TRANSFERS BETWEEN ACTUAL AND ALTERNATIVE I

Train Leave Time	Alternative I Consist	Class Track	Actual	Class Track
388 2200 Tues.	21 Main 51 Flint 23 Lansing 95 cars	6E 4E 7E	21 Main 51 Flint 72 cars	6E 4E
	23			
2388 0100 Wed.	--None--		--None--	
386 0600 Wed.	50 Main 40 Lansing 7 O.V. Parts 7 Hook 104 cars*	9E 12E 2E	30 Main 40 Lansing 7 O.V. 7 Hook 84 cars	TFO 12E 2E
	20			
384 1200 Wed.	56 Main 39 Flint 95 cars	9E,6E 3E,4E	42 Main 39 Flint 81 cars	TFO 3E,4E
	34			
2384 1400 Wed.	48 Lansing 58 Durand 106 cars	6E,12E 13E	57 Lansing 37 Durand 94 cars	8E,TFO TFO
	14			
384 0100 Thurs.	57 Main† 25 Main 82 cars	6E,2E 6E,(384)	91 Main 91 cars	9E,6E
	25			
386 0600 Thurs.	19 Durand 46 Flint 65 cars	13E 4E,TFO	33 Durand 46 Flint 79 cars	13E 4E,TFO
	7			
388 1800 Thurs.	14 Lansing 15 Lansing 39 Main 68 cars	12E 12E 6E	24 Lansing 69 Main 93 cars	12E 9E,6E,3E
	18			
0400 Fri			7 Durands leave yard	
0600 Fri			Assume 18 Lansings (12E) leave yard	

Note: Arrows indicate how blocks could have gone out.

*Includes all but 13 Mains from Alternative II - 2388 consist.

†Nine Mains from 388 inbound.

Table A-5

RELATIVE BLOCK DELAYS AND OTHER
MEASURES OF EFFECTIVENESS: ALTERNATIVES I AND II AND ACTUAL

	Alternative II over Alternative I	Alternative I over Actual	Alternative II over Actual
1. Block delay saved (car-hours)	740	2220	3440
2. Yard throughput (additional cars moved per day by 2359 each day)			
- Tuesday	-23	+23	0
- Wednesday	+51	+46	+97
- Thursday	-28	-48	-77
- Friday	0	-21	-20
	Alternative II	**Alternative I**	**Actual**
3. Overage cars			
• Mains over 18 hours at 2359 each day			
- Tuesday	0	0	0
- Wednesday	0	5	42
- Thursday	25	25	30
• Durands over 24 hours			
- Tuesday	0	0	0
- Wednesday	0	0	16
- Thursday	0	0	12
• Lansings over 18 hours			
- Tuesday	0	0	0
- Wednesday	0	0	0
- Thursday	2	2	17

reveal the cost to GT of building 2388 and then having to break it up and send it out piecemeal on subsequent trains. Either alternative would have been preferable in this case, since over 2,000 car-hours would have been avoided in the Battle Creek Yard. The "Actual" situation points to the necessity of maintaining an orderly flow of information between yardmasters and dispatchers. We would hope to formalize this mechanism through a more structured approach to shift preplanning perhaps utilizing other yard personnel such as clerks, car checkers, and assistant trainmasters. If these kinds of incidents regularly involve inexperienced yardmasters, it may also be worth exploring the idea of a structured yardmaster training program. Trainees could, for example, practice in a simulated environment where they could develop familiarity with the rudiments of building trains and the unique operating environment of the tower yard at Battle Creek.

The 740 hours of delay saved by deploying Alternative II over Alternative I is of special interest to us, since it involved more of a marginal improvement (Alternative II) over what might be described as the best possible operating strategy under the conditions that existed (Alternative I). Specifically, would it be worth defying the uncertainties associated with normal railroad operations to call a crew in Port Huron and deadhead it to Battle Creek to avoid about 700 car-hours of delay costs? Even with DMP supplying more accurate long-range predictive information, derailments, slow order, or other line-haul delays could quickly nullify the gains possible under Alternative II. For example, we estimate that a three- to four-hour delay in calling 2388 in Alternative II would make the deadheading move uneconomical. This must be traded off with possible nonquantifiable gains made through better customer relations, employee morale, and the like, that might accrue by simply making it a matter of company policy to expeditiously move traffic whenever buildups are predicted.

3. Case 3

In this instance, a train was made up on 3E during the day shift Thursday and sat in the yard ready to move until 0400 Friday.

Again, the excessive delay was caused by a train crew shortage in Battle Creek, and again we have speculated on what would have to happen for a crew to deadhead in from Port Huron to take 2384 out by 1800 Thursday:

> 1700 Wednesday--The dispatcher must anticipate a sharp increase in cars at the yard when 386, 522, and 298 arrive 12 hours later. This is a difficult task, since neither train will be called until 2000 or so. DMP, accurate interchange inventories at Thornton and Harvey, and industrial information for 522 are vital to such an advance forecasting exercise.
>
> 2200 Wednesday--386 and 522 are enroute and 398 is called out of Harvey. The dispatcher must know how the yard will look eight hours from this time when these trains hit Battle Creek; he must anticipate that a buildup of Durands, Mains, and Flints will require an extra train, and he must estimate the tradeoffs involved with deadheading the crew from Port Huron. If he chooses to deadhead, he must call the crew quickly so that they can be on 387 at 0100.
>
> 0800 Thursday--387 arrives in Battle Creek.
>
> 1600 Thursday--The deadhead crew would be rested and able to take 2384 out of Battle Creek in 1700.

The incident described in Case 3 occurred during the last two shifts of our data collection effort, so it will be impossible to conduct the exhaustive after-effect analysis performed in Case 2. Instead, we will simply estimate the immediate first-order delay effects of not getting the train out. That is, we will assume that the yard was sufficiently plugged on Thursday day shift so that the yardmaster literally had no choice but to turn Flints and Durands to a longer track so that the lower yard class tracks for these blocks could accommodate inbound traffic. The problem is then simplified to one of having crew and power available as close to the train's ready time as possible. The above chronology can be visualized from Figures A-8 and A-9 or by noting the "actual" solid line contours of Figures A-17 and A-18, with the suggested 2384 leave time shown by broken lines in Figure A-18. Dispatchers' records shown an actual leave time of 0415 Friday morning. Accordingly, we have assumed the yard delay to be approximately 80 cars x 10 hours = 800 car-hours, which we estimate to be on the low side of what a task-reordering analysis similar to Case 2 would show. (This lack of data also precludes us from calculating the other MOEs accurately.)

We must again ask if it is worth the trouble to deadhead a crew from Port Huron a good 12 hours in advance to save the money represented by the above delay. Obviously, accurate inventory information for Chicago area yards from RAILS combined with data on the predicted movement of traffic to Battle Creek from DMP would be essential to the dispatcher as a decision-making aid. He must have complete confidence in these information sources so that he can depend on his decisions to "look good" under the anticipated free-flowing conditions on the railroad. His decisions must also be flexible enough to work around unforeseen, intervening events whenever possible.

The yardmaster admittedly did not play a pivotal role in Case 3, as we have assumed that he did the only thing he could under the conditions at hand. However, he plays an important part in this type of situation in that his communication of current and projected yard status to the dispatcher is critical to the dispatcher's ultimate choice of action. Also, by forecasting a crew availability time, the yardmaster might postpone making the designated train for that crew and switch or build another train in that interval, thereby saving block delay for trains going out or making more reasonable first connections for cars on trains being switched. For example, if it were known that the 2384 crew would not be available until 2000 Thursday, the yardmaster might have taken the time to add a few more Mains from 6E to 388 on 1E, with 4E Flints added to 2384 early in the succeeding shift.

D. Summary of Case Studies

Case 1 represents the only situation described herein that is internal in scope to yard operations. It portrays a problem that can be directly attributed to yardmaster decisons regarding crew task allocations, but its "solution" also provides less dramatic, though no less visible, returns to GT than the massive, coordinated prognostications required to "solve" Cases 2 and 3. Previous discussions with yard personnel combined with the results of this analysis have enabled us to zero in on yard-related problems and to suggest solution concepts that would involve:

- Transferring some yardmaster chores to others. This would include the use of RAILS by a yardmaster assistant to prepare block counts shortly before the yardmaster starts work. This would free the yardmaster to concentrate on yard events, dispatcher coordination, and the like.
- Requiring a yardmaster assistant to use DMP/RAILS to list desirable block and train connections.
- Providing the yardmaster with a decision aid using RAILS, DMP. and interactive graphics techniques to construct current and projected pictures of the yard. The yardmaster could use this capability to experiment with alternative crew assignments before actually handing out the work and to quickly evaluate the impact of disruptions on yard operations.

Each of the above items could potentially improve current yard planning practices by reducing yardmaster distractions, enhancing yard visualization, and providing quick evaluation capability. This, in turn, would reduce the incidence of missed connections as described in Case 1.

Cases 2 and 3 call for improved lines of communication between line-haul and yard operations, with most of the decision making falling on the dispatching office, where accounting for the crew shortages could conceivably have prompted the yardmaster to proceed with an Alternative I shift plan instead of building the ill-fated 2388 in Case 2. However, yard shift planning should also include up-to-date information on crew car and power availability.

Appendix B

ANALYSIS OF SYSTEMWIDE MEASURES OF EFFECTIVENESS

Appendix B

ANALYSIS OF SYSTEMWIDE MEASURES OF EFFECTIVENESS

Introduction and Summary

In order to measure the effectiveness of RAILS and DMP (i.e., real time inventory plus predictive information) on GT's dispatching operations, selected statistical measures of effectiveness (MOEs) were obtained prior to and during the live dispatching experiment period. The bulk of the data for the MOEs was available either directly or by manipulating GT reports.

SRI obtained "before" data for the months of February, March, April, May, June, and July from daily GT reports sent to SRI weekly. The experiment week at GT was from July 25 through July 30, 1977. The same GT reports were available during the experiment. Our analysis indicated that any effect on the operation of the GT trains was not detectable statistically with the experiment data. In fact, further analysis indicated that, given a 10% effect on all MOEs, the majority of the effects would be unlikely to be statistically detected because of the large variance in the MOEs for the 165 days prior to the experiment. In two out of five MOEs tested, it was determined that at least one to six months of experiment data were required for a 90% probability of detecting a known 10% change in MOE mean.

Measure of Effectiveness Analysis

Data Collection

Daily freight train and yard information was collected from GT during the six months prior to the SRI experiment. Based on the GT information available from "Daily Reports of Locomotive and Train Performance" (GT-800 reports), "Daily Reports of Operations and Cumulative and Comparative Statements on Freight and Yard Operations," and from "Car Delay Time Summary" computer printouts for the period July 18-July 27, 1977, eight MOEs described in Table B-1 were selected that we hoped would reflect the influence of SRI's dispatching experiment on GT train operations.

Most of the information used in developing MOEs for specific trains was obtained from GT-800 reports and was manipulated by using a system of computer programs called Statistical Package for the Social Sciences (SPSS).*

The following data were encoded separately for all manifest trains on the Chicago Division from the GT-800 reports:

- Train number
- Subdivision (Flint or South Bend)
- Direction (east or west)
- Engine number(s) in operation at destination
- Train miles
- Ordered departure time
- Actual departure time
- Actual arrival time
- Tonnage (gross tons handled).

These data included 6,308 observations over 168 days and were input into an SPSS computer system in order to generate statistical MOEs for individual trains. Gross tons handled included the sum weight of all the cars and their contents picked up and set out at departure, intermediate, and destination yards. Train engine numbers were associated with information provided by GT on the approximate horsepower of that series of engine units by SPSS. SPSS data management facilities allowed generation of new variables (MOEs) which were mathematical and/or logical combinations of existing variables;

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*N.H. Nie et al., Statistical Package for the Social Sciences, 2nd ed. McGraw-Hill Book Company, San Francisco, 1970), 675 p.

Table B-1

SELECTED MEASURES OF EFFECTIVENESS

Measures of Effectiveness	Data Sources	Computation	Expected Effect	Type of Data
1. Terminal detention time	GT-800	Δ ordered and departure times*	Consistently < 1 hour	Individual trains
2. Average train speed	GT-800	Tonnage/Δ departure and arrival times*	Increase	Individual trains
3. Gross ton miles per train hour	GT-800	(Tonnage x train miles)/ Δ departure and arrival times*	Increase	Individual trains
4. On-time record of destination	GT-800, GT Schedule and Marshalling Instructions	Δ actual arrival time and scheduled arrival time*	Approach zero	Individual trains
5. Gross tons per horsepower	GT-800, GT staff	Tonnage/Σ engine HP*	Consistently close to one	Individual trains
6. Average number cars handled per train	Cumulative and Comparative Statement--Train Operations	No. cars handled No. trains	Decrease variance	Eastbound and westbound traffic
7. Average number cars handled per yard engine hour	Cumulative and Comparative Statement--Yard Operations	Provided on report(cars handled/yard engine	Increase with little variance	Port Huron, Battle Creek, Elsdon yards
8. Average pool car yard time	Car Delay Time Summary	Σ hours delay/number of pool cars	Decrease	Aggregated pools 100, 120, 124, and 179

*Computed by SPSS programming.

recording of variables; and sampling and selecting specified cases. SPSS procedures were used for descriptive statistics, frequency distributions, cross tabulations, and graphing of selected MOEs.

The daily performance of the manifest trains on the Chicago Division listed below were collected and individually coded for the period February 13-July 27, 1977.

TRAIN NUMBER	ORIGIN	DESTINATION	ROUTE*
382	Thornton Junction	Battle Creek	SB
383	Battle Creek	Thornton Junction	SB
384	Chicago	Port Huron	SB&F
385	Port Huron	Thornton Junction	SB&F
386	Thornton Junction	Port Huron	SB&F
387	Port Huron	Chicago	SB&F
388	Chicago	Port Huron	SB&F
389	Port Huron	Chicago	SB&F
390	Chicago	Port Huron	SB&F
391	Port Huron	Chicago	SB&F
392	Chicago	Port Huron	SB&F
393	Port Huron	Chicago	SB&F
394	Chicago	Flint	SB&F
395	Port Huron	Chicago	SB&F
397	Battle Creek	Harvey Markham Yard	SB
398	Harvey	Battle Creek	SB
420	Flint	Toledo	F
421	Toledo	Flint	F
430	Battle Creek	Pontiac	F
431	Pontiac	Battle Creek	F
432	Chicago	Detroit	SB
433	Detroit	Chicago	SB&F
434	Chicago	Detroit	SB&F
435	Detroit	Chicago	F

Trains that traveled on the Flint and South Bend subdivisions were coded separately as two trains even though they had the same train number. Second trains, used when two trains similar in characteristics are operated, were also coded as separate trains. Local train data were not coded.

---

*SB = South Bend subdivision; F = Flint subdivision.

The manifest trains were broken down into three categories: preferred, interroad, and drag trains. Preferred trains generally run according to a consistent schedule with a consistent set of traffic. Interroad trains run directly between an away-from-home yard and a GT yard. Drag trains are trains whose departure times and traffic are flexible. The first five MOEs described in Table B-1 were coded for all trains and were graphed for the following sample of trains from the three categories.

Preferred Trains		Interroad Trains		Drag Trains	
Train	Subdivision*	Train	Subdivision	Train	Subdivision
390	SB & F	385	SB	384	F
391	SB & F	397	SB	387	F
392	SB & F			434	SB
393	SB & F			435	SB
395	SB & F				

*SB = South Bend subdivision, F = Flint subdivision

The "Daily Report of Operations and Cumulative and Comparative Statement--Freight Train Operations" provided information on total through freight trains for Chicago Division eastbound and westbound trains. Through freight included scheduled and extra through freight (manifest traffic). The average number of cars handled per train MOE was calculated by direction for the six-month period and manually graphed for analysis.* The average number of cars handled counted the average number of cars picked up and set out at the departure, intermediate, and destination yards per train.

The "Daily Report of Operations and Cumulative and Comparative Statement--Yard Operation" provided information on total yard engine hours, cars handled and cars handled/yard engine hour for yards in the Chicago and Detroit Divisions. Three yards (Port Huron, Battle Creek,

*The daily number of trains in operation by direction on the Chicago Division were calculated by SPSS from information input from the GT-800 reports.

and Elsdon) were selected to best show the influence on yard operations of the MOE "cars handled per yard engine hour." This measure was also manually graphed separately for each yard. The number of cars handled in this MOE counted each time a car was handled in a yard (including switching and dragging).

A special program for sorting pool car information from RAILS was completed by GT one week prior to the experiment. Pool car yard time (Δ pool car arrival time and departure time) at Battle Creek Yard was provided by GT's "Car Delay Time Summary" computer printout for the period July 18-July 27, 1977. Pools 100, 120, 124, and 179 were selected for analysis. These pools of cars originate at Flint and are destined for the Elsdon, Blue Island, and Harvey stations on the GT system.

Results

SRI's project team was at GT the week beginning 25 July 1977, during which time the experiment was performed. Following the experiment, MOE data were graphed and analyzed for the six months prior to the experiment and for the experimental period.

The following trains were selected for detailed analysis:

- Preferred Train 392 on South Bend subdivision
- Preferred Train 392 on Flint subdivision
- Interroad Train 385 on South Bend subdivision
- Drag Train 384 on Flint subdivision
- Drag Train 434 on South Bend subdivision.

Five MOEs (terminal detention time, average train speed, gross ton miles per train hour, on-time record at destination, and gross tons handled per engine horsepower) are graphically presented in Figures B-1 through B-25 for these trains. These figures were derived using SPSS subprogram PLOT. The basic purpose of subprogram PLOT is to give a pictorial representation of the relationship between two variables (time and the selected MOE). Each day's performance of a

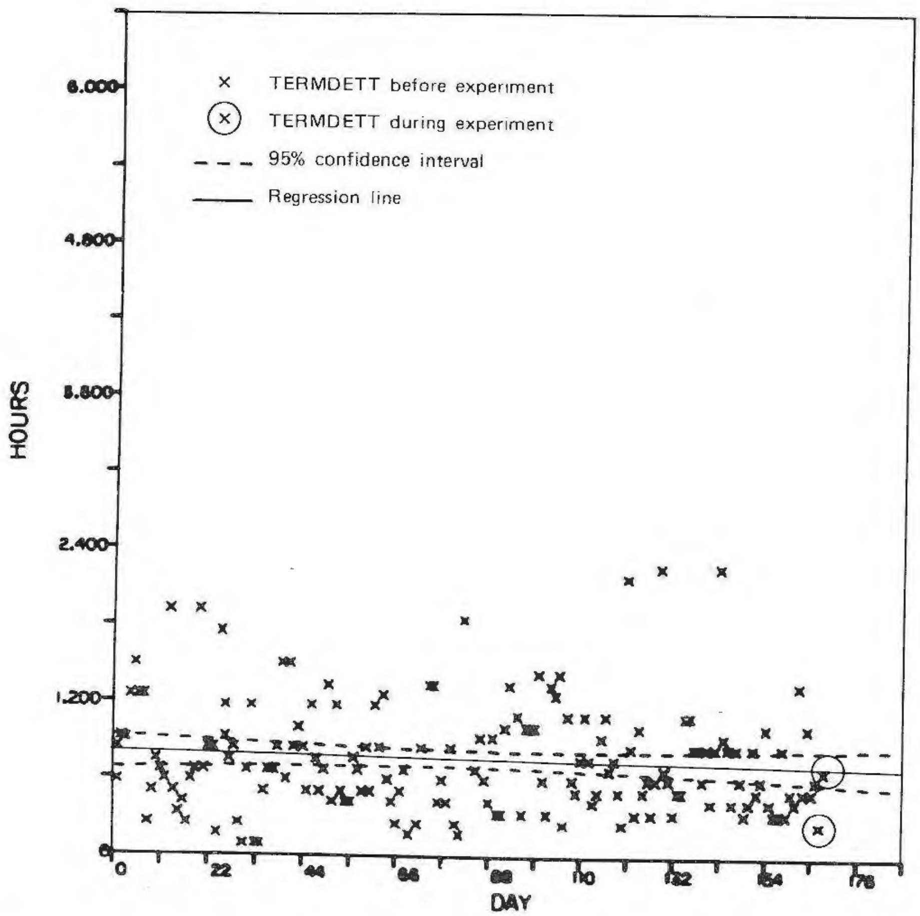

FIGURE B-1 TERMINAL DETENTION TIME (TERMDETT): TRAIN 392 SOUTH BEND

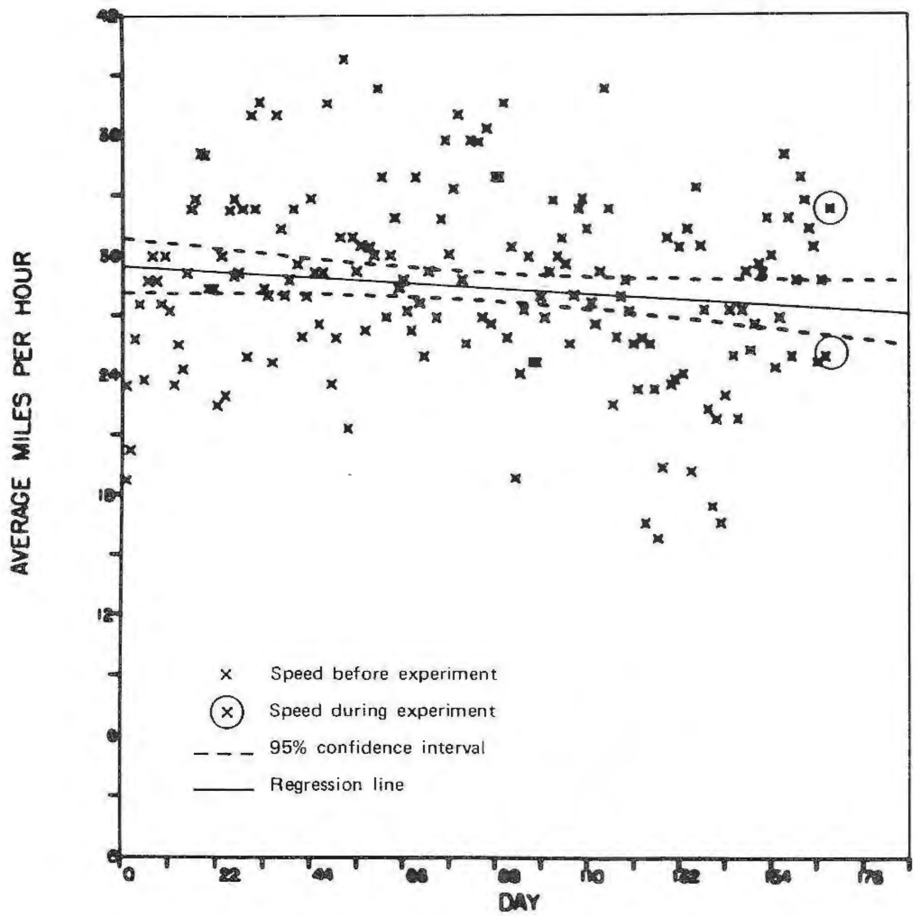

FIGURE B-2 AVERAGE TRAIN SPEED: TRAIN 392 SOUTH BEND

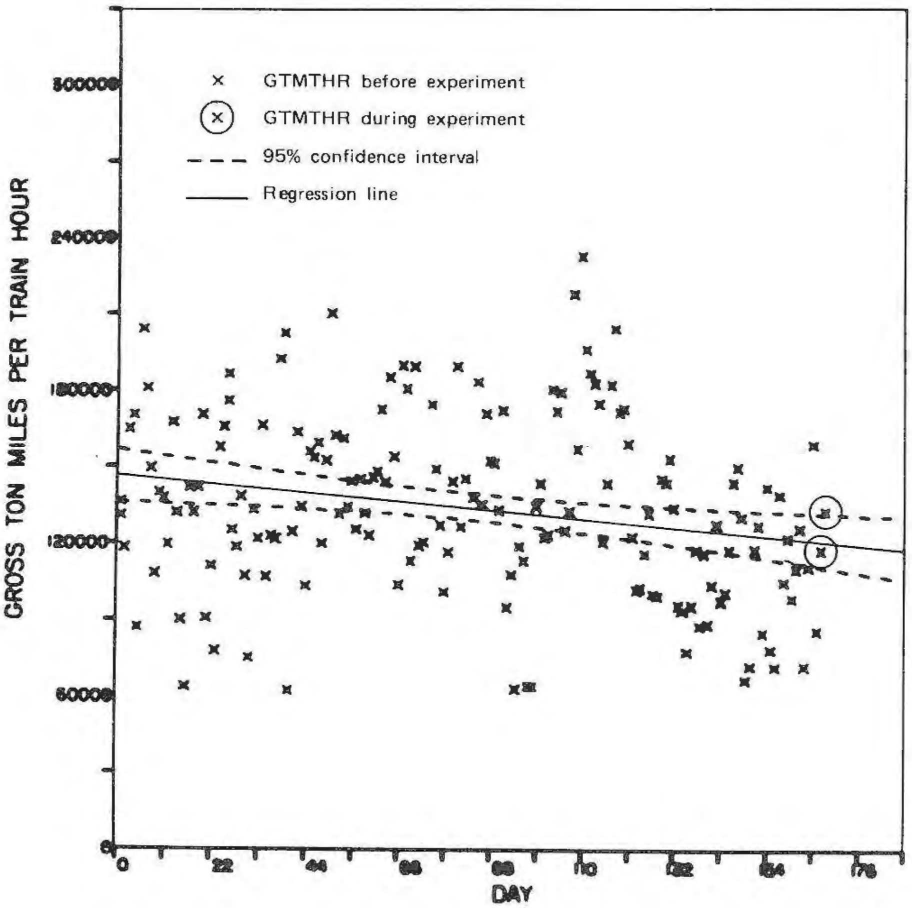

FIGURE B-3 GROSS TON MILES PER TRAIN HOUR (GTMTHR): TRAIN 392 SOUTH BEND

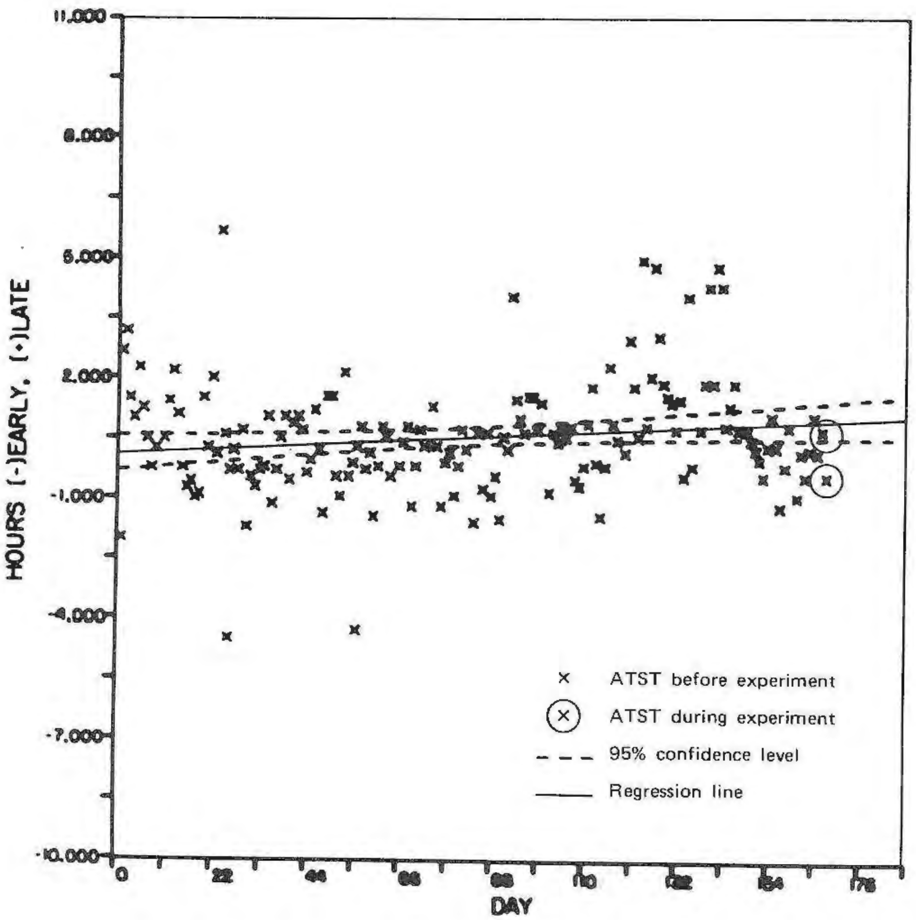

FIGURE B-4 ON-TIME RECORD AT DESTINATION (ATST): TRAIN 392 SOUTH BEND

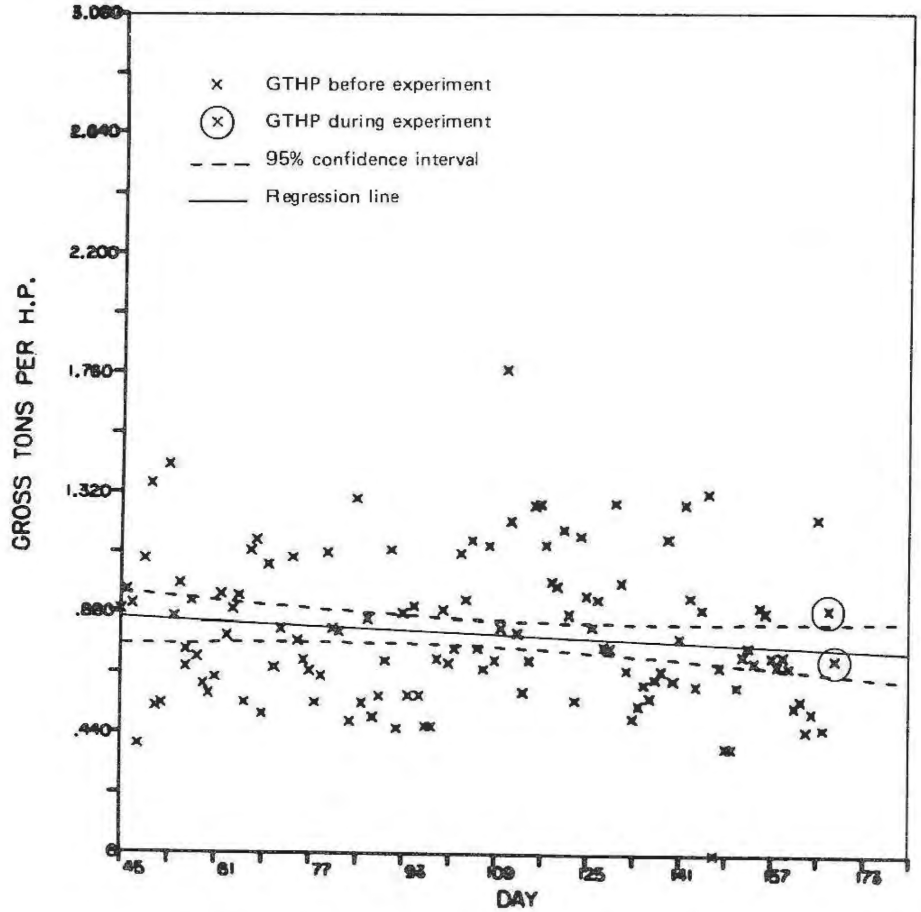

FIGURE B-5 GROSS TONS HANDLED PER ENGINE HORSEPOWER (GTHP): TRAIN 392 SOUTH BEND

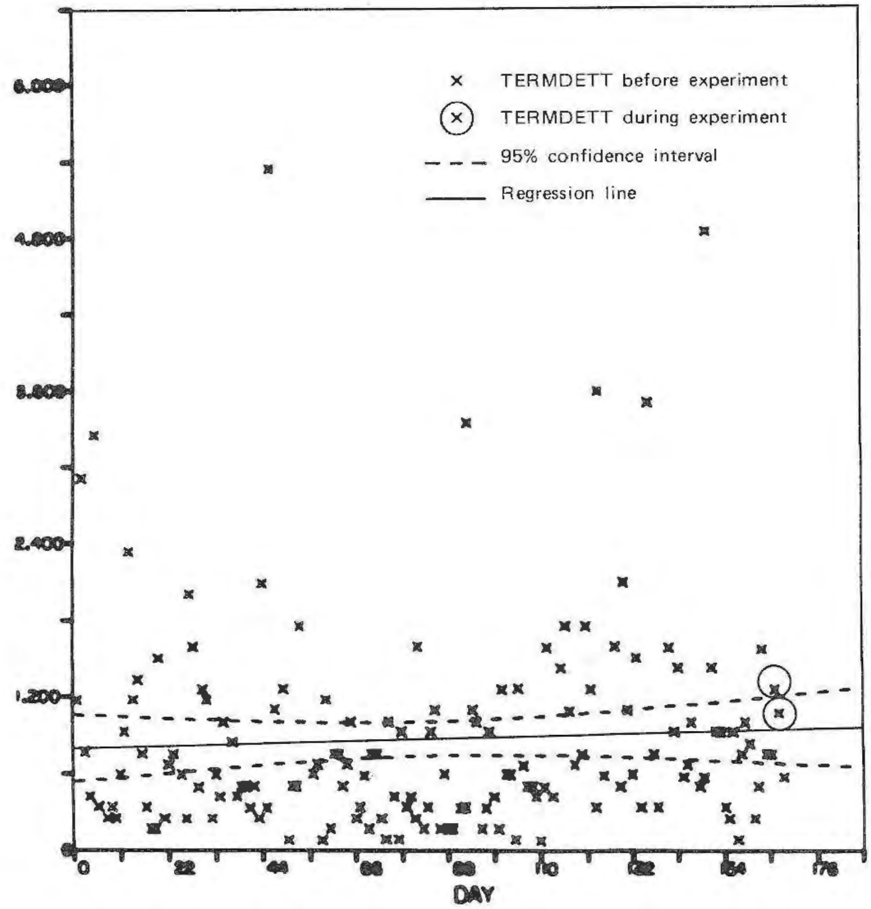

FIGURE B-6 TERMINAL DETENTION TIME (TERMDETT): TRAIN 392 FLINT

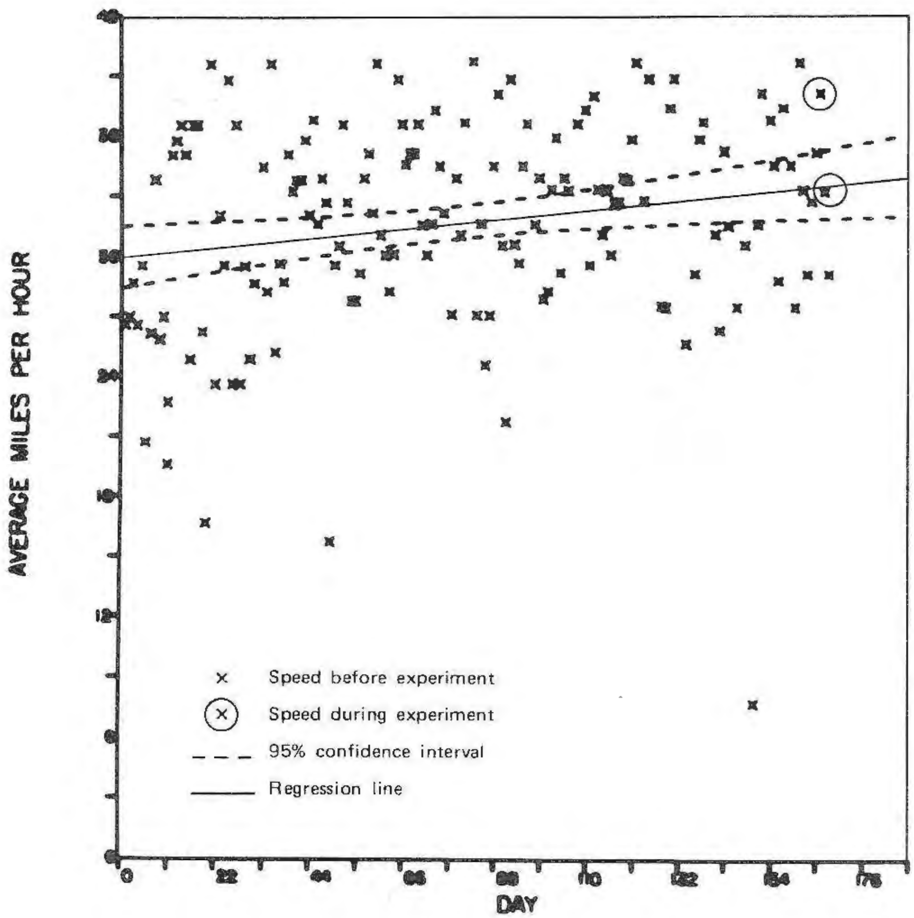

FIGURE B-7 AVERAGE TRAIN SPEED: TRAIN 392 FLINT

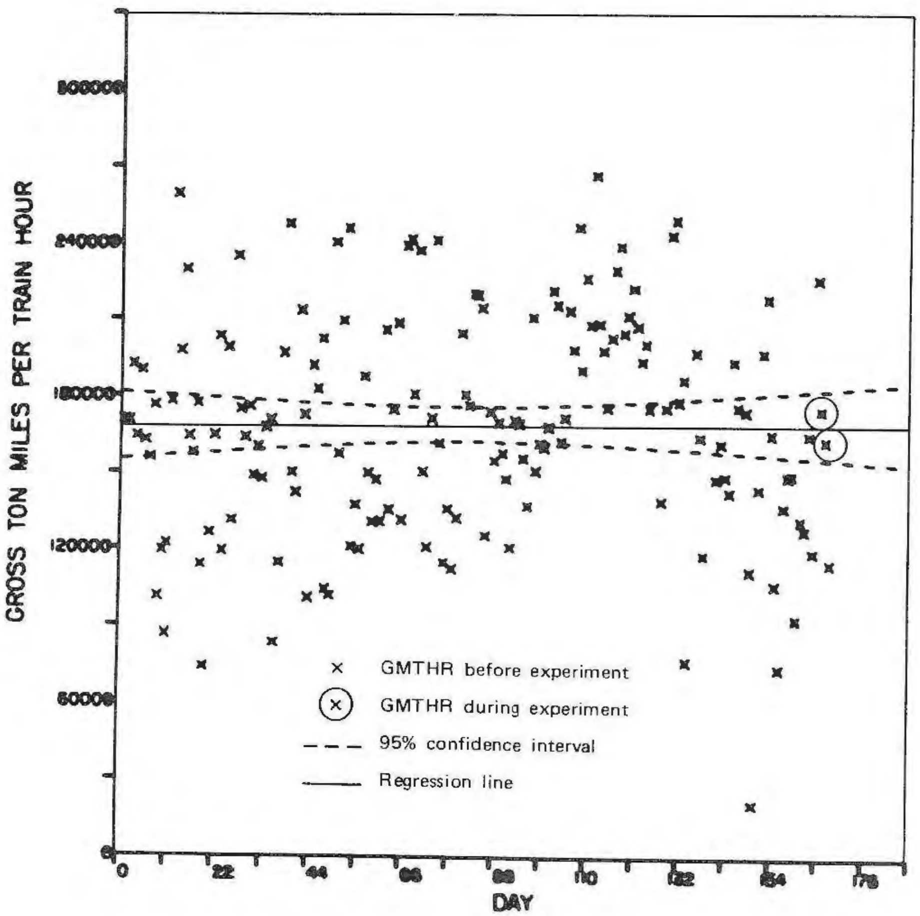

FIGURE B-8 GROSS TON MILES PER TRAIN HOUR (GTMTHR): TRAIN 392 FLINT

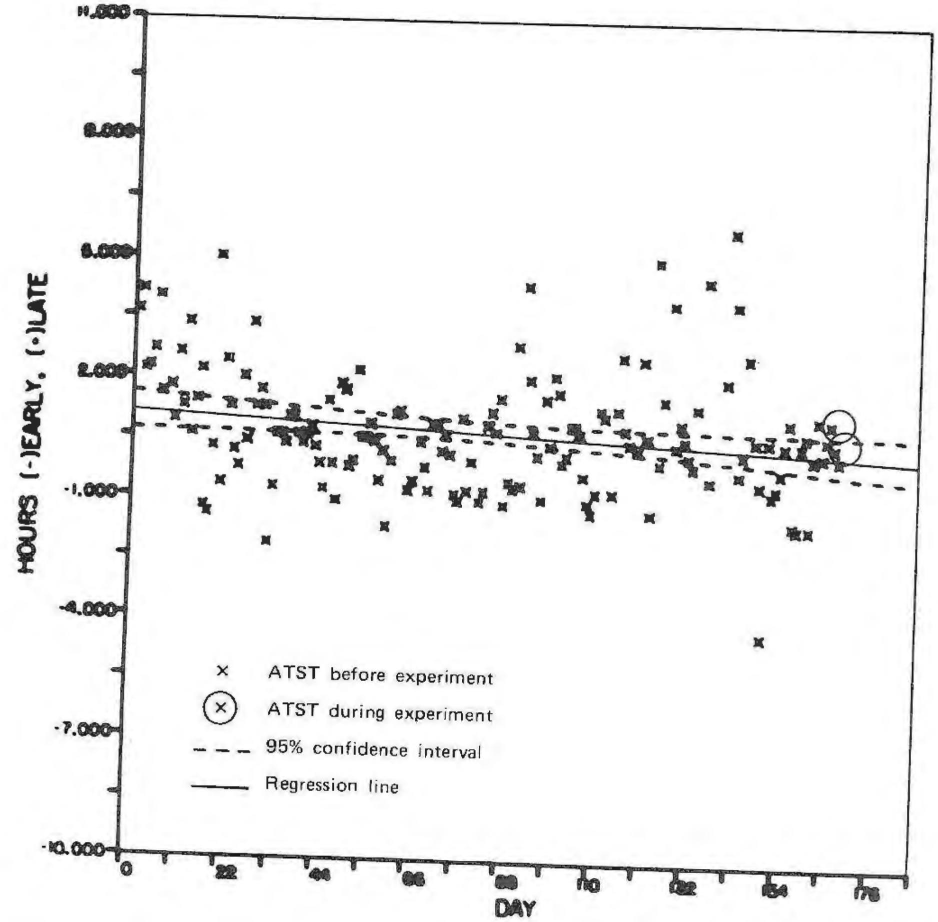

FIGURE B-9 ON-TIME RECORD AT DESTINATION (ATST): TRAIN 392 FLINT

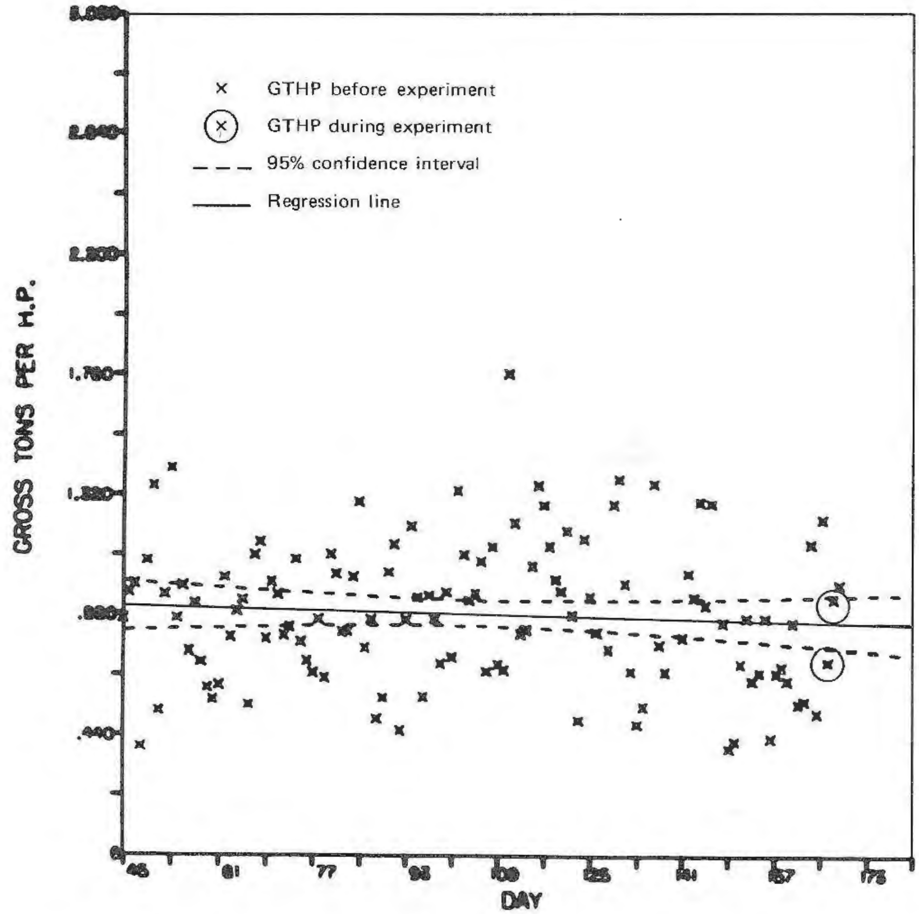

FIGURE B-10 GROSS TONS HANDLED PER ENGINE HORSEPOWER (GTHP): TRAIN 392 FLINT

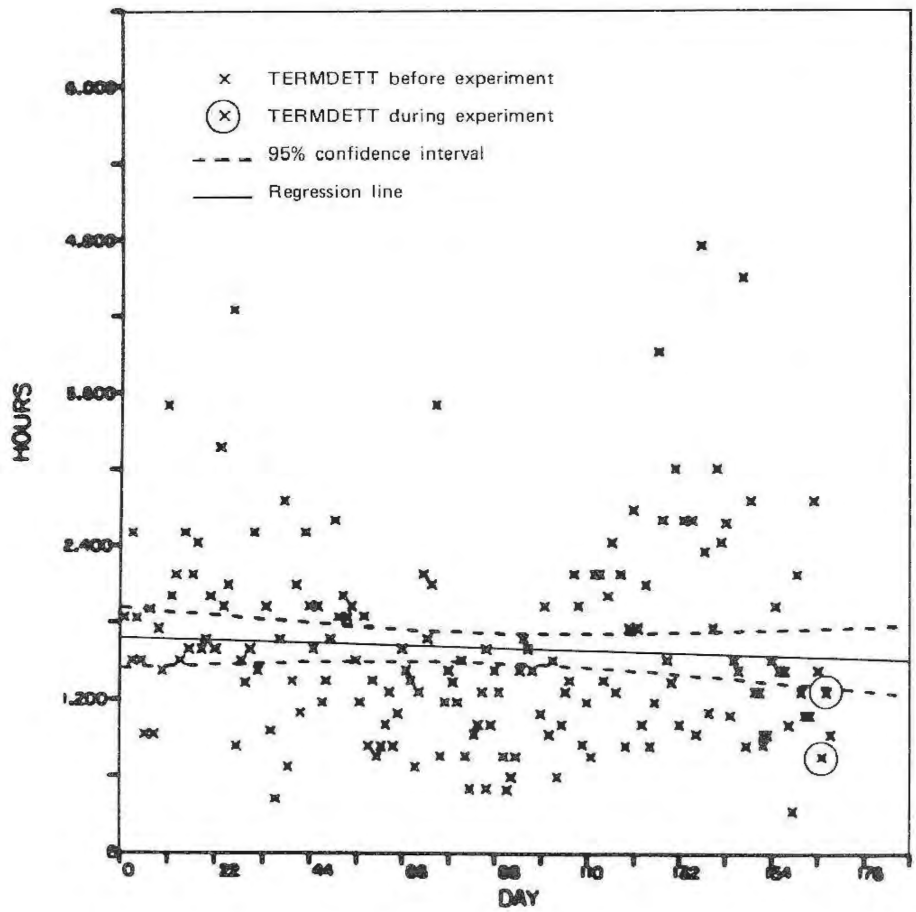

FIGURE B-11 TERMINAL DETENTION TIME (TERMDETT): TRAIN 385 SOUTH BEND

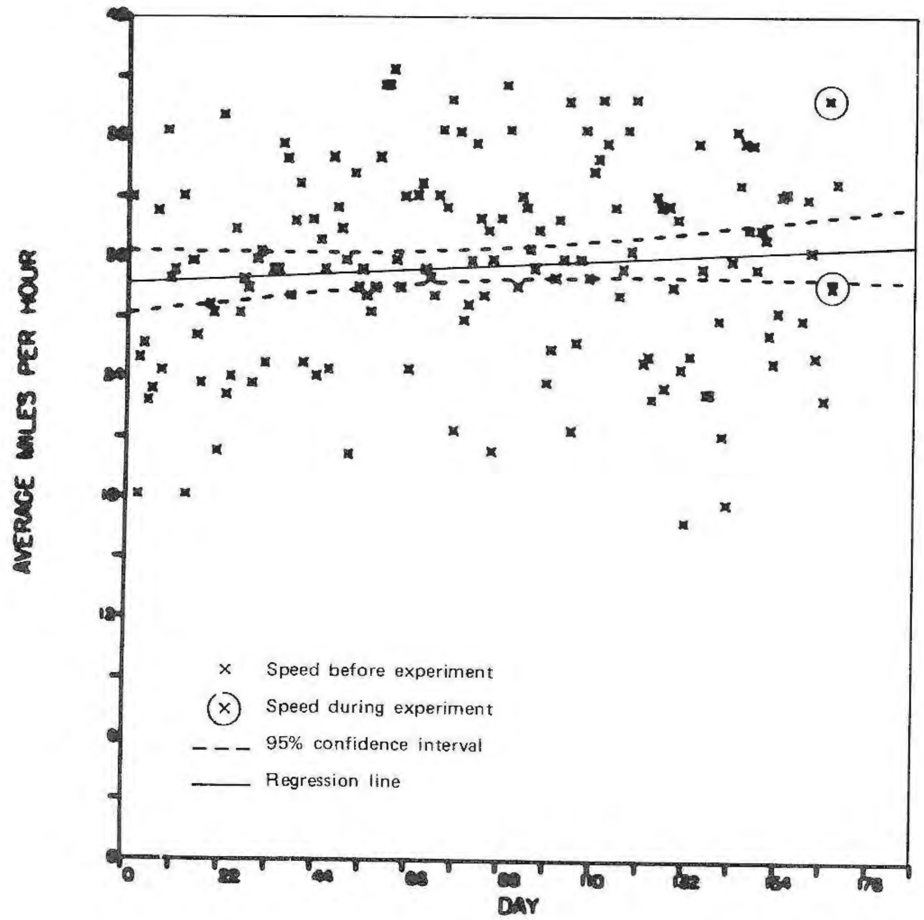

FIGURE B-12 AVERAGE TRAIN SPEED: TRAIN 385 SOUTH BEND

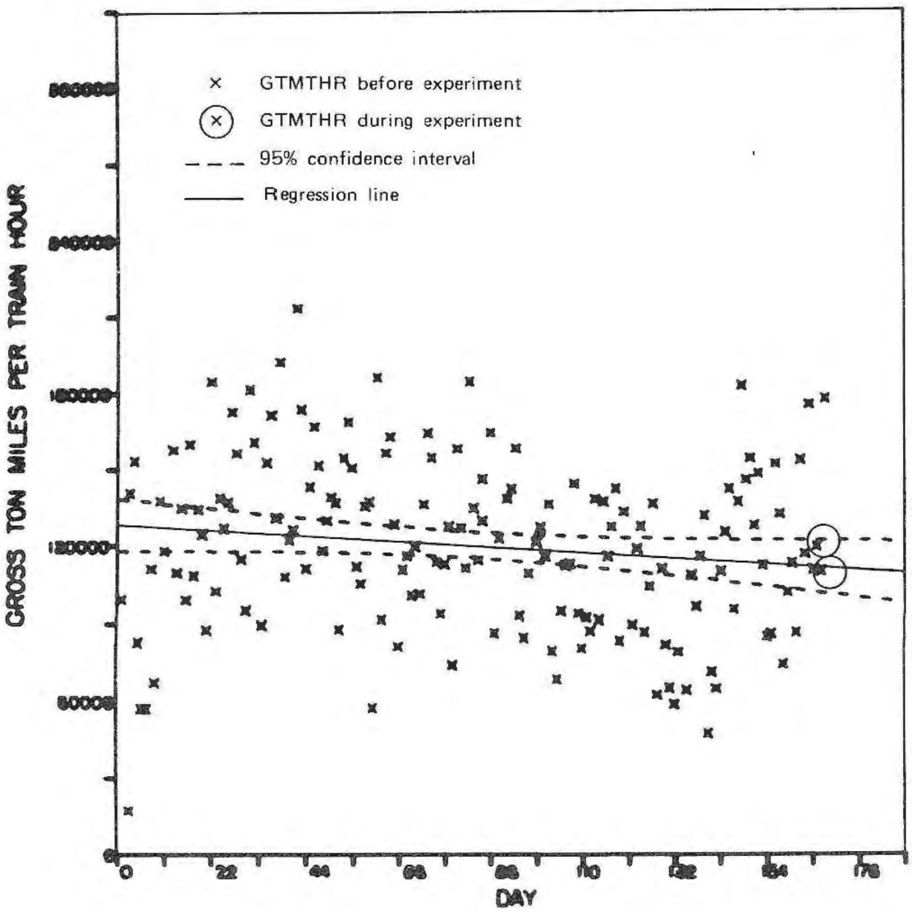

FIGURE B-13 GROSS TON MILES PER TRAIN HOUR (GTMTHR): TRAIN 385 SOUTH BEND

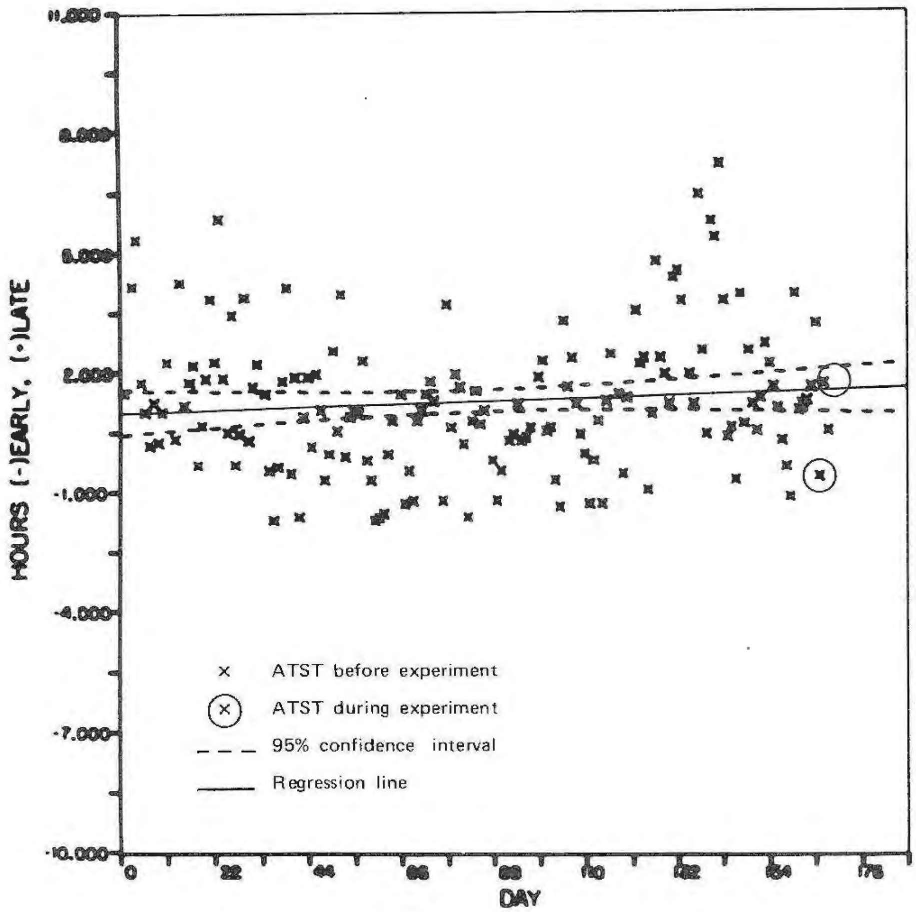

FIGURE B-14 ON-TIME RECORD AT DESTINATION (ATST): TRAIN 385 SOUTH BEND

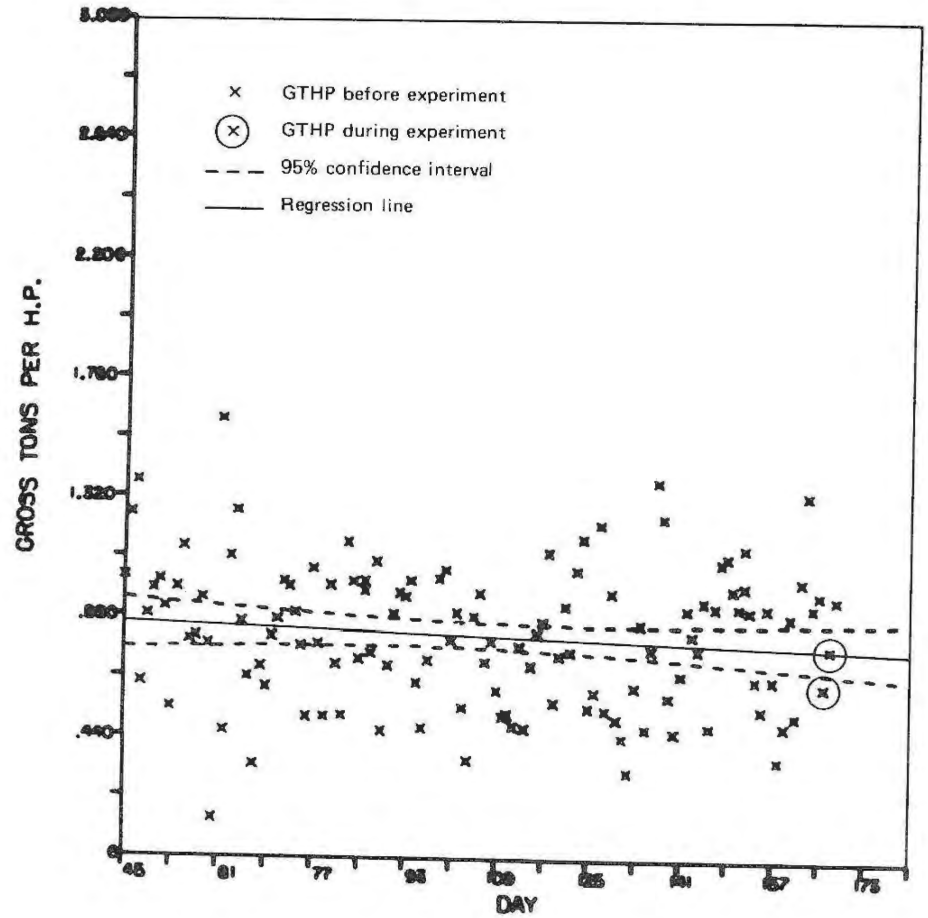

FIGURE B-15 GROSS TONS HANDLED PER ENGINE HORSEPOWER (GTHP): TRAIN 385 SOUTH BEND

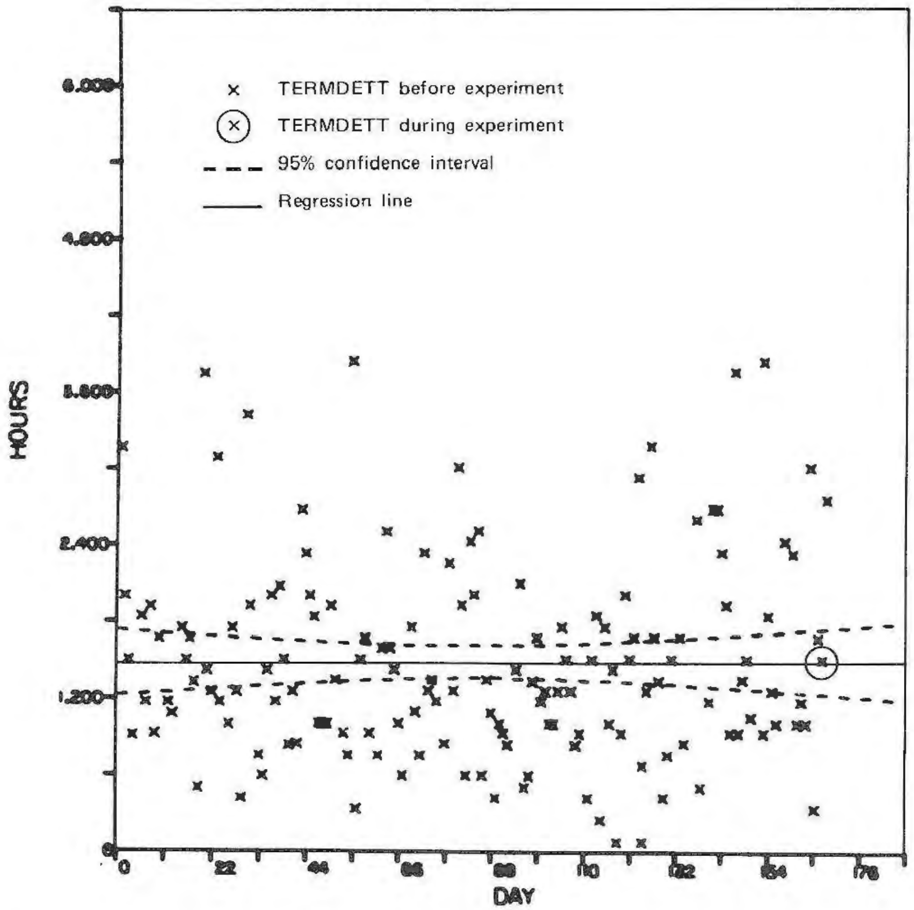

FIGURE B-16 TERMINAL DETENTION TIME (TERMDETT): TRAIN 384 FLINT

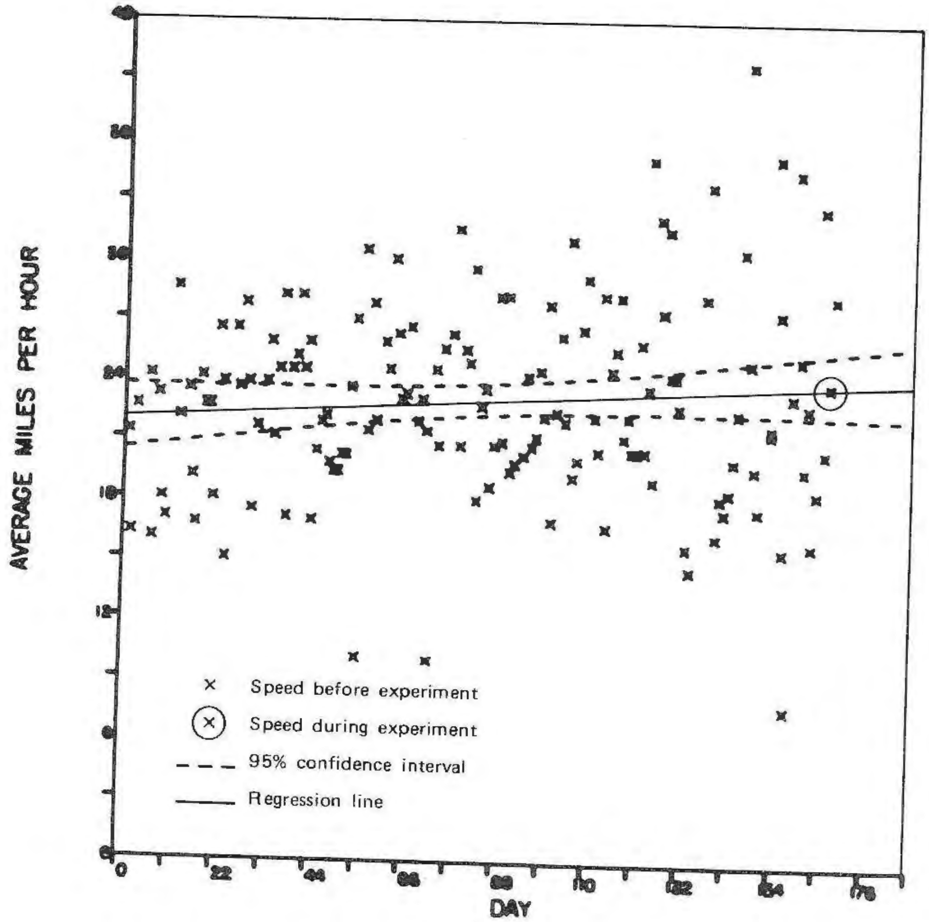

FIGURE B-17 AVERAGE TRAIN SPEED: TRAIN 384 FLINT

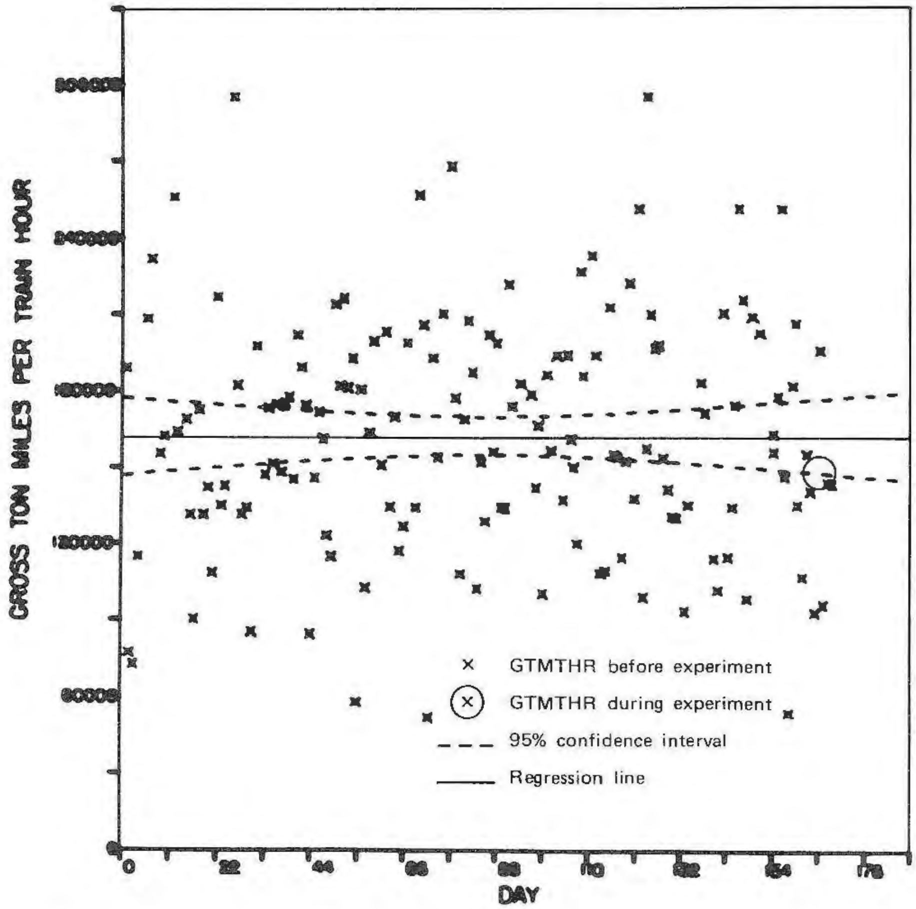

FIGURE B-18 GROSS TON MILES PER TRAIN HOUR (GTMTHR): TRAIN 384 FLINT

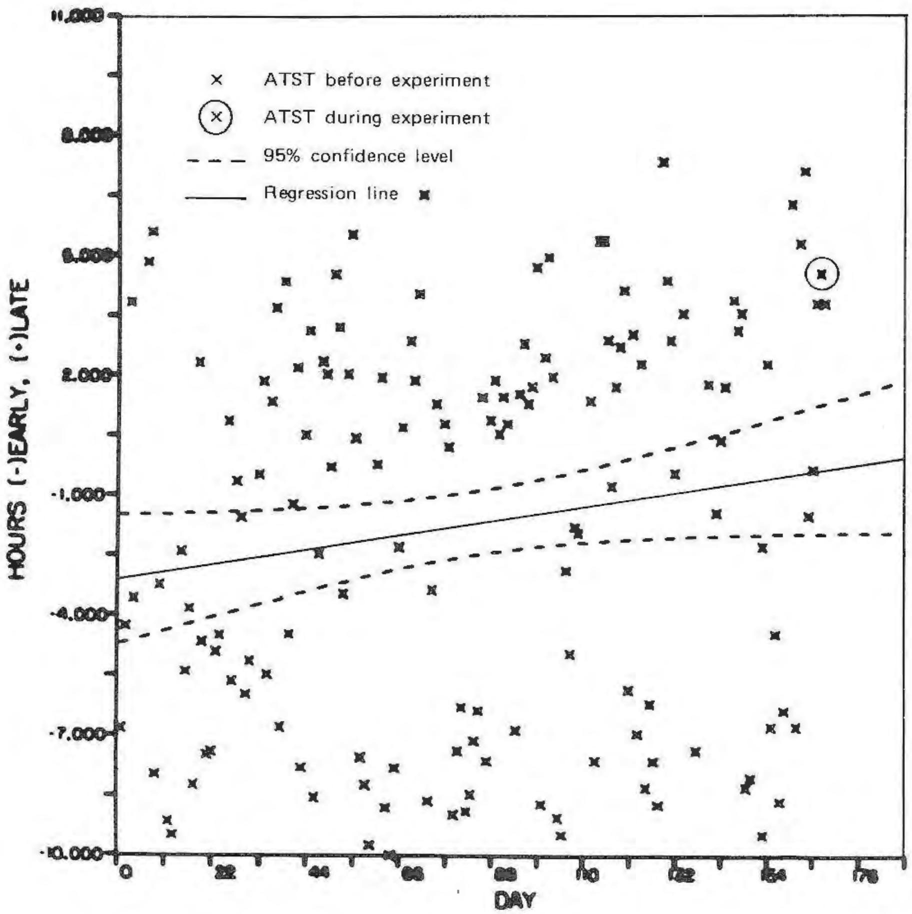

FIGURE B-19 ON-TIME RECORD AT DESTINATION (ATST): TRAIN 384 FLINT

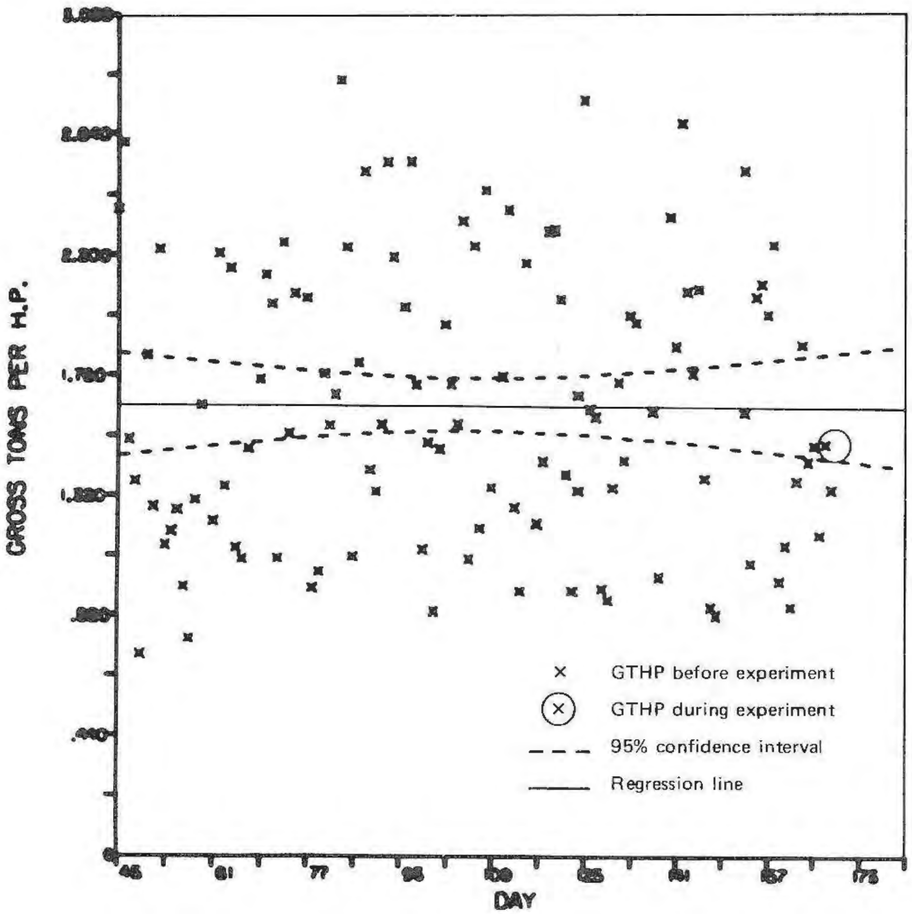

FIGURE B-20 GROSS TONS HANDLED PER ENGINE HORSEPOWER (GTHP): TRAIN 384 FLINT

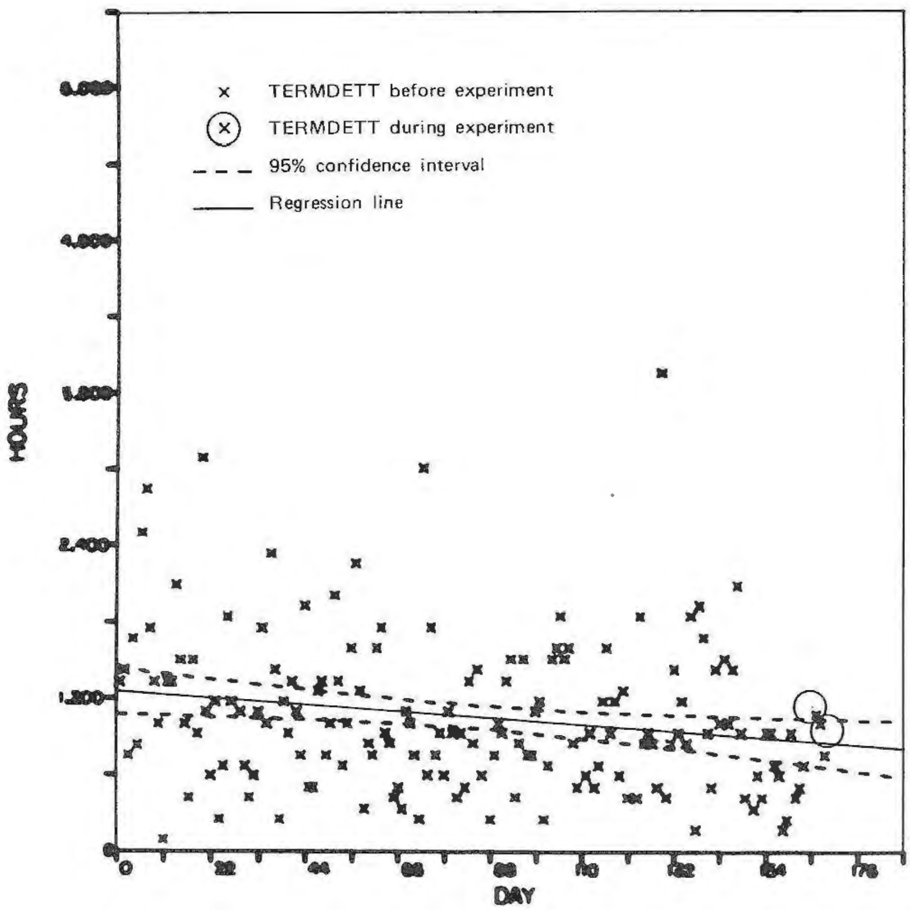

FIGURE B-21 TERMINAL DETENTION TIME (TERMDETT): TRAIN 434 SOUTH BEND

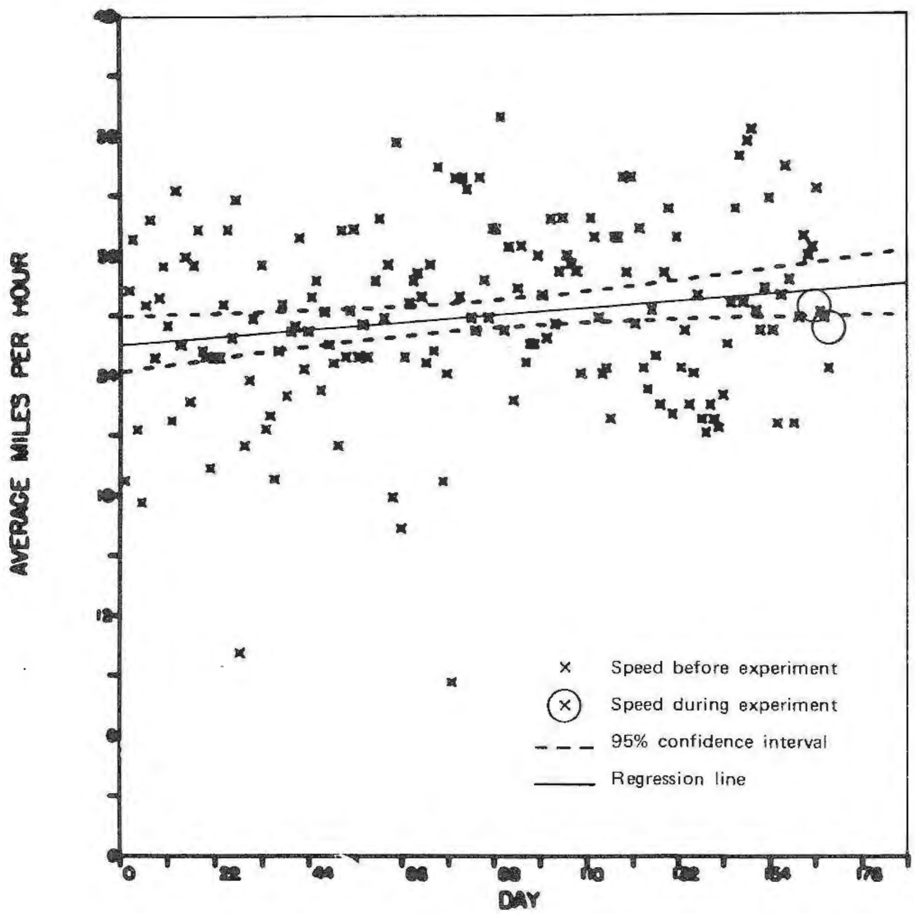

FIGURE B-22 AVERAGE TRAIN SPEED: TRAIN 434 SOUTH BEND

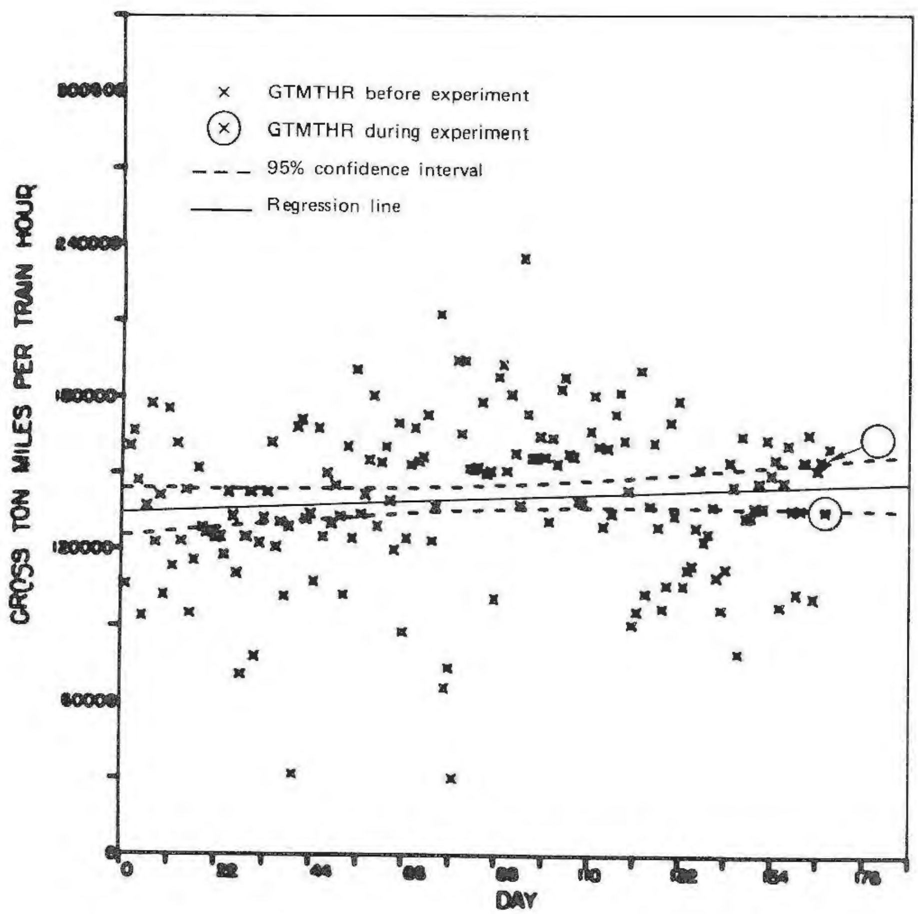

FIGURE B-23 GROSS TON MILES PER TRAIN HOUR (GTMTHR): TRAIN 434

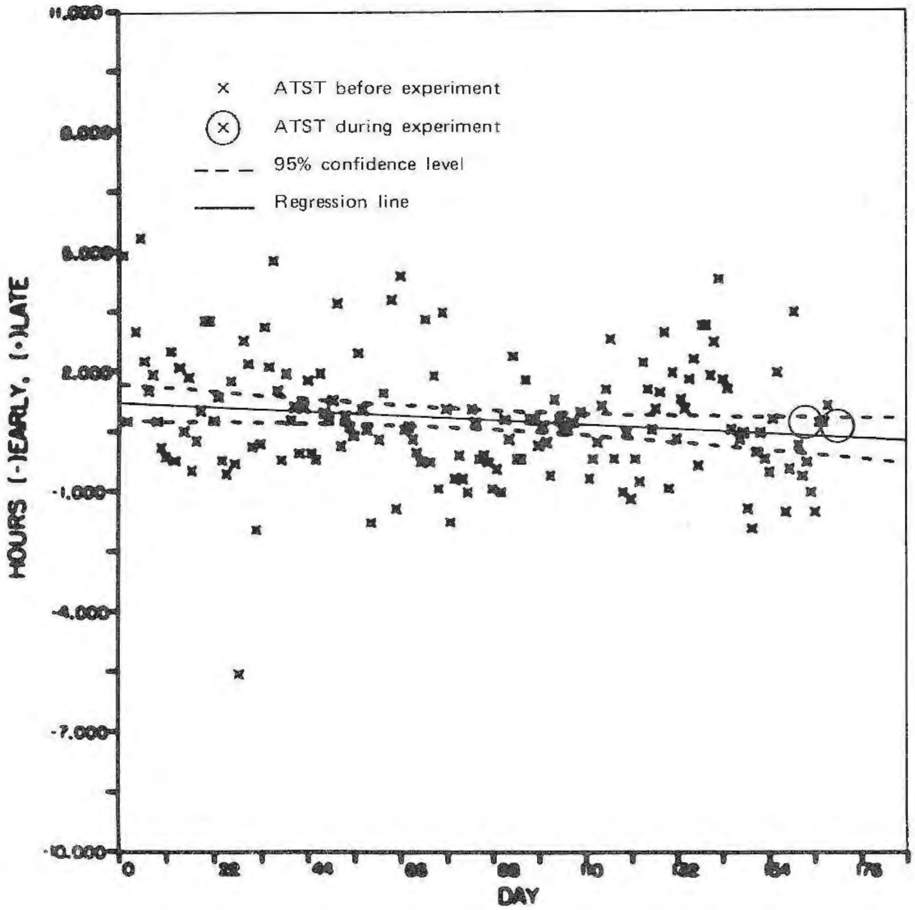

FIGURE B-24 ON-TIME RECORD AT DESTINATION (ATST): TRAIN 434 SOUTH BEND

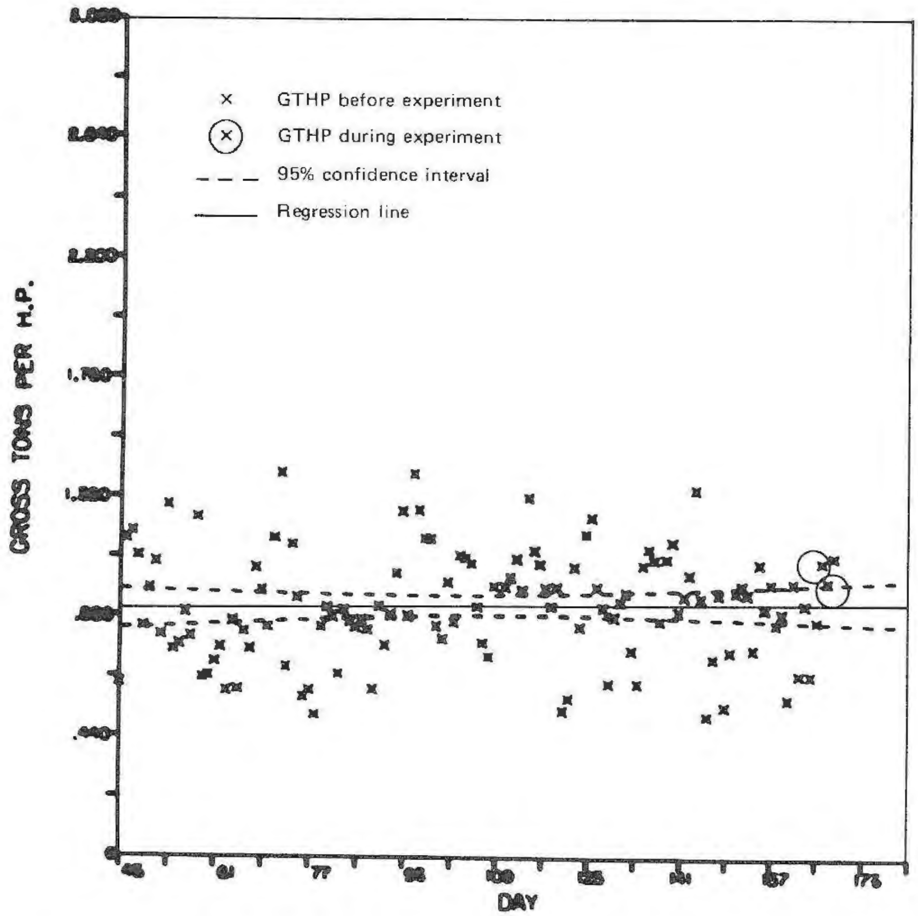

FIGURE B-25 GROSS TONS HANDLED PER ENGINE HORSEPOWER (GTHP): TRAIN 434 SOUTH BEND

selected train is represented by a point on the graph. These graphs show the typical daily operation of a railroad with wide variations associated with traffic, weather, derailments, engine failures, and so forth.

One hundred and sixty-eight (168) consecutive days of train MOE were plotted. Day 1 is February 10, 1977; days 166, 167, and 168 are July 25-27 of the experiment. All five trains were in operation on Tuesday; however, the time of day a train was ordered on Monday and Wednesday determined whether it could be affected by the experiment. The particular day(s) these trains could be influenced by the experiment are circled on each graph.

Analyses of the five MOEs that were to show an improvement in the operation of the railroad during the experiment indicated that there was no statistically significant change in GT train performance. There is a straight, wide pattern of data points on each graph indicating relative freedom from abnormalities. The regression line is plotted on each MOE graph and has a slope of approximately zero, consequently almost equal to the mean. The 95% confidence interval (C.I.) for the regression line is also plotted. Statistics available for analysis by PLOT included mean, standard deviation, and minimum and maximum values for all variables (see Table B-2).

The mean, the most common measure of central tendency for variables measured at the interval level, is often referred to as the "average" and is the sum of the individual values for each case divided by the number of cases. The standard deviation is a measure of the dispersion about the mean of an interval-level variable. It is the square root of the variance. The minimum and maximum, of course, denote the smallest and largest value of a variable encountered among the cases.

The 95% C.I. for the true mean of the observations taken during the experimental period was manually calculated as $\overline{X} \pm \frac{2S}{3} = \text{C.I.}$ where $\overline{X}$ is the mean and S is the standard deviation. The means of the observation(s) that were expected to be influenced by the experiment

Table B-2

MEASURES-OF-EFFECTIVENESS STATISTICS

MOEs*	Number of Days Plotted	Mean (Before Experiment) X	Standard Deviation (S)	Minimum	Maximum	Mean (48-hr experiment) Y
Train 392 South Bend						
TERMDETT	165	.806	.751	.090	8.750	.46
SPEED	168	28.388	4.609	15.751	39.723	28.5
GTMTHR	168	133303.236	35251.373	616603.752	232231.273	124020.
ATST	162	.506	1.458	-4.500	5.670	.09
GTHP	123	.586	.426	0	1.771	.80
Train 392 Flint						
TERMDETT	153	.968	1.483	.080	16.170	1.16
SPEED	150	32.557	5.962	7.594	49.051	35.5
GTHTHR	163	168330.769	43544.206	20565.409	266077.017	167956.
ATST	156	.684	1.519	-4.330	5.760	.71
GTHP	119	.640	.451	0	1.759	.815
Train 385 South Bend						
TERMDETT	167	1.658	1.038	.330	10.670	1.00
SPEED	153	30.233	5.597	16.649	46.246	33.0
GTMTHR	162	119627.780	33560.060	17048.706	212923.529	114310.
ATST	157	1.381	2.086	-1.750	12.000	.50
GTHP	125	.605	.419	0	1.607	.70
Train 384 Flint						
TERMDETT	151	1.690	2.119	.080	23.920	1.50
SPEED	153	23.099	5.135	7.688	40.104	24.0
GTMTHR	152	163727.840	49666.494	51057.252	341302.099	147838.
ATST	147	-1.754	5.358	-11.580	11.000	4.50
GTHP	113	1.266	.891	0	3.544	1.50
Train 434 South Bend						
TERMDETT	161	1.097	.814	.090	8.090	1.04
SPEED	165	27.112	4.825	8.584	42.157	27.0
GTMTHR	167	139650.891	30979.250	30042.918	234205.654	144443.
ATST	160	.765	1.539	-5.580	5.340	.67
GTHP	123	.676	.440	0	1.404	1.04

*TERMDETT=terminal detention; SPEED=average train speed; GTMTHR=gross ton miles per train hour; ATST=on-time record at destination; GTHP=gross tons handled per engine horsepower.

were calculated to determine if they fell within the 95% C.I. $(\frac{\Sigma Y}{n} = \overline{Y})$. The MOE C.I.'s included $\overline{Y}$ in all cases.

A comparison of $\overline{Y}$ with $\overline{X}$ of the same day's operations of the previous week was also made and no significant trend was found.

The average number of freight cars handled per yard engine hour (CH/YEH) in Port Huron, Battle Creek, and Elsdon yards were manually plotted over the same six-month period (see Figs. B-26 through B-28). The average CH/YEH over the six months were 7, 13, and 11.5 cars, respectively. These graphs show no noticeable change in yard operations during the two days of the dispatching experiment for which data were available.

Figures B-29 and B-30 show the average number of freight cars handled per train by eastbound and westbound manifest trains that traveled on the Chicago Division. The average number of cars handled by eastbound trains was somewhat greater with less variance than the westbound trains during the six-month period. As in the other MOE analyses, the experiment data were not sufficient to reflect any influence of the dispatching experiment.

To measure the effect of the experiment on the operation of the whole Chicago Division, a sample of four large pools of cars that cycle between Flint and Elsdon stations (pools 100, 120, 124 and 179) were selected for analysis. The information available for these pools included the day, time, and train on which each car arrived and departed Battle Creek Yard from July 18 to July 27, 1977. The 0-48 hour delay information on each car for all four pools was aggregated to obtain a sufficient sample size to compute the average pool car delay time in Battle Creek Yard.

Figure B-31 shows that on the two experiment days that could reflect a change (July 26 and 27) pool car elapsed time in Battle Creek decreased. One explanation for this decrease is that by dispatching pool cars on different trains at the originating station (e.g., Flint), pool cars arrived at Battle Creek in time to be put on an earlier train.

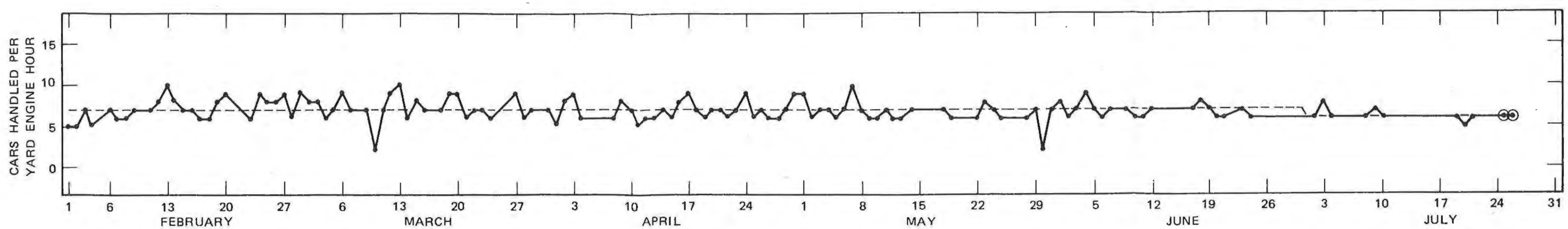

FIGURE B-26 CARS HANDLED (CH) PER YARD ENGINE HOUR (YEH): PORT HURON YARD

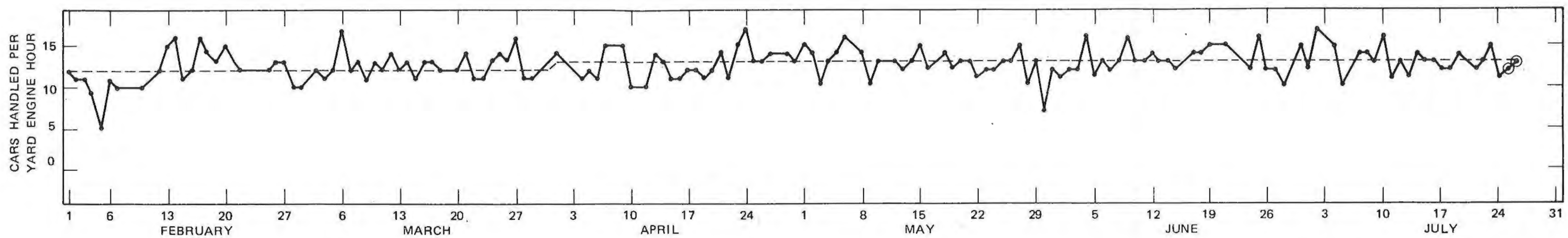

FIGURE B-27 CARS HANDLED (CH) PER YARD ENGINE HOUR (YEH): BATTLE CREEK YARD

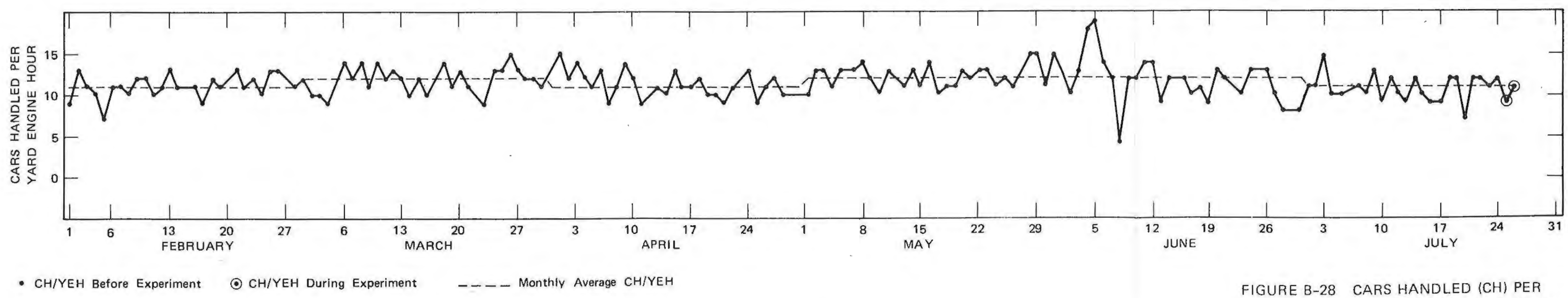

FIGURE B-28 CARS HANDLED (CH) PER YARD ENGINE HOUR (YEH): ELSDON YARD

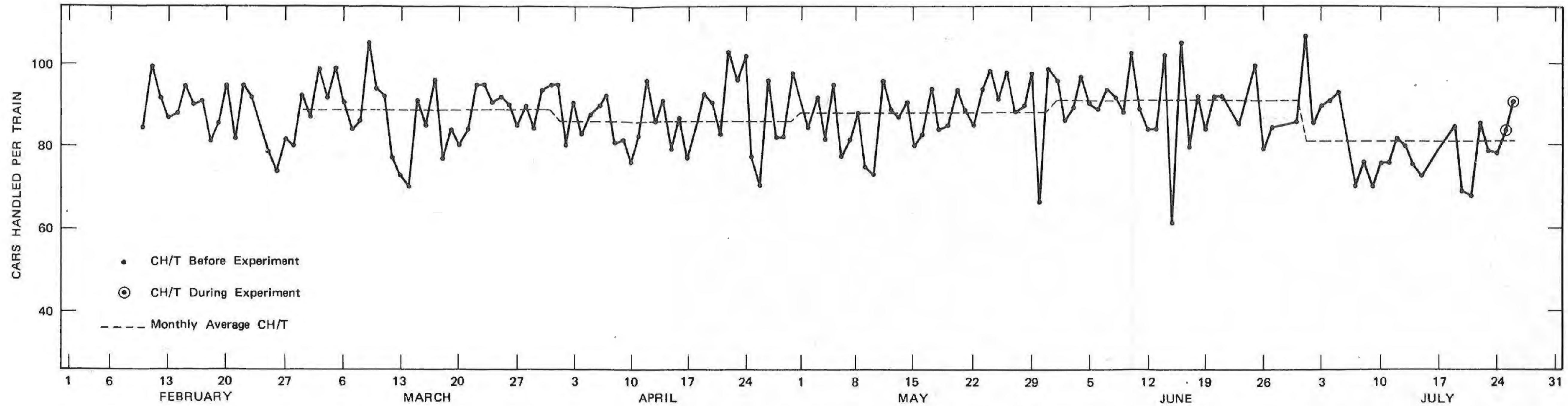

FIGURE B-29 AVERAGE NUMBER OF CARS HANDLED PER TRAIN (CH/T): CHICAGO DIVISION EASTBOUND

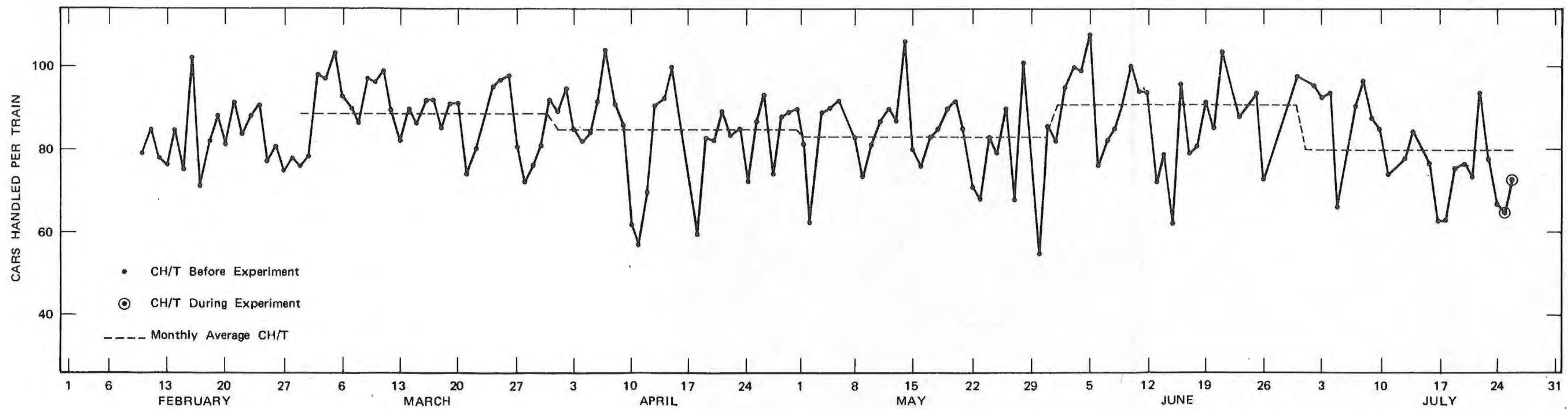

FIGURE B-30 AVERAGE NUMBER OF CARS HANDLED PER TRAIN (CH/T): CHICAGO DIVISION WESTBOUND

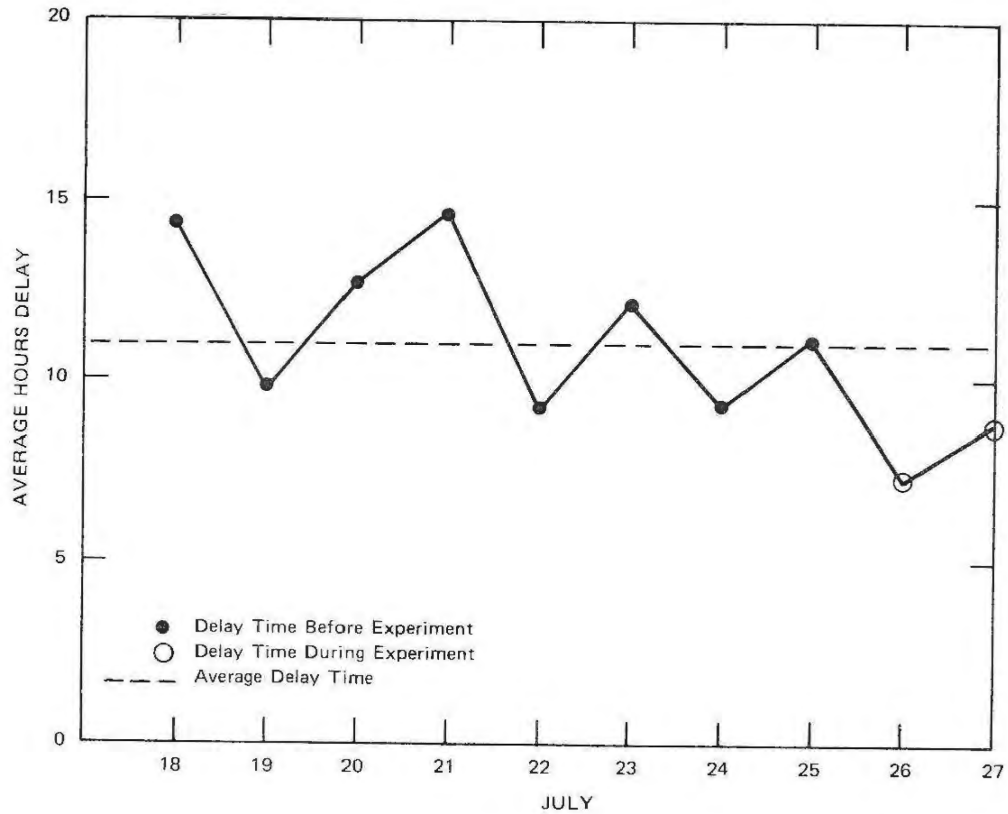

FIGURE B-31 POOL CAR DELAY TIME IN BATTLE CREEK YARD: POOLS 100, 120, 124, 179.

The apparent decrease in average hours delay in Battle Creek during the experiment, however, may be a result of the way in which pool data were extracted from RAILS. Four "Car Delay Time Summary" reports were generated by GT for one week (July 18-24) and three days (July 25, 26, and 27). A brief study of these reports showed that a number of pool cars were excluded (i.e., those cars arriving in Battle Creek before report generation and those cars departing Battle Creek after report generation). Therefore, the most reliable data are for July 20-23 in the middle of the week summary. These days consequently have a greater number of car data as shown below.

Day Car Arrived	Number of Pool Cars	Average Hours Delay in Battle Creek
July 18	66	14.28
July 19	95	9.95
July 20	143	12.70
July 21	85	14.58
July 22	107	9.28
July 23	118	12.11
July 24	44	9.41
July 25	45	11.14
July 26	75*	7.32
July 27	81*	8.97

In conclusion, the short duration of the dispatching experiment provided an insufficient amount of data to show any significant change in the railroad's daily operations because of the large variance in the 165 days prior to the experiment.

Estimating Required Experiment Sample Size

Because we could not detect a statistically significant change in the selected MOEs during the brief experiment, we decided to apply additional analysis procedures to five MOEs to determine not only whether it would ever be possible to detect a reasonable change in MOEs with such a wide variance before the experiment but also the number of experiment days necessary to show significant statistical results.

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*All pool cars arrived in Battle Creek yard during the experiment.

Using the six months of MOE statistics given in Table B-2 and the following:

- Before Experiment data (February 10 - July 24)

  n_1= number of days (observations)

  θ_1= true mean (unknown but estimated by $\overline{X}_1$)

  S_1= standard deviation

- Experiment data (July 25-27)

  n_2= number of proposed days (observations)

  θ_2= true mean

  S_2=S_1= standard deviation (assumption),

we assumed an experimental period (e.g., 6 months = 180 days) and calculated how large $|\theta_1 - \theta_2|$ must be in order to have a .9 probability of statistically detecting a difference (see Table B-3). The following approximating procedure was performed for all five MOEs for each train:

$$\frac{|\theta_1 - \theta_2|}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_1^2}{n_2}}}$$

The influence of the experiment on train MOEs would have had to have been unrealistically great to have been detected for most MOEs, as shown in Table B-3. In fact, a 10% decrease in terminal detention time for train 392 on the South Bend subdivision (e.g., 0.725) would be unlikely to be detected because of the large variance in the past 165 days' data. A $|\theta_1-\theta_2|$ of 10% would be unlikely to be detected in the following MOEs: terminal detention time, on-time record at destination, and gross tons handled per horsepower. Given a realistic 10% increase in average train speed (ATST) and gross ton miles per train hour

Table B-3

CHANGE NEEDED FOR A 90% PROBABILITY OF DETECTION GIVEN SIX MONTHS OF EXPERIMENT DATA

MOEs*	Number of Experiment Days Required Given a 10% Effect	Percent Change Required With Six Months Experiment Data
Train 392 South Bend		
TERMDETT	†	29.84%
SPEED	26	2.54
GTMTHR	94	8.34
ATST	†	92.04
GTHP	†	25.09
Train 392 Flint		
TERMDETT	†	49.63
SPEED	36	5.96
GTMTHR	90	8.23
ATST	†	71.54
GTHP	†	24.72
Train 385 South Bend		
TERMDETT	†	19.83
SPEED	37	5.99
GTMTHR	117	8.94
ATST	†	48.55
GTHP	†	23.77
Train 384 Flint		
TERMDETT	†	40.71
SPEED	60	7.19
GTMTHR	167	9.83
ATST	†	99.84
GTHP	†	25.02
Train 434 South Bend		
TERMDETT	†	23.81
SPEED	33	5.64
GTMTHR	57	7.01
ATST	†	64.30
GTHP	†	22.58

*TERMDETT=terminal detention time; SPEED=average train speed; GTMTHR=gross ton miles per train hour; ATST=on-time record at destination; GTHP=gross tons handled per engine horsepower.

†More than 180 or excessively large number of experiment days required.

(GTMTHR), at least one to two months of experiment data for ATST and at least three to six months of experiment data for GTMTHR would be required in order to have a .9 probability of statistically detecting a difference.