# STATISTICAL PROCESS CONTROL APPLIED TO RAIL FREIGHT TERMINAL PERFORMANCE: A CASE STUDY OF CSX'S RADNOR YARD

by

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S. B., Management Science
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Submitted to the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degree of

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Abstract

Rail terminal performance is important to the economic viability of railroads. In order to improve rail reliability, train connection standards within terminals need to improve (i.e., a reduction in average yard times) and become more reliable. In the world of just-in-time manufacturing and lean production systems, the unreliability of rail shipments often causes inventory conscious customers to utilize other modes of transportation when shipping their freight. Using terminal unreliability as a theme, this thesis recommends using and demonstrates how to use a manufacturing quality control technique known as statistical process control (SPC) to pinpoint causes of poor performance within a yard. SPC utilizes the mean and an approximation for the standard deviation of each individual yard process in order to highlight "out of control" points. The out of control points identify periods of time in which the yard was running efficiently, as well as times when there were excessive processing times. The research presented in this thesis was performed using data gathered from Radnor Yard, a major hump yard on the CSX system located in Nashville, Tennessee.

The analyses associated with the research support three major conclusions. First, SPC offers insight into the causes of poor terminal performance and can be effectively used in the railroad industry for terminal causality analyses, analyses that are as thorough as previous line performance studies. Second, the processing capabilities of the yard can be defined from the results of an SPC analysis. Rather than simply give the average yard time for a car, an SPC analysis will give the mean and standard deviation of each individual process faced by a car when going through a particular yard. From here, industrial engineering techniques can be used to determine the maximum processing capabilities of the yard. Third, SPC is useful in monitoring freight terminal performance. Achieving a state of control for each yard process through the use of SPC will have three advantages: (1) It will give more predictable yard outcomes; (2) Methods to tighten the control limits of each process can be invoked. Tighter control limits will improve reliability as there will be less variability associated with that particular process; and (3) Operational changes that lead to reductions in individual mean process times can be applied, as lower mean times for each process will lead to lower average yard times.

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Title: Senior Research Associate

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And, above all, to my parents.

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I. Introduction

Rail terminal performance is important to the economic viability of railroads. In order to improve rail reliability and, therefore, increase rail profitability, terminals need to become more than just a "black box." Train connection standards within terminals need to improve (i.e., a reduction in average yard times) and become more reliable. As studies have placed the probability of an inbound car meeting its appropriate outbound connection anywhere from 70-90% for a given terminal [Martland, Little, Kwon, and Dontula, 1992], cars traveling through three or more terminals have less than a 75% chance of being on the appropriate train upon reaching their final destination. In the world of just in time manufacturing and lean production systems, this unreliability often causes inventory conscious customers to utilize other modes of transportation when shipping their freight. With this in mind, the objectives of the research presented in this thesis are as follows:

> 1. Present a generic methodology that can be used at other classification yards in order to identify the excessive process times involved in moving cars through the yard.
>
> 2. Identify the reasons for missed connections within one terminal.

Before the necessary steps to improve terminal performance can be undertaken, however, a thorough understanding of terminal operations and how they effect each other is needed. Many papers have been written on how to improve the hump sequencing decisions a yard master makes (see Daganzo and Deloitte Haskins & Sells), yet none explore the other decisions a yard master makes and how the decisions effect train connection performance. This thesis will document these decisions and show how they effect the reliability of the yard.

The research methodology presented in this thesis has the capability to highlight and address the areas of terminal operations that are in need of improvement. This methodology uses a manufacturing quality control technique known as statistical process control (SPC) and will aid in improving terminal reliability. SPC "is a philosophy, a system, and a set of specific techniques for controlling and improving production and service processes" [Constructing and Using Process Control Charts, 1986]. SPC is not a cure all, but a management tool that should be incorporated into an overall management approach toward improving terminal performance. SPC does not solve problems, but can detect when something is wrong (i.e., abnormal or "out of control") with a process and offers clues as to what caused these abnormalities. Having a process "in control" will allow the user to more accurately predict the process output (in the case of a rail terminal, it will allow for more reliable train connections). Although SPC is primarily used in manufacturing applications, it will be demonstrated how SPC can aid in improving rail reliability.

Additionally, an objective of this thesis is to identify the reasons for missed connections within one terminal. A complete investigation of and insight into the causes of the missed connections will aid in the improvement of terminal performance and rail reliability. There is a link between the two objectives as the second objective is concerned with the macro performance of the terminal (are cars making their appropriate connection), while the first objective deals with the micro performance of the yard (which of the individual processes is most detrimental to yard and connection performance).

### 1.1 Background on rail reliability research

The history of rail reliability problems in the United States has been well documented over the years. In the early 1970s, in conjunction with the Federal Railroad Administration (FRA), the Massachusetts Institute of Technology (MIT) investigated the causes of railroad unreliability. This research was initiated as a direct result of railroads losing intercity traffic to truck and water transportation services [Lang and Martland, 1972]. Two main goals of the research were to "isolate the causes of unreliability...[and] begin to formulate industry-wide strategies for dealing with unreliability" [Sussman, Martland, and Lang, 1974]. MIT's research approach was to examine the effects of line-haul reliability, classification yard reliability, and the interactions between the line and terminal on the overall trip time reliability of shipments.

An initial conclusion of the research was "yard reliability emerges as a problem of central importance to overall movement reliability" [Lang and Martland, 1972]. Additional studies conducted by MIT supported these original findings. Therefore, the unreliability of train connections within terminals was concluded to have a more pronounced effect on service reliability than the line performance [Sussman, Martland, and Lang, 1974]. To follow up on this conclusion, MIT conducted a case study of the Southern Railway in order "to transfer generalized research results into railroad operating procedures" [Martland, 1974] so that the reliability of the railroad may improve.

By instituting policies that had trains bypass a classification yard and increased scheduled yard times for outbound connections, Southern demonstrated how changes in operating policies could improve rail reliability without increasing costs. As these two measures led to more reliable car connection performance, the major conclusion of the Southern case study reiterated the findings from previous studies: classification yards are at the "very heart of the reliability problem."

From here, as part of the Freight Car Utilization Program (FCUP), MIT conducted additional studies for the Association of American Railroads (AAR) and the FRA in hopes of improving both the productivity and service reliability of railroads. In conjunction with the Boston & Maine, Delaware & Hudson, and Southern Pacific railroads, MIT was able to develop and test a model to be used in predicting the probability of cars meeting their scheduled outbound connection within a given terminal. This model, called PMAKE, "relates the probability of making a particular train connection to the time available to make that connection" [Martland, 1982]. PMAKE was the first attempt at predicting connection reliability within a terminal. It also was incorporated into the MIT Service Planning Model, a model which aided marketing departments in setting trip time standards for customers.

At first, PMAKE functions were calibrated using train connection data. PMAKE was strongly related to the percentage of cars that actually made their scheduled outbound connection and the average yard time available to make this connection. This approach to calibrate PMAKE had two shortcomings. First "[PMAKE] functions do not explicitly include details of terminal operations" [Tykulsker, 1981] and, second, they "can not examine the effects of hump crew and assembly crew capacity" [Chatlosh, 1991]. As the PMAKE function was based on connection performance, it did not account for the individual process times a car faces when going from an inbound train to its outbound connection.

Tykulsker argued that by utilizing the process distributions associated with train arrival, classification, assembly, and departure times, more meaningful PMAKE functions, called process PMAKE, could be developed. Using data from East Deerfield (MA) Yard, Tykulsker showed in his thesis that the process PMAKE function is better in reflecting yard operations effects on car connections, as car yard performance predicted by the process PMAKE functions developed closely matched their actual performance.

In his conclusion, Tykulsker called for the use of a terminal process performance report. These "reports will help to improve terminal control by indicating which processes are performing below standard [as defined by management]...who is responsible for improving performance...[and] develop the relations between processing times and yard operations such as number of crews working and the yard volumes" [Tykulsker, 1981].

Individual yard process times and number of crews working and their effects on yard connections performance, however, were largely ignored until Chatlosh explored them in his thesis. Chatlosh devised a computer simulation that would measure both the amount of time a car spent in a terminal and the reliability of a car making a connection. The variables he used in his analysis included "the reliability of train arrival times...the number of hump and assembly crews working, and the physical layout of the classification yard" [Chatlosh, 1991].

In his simulations, Chatlosh used a generic hump yard and generic yard processing times. His main conclusion was that train arrival and departure schedules, yard capacity, and outbound train size were the key factors that determine average yard times. In his research, however, Chatlosh assumed "that the amount of time a train spends in the receiving yard does not vary significantly from train to train to warrant being examined as a variable in the model" [Chatlosh, 1991] and, therefore, ignored this time in his simulations. As will be demonstrated in this thesis, the receiving yard time does vary significantly from train to train and is a key variable in cars making their appropriate outbound connection.

## 1.2 Objective of rail terminal research

The need for a more complete rail terminal control system has been addressed for many years. In 1975, Mr. W. V. Williamson of the Southern Pacific stated that there "is no question that a better terminal control system is necessary...[as] the rail terminal is the biggest culprit in adversely impacting service reliability" [Freight Car Utilization and Railroad Reliability: Case Studies, 1977]. Despite Williamson's plea for controlling terminal operations, the terminal was largely ignored, as, until recently, the terminals have been treated by operation control centers as a "black box."

Sophisticated terminal models, similar to complicated line planning algorithms (LPA's), are not available to terminal operators searching for ways to increase the capacity at their yard or to operating officers hoping to understand what really goes on inside a yard. This could be a result of terminals not being monitored as tightly as line performance, or because terminals are more complex and the causes of terminal delay are poorly understood. Improvements in the performance of terminals will result in greater service reliability as "the majority of trip time is spent in yards. [Conversely] a substantial increase in line haul speed will have a minor effect on trip time" [Martland, Little, Kwon, and Dontula, 1992].

In their research, Lang and Martland [1972] concluded that "a reduction in the number of yards handling a car increases the overall reliability of its movement significantly." Therefore, rail officials looked for ways to block traffic in order to bypass certain yards (specifically, the yards with excessive car dwell times) and to minimize the number of terminals a car must be classified in during its origin to destination (O-D) trip.

More recently, Little and Martland [1993] performed a root cause analysis in order to understand the causes of rail unreliability. The analysis was done using train service reliability data from several Class I railroads and mechanical repair records for double stack cars from the TTX Company. As they concluded that 20.2% of all train delays were caused by the terminal, Little and Martland called for studies to be performed in order to understand what really happens in terminals. These terminal delays included yard congestion, cars not switched in time, and switching errors, but did not include trains delayed in leaving a terminal due to a lack of power. The lack of correct tonnage predictions (due to unreliable train connections) causes some outbound trains to be underpowered, resulting in additional terminal delays for the outbound train.

Martland, Little, and Sussman [1993] concluded that a major weakness in service design (car trip scheduling) is the treatment of terminals as black boxes. For a given O-D pair, car connections within a yard are based on cut-offs, and not on the actual processing capabilities of the yard. As "terminal managers do not have well-defined terminal operating plans, nor [have] tools to assist them in creating better plans or in estimating the incremental costs of different strategies for operating terminals" [Martland, Little, and Sussman, 1993], the operations that are carried out in the yard are often not done in the most efficient or productive manner.

Additionally, within past rail reliability research, there has been a lack of terminal causality analyses. While causes of poor line performance are documented and well understood, terminals have largely been ignored. Therefore, a terminal delay causality analysis that is as in depth and detailed as previous line causality studies is needed. This type of analysis will provide insight into the factors and decision variables that go into running an efficient yard.

1.3 SPC and its application to a railyard

SPC is a tool used by manufacturers in order to reduce defective items and rework. Developed in the 1930s by Dr. Walter Shewhart of Bell Laboratories, it has increasingly been used as part of manufacturing companies Total Quality Management programs. Although primarily used to manage product quality in manufacturing environments, SPC can be used to monitor any set of conditions that produce a given result. In a railyard, these "conditions" are the processes associated with receiving, classifying, and departing trains.

Like a manufacturing plant, a railyard has different processes a rail car must go through in order for it to reach its final destination. A car comes into the yard as a "raw material" and proceeds through the eight processes described earlier before it becomes a finished good (i.e., placed on a departing train). These processes need to be monitored in order to assure that all due dates (i.e., planned connections) will be met, as excessive processing times at any time in the yard could lead to planned connections being missed. Using SPC methods in order to monitor each process will aid in improving rail terminal performance and reliability.

SPC charts the individual yard process times on a graph and utilizes the mean and an approximation for the standard deviation of each process in order to highlight out of control points. The out of control points identify periods of time in which the yard was running efficiently, as well as times when there were excessive processing times. A Pareto analysis is then performed to get to the root cause of each out of control point as understanding the reasons for excessive, as well as efficient, process times will aid in improving yard performance.

Improvements in rail terminal performance will be a result of eliminating the out of control points on the control charts. This elimination of out of control points will produce proper, and realistic, standards for individual yard process times as well as good performance predictions for the yard. More reliable connection predictors will aid service design departments when making up car trip plans. Once statistical control is achieved, improvements in the process can be researched and undertaken. Tightening the control limits (i.e., bringing the control limits closer to the mean) will bring improved reliability, while reducing average yard process times will provide customers with lower trip times.

### 1.4 Research approach

The research performed in this thesis will use SPC and show how it can be applied to the monitoring of rail terminal performance. The SPC methods will also offer insight into the causes of poor terminal performance. The research will be carried out in the spirit of both MIT's long relationship with the rail industry and its history of rail reliability research.

The research presented in this thesis is performed using data gathered from Radnor Yard. Radnor Yard, located in Nashville, Tennessee, is a major hump yard on the CSX system. As part of improving their service reliability in the Nashville-Chicago corridor, CSX spent considerable time and resources collecting data from Radnor, data which is used in this research. The data was collected during the week of September 15-21, 1993, and included the starting and ending time for every process in the yard over all shifts.

The terminal operations involved in moving traffic from arriving trains to departing trains can be separated into three groups: pre-classification, hump utilization, and preparation for train departure. The pre-classification process includes the idle time from actual train arrival until start of inbound inspection, the inbound inspection process, and the idle time from train hump ready to hump start. The hump utilization process is defined as the periods of time that the hump is being used. The preparation for train departure process includes: time to assemble train, idle time from those trains done assembling to start of outbound inspection, outbound inspection, and idle time from train depart ready to actual departure.

These eight operations were analyzed using SPC. The individual process times for each of the eight operations were charted and analyzed using a control chart for individual measurements based on the moving range. Out of control points on the control charts were then identified and analyzed. The elimination of these out of control points will bring the process in control. Once the process is in control, methods to reduce the average processing times can be invoked.

Once the processes have been analyzed and the out of control points identified, attention will be turned to determine the exact nature of the missed connections that occurred at Radnor during the course of the study. Insight into the causes for missed connections will aid in the goal of improving the terminal performance at Radnor.

## 1.5 What is to come

The rest of the thesis is organized in the following manner: Chapter 2 presents a typical rail hump yard, its role in the rail network, and the functions involved in moving traffic through it, as understanding how a terminal works is the first step toward terminal operation improvement.

Chapter 3 details the pre-classification process, presents the average processing times involved in receiving an arriving train and making it hump ready, and shows how SPC will aid in the improvement of these process times. The utilization of SPC charts will highlight times (i.e., out of control points) during the study week in which the terminal operations performed better or worse than usual, while a Pareto analysis will describe in detail why these points occurred. Understanding the causes for the out of control points will aid in improving terminal performance. Action items for process time improvement that can be taken by a yard master are also given. Additionally, summaries of reasons for delays and efficiencies are presented at the end of the chapter.

Chapter 4 presents SPC charts for the utilization of the hump. As hump utilization is key in moving cars from the receiving yard to the bowl in order for the cars to meet their proper connections and for the receiving yard to remain uncongested, this process is monitored. The difference in processing times for one and two hump crew shifts is also presented.

In a manner similar to Chapter 3, Chapter 5 deals with the preparation for train departure process. The preparation for train departure is defined as the time from the start of assembly on an outbound train until the actual departure of that train. The average process times involved in this procedure are monitored using the same SPC methods presented in Chapter 3, with the out of control points also being identified. Causality analyses for the out of control points, as well as for trains not departing on time, are presented.

Chapter 6 gives the average process times for the entire yard. The chapter then presents the missed connections that occurred during the course of this study and places them in one of eight groups; groups based on missed connections due out of control points, late arrivals, tight connections, combinations of the three, or other reasons.

Chapter 7 is a summary of the research presented and offers suggestions for further work. Additionally, the need for industry benchmarks is addressed and called for. Benchmarking the eight processes described above will offer understanding into the operational differences that lead to lower average yard times between two yards, and will allow for the proper utilization of resources.

## II. The Hump Yard

Classification yards are vital to a rail network. They are needed as they enable railroads the ability to group blocks of cars heading to the same terminal, whether it be a final destination or an intermediate point, on to the same train. This provides for economies of scale as running long trains is more efficient than running short trains.

General freight movements along a rail network can be classified into three groups: line haul, terminal, and industry. The line haul portion of the trip is simply the time a car spends as part of a train when moving from terminal to terminal. The industry movements are defined as the time a car spends moving from industry to its originating railyard and from its final destination railyard to industry.

For example, tires from a Goodyear rubber plant are to be shipped to a automobile assembly plant. The tires leave a Goodyear plant in Akron and head to a rail terminal on a rail network. This particular rail terminal is the origin point. The tires end up in a railyard in Dearborn, MI, (its destination) before winding up at the car assembly plant. The time from the Goodyear plant to its originating railyard and from the destination railyard to the auto plant is attributed to local switching.

The terminal, however, is where a car spends most of its trip time. Rail terminals, or classification yards, can be characterized as one of two types: a flat yard or hump yard. Hump yards are generally much larger than flat yards and handle more traffic. Although this thesis is based on operations at a hump yard, an analysis for a flat yard can be carried out in a similar manner. All that needs to be changed is the way the classification process is monitored (i.e., switch engine utilization instead of hump utilization).

At a hump yard, trains are received and then classified, or broken up, on to bowl tracks. The cars are classified by a process called "humping." Cuts of cars are pulled from the receiving yard and shoved over a hump (a small hill) by a hump engine. The cars travel individually down the hump and on to the appropriate classification track. The classification, or bowl, track assignment is determined by the final destination of the car. Each bowl track represents a block of cars. These blocks are then pulled and assembled into outbound trains.

In a flat yard, however, there is no hump and the cars are classified by switch engines. The train, or cut, that is to be classified next is first attached to a switch engine. The switch engine and its crew then pushes the cars on to their appropriate classification track. Next, a switchman uncouples the cars from the train that are destined for that particular classification track. Lastly, the train pulls the remainder of the cut back and goes to the next classification track.

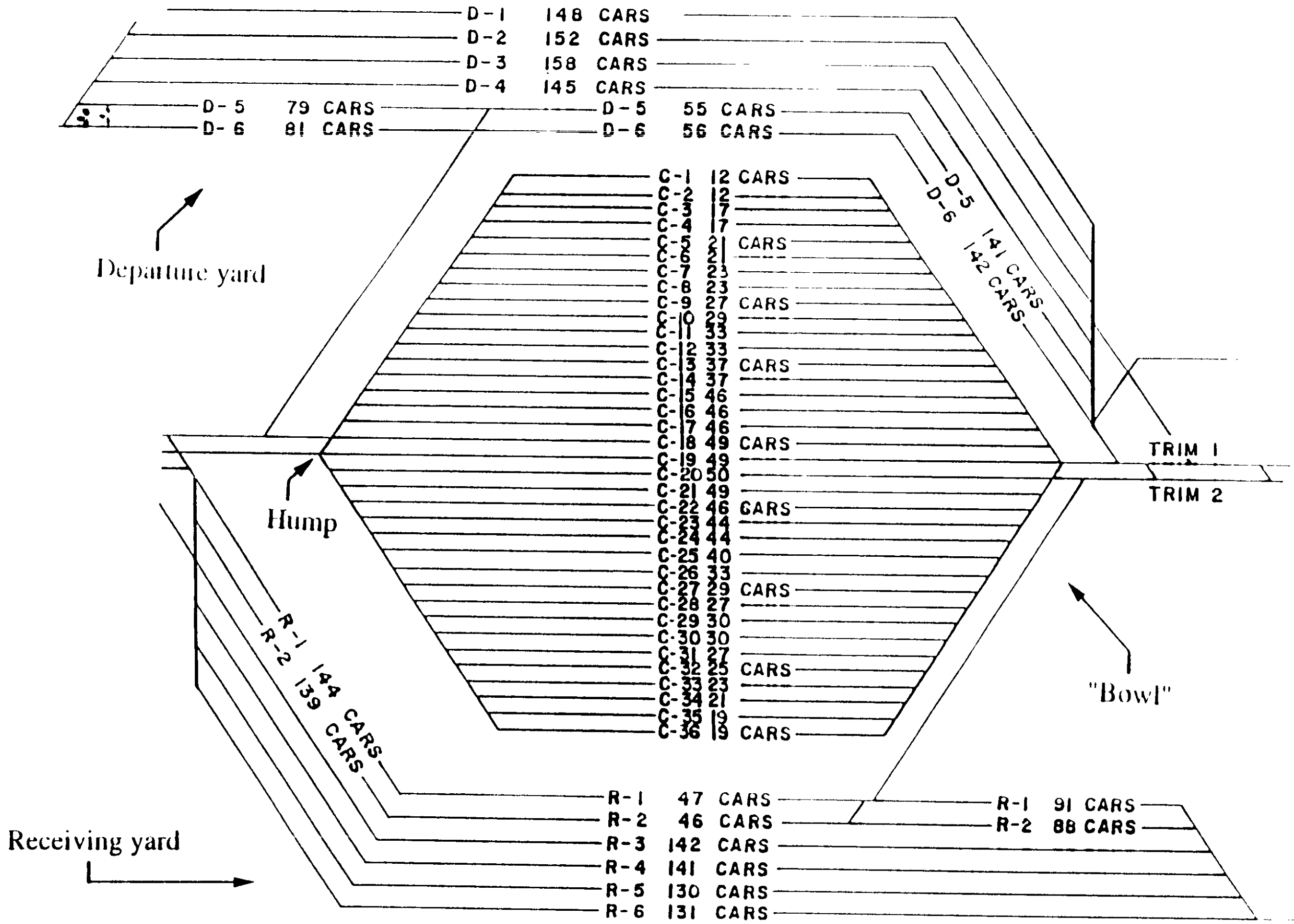


Figure 2-1: Typical rail hump yard

A typical schematic of a hump yard is presented in Figure 2-1. As described previously, inbound trains arrive at a yard and are placed in the receiving yard. The trains are then classified, with the individual cars winding up in the bowl (or classification tracks). Outbound trains are assembled and placed in the departure yard until they leave the yard. The rest of this chapter presents more extensive (but certainly not exhaustive) descriptions of these processes.

2.1 Yarding a train

When a train has received permission to enter a yard, these physical activities occur for it to be properly yarded (or received):

1. Placement of trains on tracks. The train is received onto a receiving track that is free in the yard. If a train is longer than an available track, it is doubled-over. A double-over is when the train is broken into as many as three parts, with the parts placed on different receiving yard tracks.

2. Detach and process locomotives. The locomotives are detached and moved to the service area.

3. Process end of train devices (EOT's). The EOT is taken off of the last car and brought to an area designated for EOT's. Although generally processed by the conductor, EOT's are sometimes processed by the inspection crews.

4. The conductor delivers the waybills for all the cars on the train to the yard clerks for processing.

5. Train released to inspectors. The yarded train is now released to the car inspectors as it is ready for inbound inspection.

Additionally, the following information flow needs to occur:

1. Verification of consist. This ensures that the train makeup is the same as it is ordered on the consist list, or waybill. The consist list is a sequencing of all the cars on the train and is used in identifying hazardous materials, classifying the train, and in keeping track of individual rail cars. Generally, this task is performed by a clerk sitting in an office, and is done as the train moves by a video camera placed on the outskirts of the yard. At the latest, this process should be performed before the train is classified as the consist list is used to make up the switch list.

2.2 Inbound inspection

1. Inspectors lock (blue flag) the track. When the inspectors are ready to inspect a train, they lock the track to ensure their safety as additional trains will be unable to

arrive on a locked track.

2. The inspectors then perform a walking inspection. Before starting the inspection, the inspectors are told the type of train being inspected, the number of cars to be inspected, and the priority of the tracks to be inspected (if necessary). Bad ordered cars (cars in need of repair) are either fixed by the car inspectors, or tagged for the shop. Cars that are tagged for the shop will be sent to the service area during the classification process. While the inspectors walk the length of the train, they release the air (brakes), so that the cars can roll over the hump.

3. Upon completion of the inspection, the car inspectors unflag the track and declare the track to be hump ready.

### 2.3 Classification

1. The classification process starts with the hump crew receiving a switch list. The switch list tells the crew what train to classify, where the train is located, where in the bowl the cars will be going, and special equipment handling information (hazardous materials, auto racks, and intermodal cars requiring special handling are generally shoved to rest by the hump engine during the hump process). After receiving the switch list, the hump crew then retrieves the train, or cuts, to be humped and pushes them to the hump.

2. While the hump engine pushes the train over the hump, someone (either a conductor or a trainman) is standing at the top of the hump crest with a switch list. This person uncouples the cars as they reach the hump crest, sending the cars to their appropriate bowl destination.

3. After the last car has rolled over the crest and down into the bowl, the hump engine will have to do some trim work if there were either errors due to misroutes or cars hung up on retarders. Misroutes, or cars that go to the wrong bowl track, are sometimes switched out when building the outbound train, while cars that get hung up on the retarders (due to air in their brakes or mechanical errors) need to be pushed through the retarder and into the bowl.

### 2.4 Assembly

1. The trim engine receives orders to build a train from the bowl tower. In these orders, the bowl tracks to couple and pull and the location where to place the outbound train are given. Upon receiving these orders, the trim engine crew locks the bowl tracks that are to be pulled. Locking the bowl tracks ensures that additional traffic will not roll over the hump and on to this particular bowl track.

2. Before pulling a locked-out track, the trim engine must couple all the cars on that track together, or at least the cars that are to be pulled for that particular outbound

train. This is done by using the trim engine to push the cars together so that their couplers lock. If the couplers do not initially lock, a crew member must open the coupler that is closed; the cars are then pushed together again.

3. As mentioned previously, during the assembly process any misroutes still in the bowl will be placed out. When the trim engine is finished pulling a track, the track will be unlocked, and the flag taken off.

4. After completing the assembly process, the train is placed on an outbound track and awaits its outbound inspection.

### 2.5 Outbound inspection

When the train is placed on the departure tracks and the trim engine has detached itself from the train and left the departure track, the train is ready for outbound inspection. The same process as in the inbound inspection is followed for the outbound inspection. Bad ordered cars that can not be repaired on the departure track will be switched out and sent to the shop.

### 2.6 Train departure

1. When the train is declared departure ready by the inspectors, the locomotives are coupled to the train, a brake test is performed, and an EOT is placed on the last car.

2. Thirty to forty five minutes prior to departure, the crew for the outbound train arrives. The crew will receive the train consist for that particular train and check to ensure that all cars, especially those with hazardous material containers, are in the same sequence on the train as they are on the consist. When this is done, the crew will request authority to depart.

3. Upon receiving permission, the train then departs the yard. A verification of the consist is performed as the train leaves the yard.

The above processes describe what happens to freight trains that go through the classification process. In the analysis to follow, only general merchandise freight trains are considered. Intermodal trains are left out of all the analyses (except for when they are occupying a receiving or departure yard track), as intermodal traffic is generally classified in a special manner. Since industry and intermodal trains are not included in the research for this thesis, a detailed description of the processes they go through was not given.

### 2.7 Typical yard dimensions

A typical rail hump yard has anywhere from 8 to 15 receiving yard tracks. These tracks can be up to 8500 feet long, which translates to a 154 car (if each car is 55') capacity. Generally, though, only a couple of the receiving yard tracks have capacities this high, with the rest of the track capacities on the order of 75 to 90 car lengths. The classification yard has 50 to 75 tracks. The tracks vary in size, and have total capacities of up to 3,000 cars. The departure yard is similar to the receiving yard for both the number of tracks and the track sizes.

## 2.8 Description of Radnor Yard

Radnor Yard has 13 receiving yard tracks. These tracks range in size, from 6005' (capacity of 109 cars) to 6548' (119 cars) long. The total capacity in the receiving yard for the 13 tracks is 1,479 cars. The classification yard has 56 tracks. These 56 bowl tracks have a total capacity of 2,631 cars. The longest bowl tracks can hold up to 68 cars, while the smallest have a maximum capacity of 36 cars. Five trim leads connect the bowl to the departure yard. Radnor's departure yard is comprised of 26 tracks. However, 9 of the tracks have a collective capacity of only 245 cars and are generally not used for outbound train makeups. The other 17 tracks have a total capacity of 1,900 cars and range in individual maximum car capacities from 124 to 45 cars.

The beginning and ending times for worker shifts vary at Radnor. The hump and trim engine crew shift times are 0700-1500, 1500-2300, and 2300-0700 (Eastern). The carmen, however, have shift times of 0800-1600, 1600-2400, and 2400-0800. Additionally, Radnor has 22 trains arriving and 26 trains departing per day (these numbers include intermodal trains) and processes, on average, 1850 cars per day.

The following chart presents the events that occur in a yard as the train moves from an inbound train to its outbound train connection. The process time associated with the events is also listed. Lastly, factors that contribute to the duration of the process time are given.

| Event | Process Time | Related Factors |
|---|---|---|
| 1. Train arrives | | |
| | 1. Train waits for inspection | 1. Scheduled arrival time |
| 2. Train starts inspection | | 1. Number of cars inspected<br>2. Number of inspectors performing inspection |
| | 2. Train inspected | |
| 3. Train ends inspection | | |
| | 3. Train waits to be humped | 1. Number of hump crews working shift |
| 4. Train starts hump | | 1. Crew performing hump job<br>2. Trim work performed by crew |
| | 4. Train humped | |
| 5. Train ends hump | | |
| | | |
| 6. Outbound train assembly starts | | 1. Bowl tracks to pull<br>2. Number of cars<br>3. Pull out lead(s) used<br>4. Number of train assemblies occurring simultaneously |
| | 5. Outbound train assembled | |
| 7. Outbound train assembly ends | | |
| | 6. Train waits for inspection | |
| 8. Train starts inspection | | 1. Number of cars inspected<br>2. Number of inspectors performing inspection |
| | 7. Train inspected | |
| 9. Train ends inspection | | |
| | 8. Train waits for departure | 1. Time engine(s) attached to train<br>2. Scheduled departure time |
| 10. Train departs | | |

Figure 2-2: Summary of yard processes.

## III. Analysis of the Pre-Classification Process

The pre-classification process is defined as the time from the train arrival until the beginning of the hump process. In his thesis, Reid concluded that delays in this process were a major reason that cars missed their appropriate outbound connection. This chapter will go beyond Reid's conclusion and demonstrate a method that pinpoints the reasons for the delays.

Within the pre-classification process, both the scheduled and actual arrival times are to be utilized in the construction of control charts as (1) cut-offs for outbound train connections are based on the scheduled arrival time of inbound trains and (2) the actual arrival times drive the scheduling of events within a yard and have the most pronounced effect on cars meeting their connections. This chapter will present a method to highlight trouble areas (i.e., out of control) in the receiving yard, trouble areas that lead to missed connections. The elimination of these out of control points will lead to a more reliable and efficient yard.

Four areas in the pre-classification process were monitored. The four areas were chosen as they are correctable, three by the yardmaster and one by the network, and are the "processes" an inbound train goes through. Defining an area as correctable means that action items can be taken that would improve the performance of the process. The four control charts monitor the following:

1. The (actual) train arrival's deviation from scheduled arrival

2. Idle time from actual arrival of train to start of inbound inspection

3. Time to complete inbound inspection

4. Idle time from hump ready to hump start.

Adherence to running a plan and, therefore, operating a reliable railroad starts with trains arriving at and departing from terminals on time. If plans are to be made and carried out by yardmasters, reliability of train arrivals is needed so that the plans can be made in advance of the scheduled arrivals. This is a correctable item as a railroad's network control and dispatching center can run trains in a strict manner. As it is important to pin the blame for missed train connections to the appropriate cause, this is a vital process to be monitored. If connections are missed due to late arrivals, it is non-productive to fault the yardmaster and criticize the way he operates his yard as the fault lies with a higher authority.

Long idle times, or non-value added processes, are representative of poor planning and should be eliminated, or at least minimized. The idle time spent by the train from actual arrival until inbound inspection starts is correctable by adding inbound inspectors, scheduling train arrivals at a later/earlier time, and inspecting only certain trains (e.g., 1000 mile inspections only). Similarly, the idle time spent by a train that is hump ready until it is humped is a direct reflection of two decisions a yard master must make: hump sequencing and number of hump crews to work a given shift.

Lastly, the time for inbound inspection is a hard item to correct as you do not want car inspectors to go so fast that they miss bad ordered cars. However, inspection times should not be equivalent for 40 and 110 car trains. Action items to increase inbound inspection performance include adding more inspectors (e.g., four inspectors per train rather than one or two), utilizing a hi-rail truck to perform light repairs, and improving supervisory capabilities.

From these charts, out of control data points, which lead to the unreliability of the yard, can be determined. Once an out of control point has been identified, further root cause analyses can be performed so that the exact cause of the failure can be identified. Removing these causes will lead to a more efficient and predictable yard. Conversely, points that exhibit periods of excellent performance by the yard will also be highlighted. Understanding why these points had such good processing times and applying those characteristics across all shifts will further add to the improved productivity of the yard.

The data for the operations performed at Radnor Yard during the study period was organized sequentially. Trains were ordered according to their arrival time for the construction of control charts for the difference between actual and scheduled arrival times and for the idle time between arrival to start of inspection. For the inbound inspection process, the data was organized in the order the inspections were initiated. Similarly, trains waiting to be humped are in order of their hump ready times.

In this analysis, 121 trains were received (double-overs count as two trains received), of which 114 were inspected. Seven trains were pulled from the receiving yard right to the hump and were not analyzed. It is not known why this occurred, as no explanations were given.

## 3.1 Definition of variables

The variables used in the analysis were:

1. Time train scheduled to arrive
2. Time train actually arrived
3. Time inbound train inspection started
4. Time to complete inspection
5. Time train hump ready
6. Number of cars inspected
7. Number of inspectors performing the inspection
8. Time train humped

It should be noted that for each inspection that took place, a fixed time of 10 minutes was encountered. This was the time it took for the track to be blue-flagged, at the outset of the inspection, and for the track to be unflagged at its completion (exactly 5 minutes for each). Since this time was constant in the data reports for every inspection that occurred, it was not incorporated into the cars inspected per minute calculations, as it would skew the data when comparing the cases of inspecting a 20 car cut and a 120 car train, but was incorporated into the average process time to inspect a train (as a fixed component) presented in Chapter 6.

The time a train is defined to be hump ready is the time in which both the inbound train has been inspected and the receiving track has been unflagged by the car inspectors. Likewise, the time hump starts is defined to be when the first car in the cut to be humped reaches the hump crest. Therefore, some of the idle time between time train hump ready and time train humped is a result of the time it takes the hump engine to move the cut from the receiving tracks to the hump crest.

### 3.2 Constructing the control chart

The type of SPC chart to be used for the analysis of the inbound inspection process was a chart for individual measurements, in which the control limits would be based on the "moving range." The moving range is defined to be the difference between consecutive data points in a series of numbers. This type of chart was chosen over standard X bar and R bar charts because of the nature of the data. It was first thought that the data could be grouped by day, according to shift. This was not feasible because, first, the number of sample points in each shift was not the same, as some shifts had eight data points while others had three or four. For a control chart to be utilized in the correct manner, each group must have an equivalent number of data points. Secondly, the data within each shift was not consistent. For example, two inspectors generally inspected each arrived train. However, occasionally one or four inspectors would perform the task. Therefore, within each grouping, the data would not be consistent.

To plot an X chart based on moving ranges, the following procedures are followed (AT&T, page 21-22):

> 1. Start with a series of numbers; 20 or more if possible, but not less than 10.
>
> 2. Take the absolute difference (no regard to sign) between the first and second numbers, and record it; then the difference between the second and third numbers, etc. Continue until you have taken the difference between the next-to-last and the last numbers. The number of differences, or "ranges", should be one less than the number of individuals in the series.
>
> 3. Take the average of the original numbers in the series (X bar). This is

the centerline for the chart and is drawn as a solid horizontal line.

4. Take the average of the "ranges" obtained in Step 2. Be sure to divide by the number of ranges, which is one less than the number of original measurements. This average range is called MR bar.

5. Multiply MR bar by 2.66 (a constant factor) to get the width of the control limits for the moving range chart. Add this value to (and subtract it from) X bar to get the location of the upper (and lower) control limit.

6. Plot the series of original numbers, and connect the points with straight lines. Draw in the control limits.

MR bar is used to estimate the standard deviation of the population. The control limits are based on the statistical variation of the process. They are established on the premise that the population is normally distributed and that the mean plus or minus three standard deviations will account for almost 100% (99.7%) of the observed values. Therefore, because the chart being formulated is done so using individual measurements, the product resulting from the constant factor of 2.66 multiplied times MR bar is utilized in the construction of the upper and lower control limits [Juran, 1988].

This procedure was followed for the construction of the X charts for not only the pre-classification process, but for all processes analyzed in this thesis.

### 3.3 Time between scheduled and actual train arrival

This chart is utilized when assigning causes to the long, or short, idle times an inbound train faced. For example, if a train arrives six hours early, it might not be inspected until next shift as no connections are in danger of being missed. Therefore, 360 minutes of idle time would be attributed to the early arrival. Likewise, an idle time of 20 minutes from train arrival to start of inspection could be a result of a late arrival and the need to inspect and hump the train immediately.

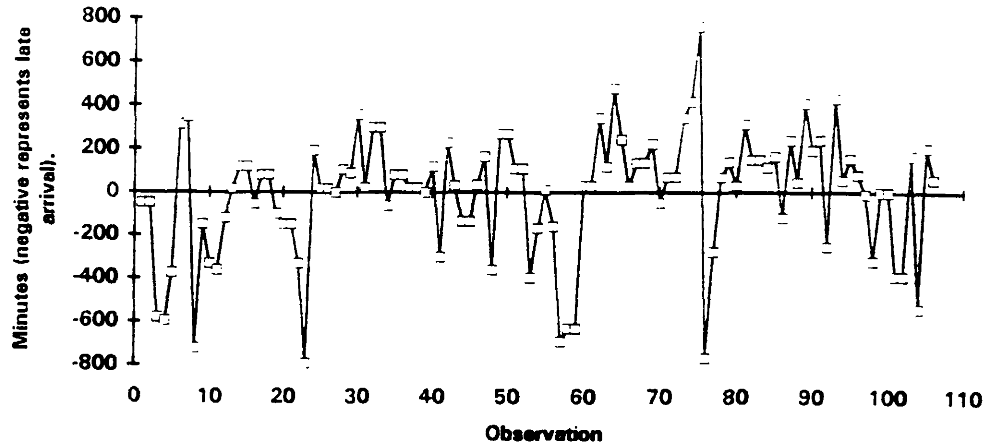


Figure 3-1: Time between scheduled and actual train arrivals.

Figure 3-1 shows there is substantial unreliability in train arrivals (late arrivals are shown with negative minutes, early arrivals with positive minutes. Note: the observations in the above figure are not equal to 121 as S trains do not have scheduled arrival times). Although the average arrival time is only seven minutes late, the standard deviation is 288 minutes. This unpredictability prevents a yardmaster from scheduling yard operations in advance. Instead, operation decisions must be made at the time action is needed. Therefore, an inexperienced yardmaster may not make the appropriate decision (concerning which train to inspect or hump next) when making it on the spot. If he had enough time to plan the activities that would be undertaken in the yard for the next couple of hours, proper decisions could be made.

Additionally, although trains arriving at a yard +/- two hours of their scheduled arrival time may be considered "on time" at the network level (as is the case for this yard), they are actually disruptive to the yard (at the micro level). In this data sample, 43% (46) of the trains arrived on time, with 30% (32) arriving more than two hours early and 26% (28) arriving more than two hours late. These early and late arrivals disrupt any planning attempts by the yardmaster.

Further, this two hour window is quite large as trains may arrive at a yard on time, yet still disrupt yard operations. For example, if two trains both arrive at 0700, instead of at 0500 and 0900, neither may be inspected until the next shift begins. This means a queue of two trains was just formed. If the first train had arrived as scheduled at 0500, it might have been inspected before the first shift began. Therefore, when the 0900 train arrives, it could be inspected next by the car inspectors.

### 3.4 Idle time from train arrival until start of inbound inspection

As previously mentioned, the data for this idle period was entered into a spreadsheet in the order the trains arrived. The control chart (Figure 3-3) was then constructed. The statistics used in the construction of the chart are presented in Figure

3-2, while the methodology utilized is explained in Sections 3.4.1 - 3.4.4.

| | |
|---|---|
| MR bar (average of the series) | 138 minutes |
| X bar (average idle time) | 154 |
| Standard Deviation | 154 |
| Upper Control Limit | 520 |
| Test Two (A top) | 398 |
| Test Three and Four (B top) | 276 |
| Lower Control Limit | 0 |
| Test Two (A bottom) | 0 |
| Test Three and Four (B bottom) | 32 |

Figure 3-2: Summary statistics for idle time from train arrival to start of inbound inspection process.

Now that the control chart has been formulated, we can test for unnatural patterns. Once an unnatural pattern is detected, a root cause analysis can be performed in order to identify, study, and eliminate it. With the absence of unnatural patterns, statistics can be used to predict the behavior of the "in control" process. As SPC charts highlight the terminal operations that need improvement, they will aid in improving the performance of the terminal.

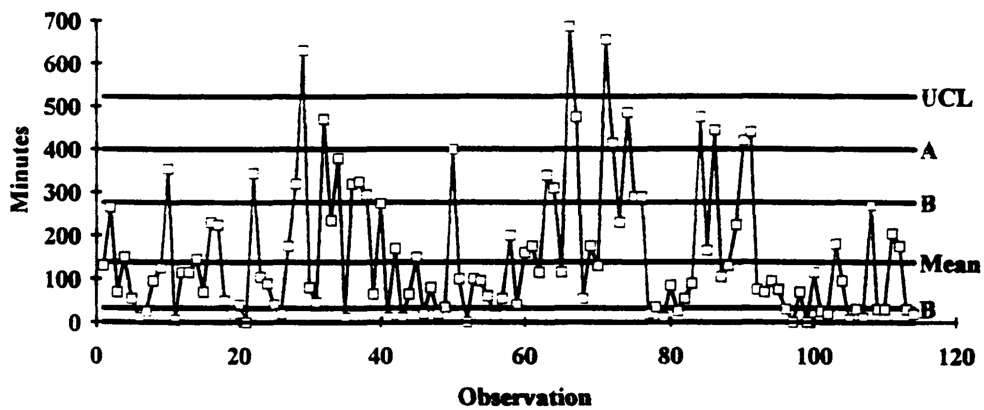


Figure 3-3: Control chart for the idle time from train arrival until start of inbound inspection.

Additionally, separate examinations of the top and bottom halves of the graph will lead to different conclusions. The top half of the graph contains points which have idle times longer than the average. Out of control points in this half are unwanted and methods to eliminate them should be undertaken. The bottom half of the graph, however, illustrates periods in the yard when trains were being inspected upon arrival in a relatively swift manner. Comparing the variables associated with these points (e.g., shift, number of inspectors, train arrivals) to the ones associated with data points from the top half of the graph will offer insight into how the operation is being conducted differently and how improvements can be made. Lastly, the more out of control points that are present on the (entire) graph, the greater the instability of the process being monitored.

### 3.4.1 Test 1: Single point out

Test 1 is a test for points which fell above the upper and below the lower control limits of 523 and 0, respectively. Although, the derivation of the lower control limit resulted in a negative number, zero is used as negative minutes are not applicable. The out of control points are listed in Figure 3-4 (the observation number corresponding to the plotted point on the graph is in parenthesis).

| Train Id | Arrival Time | Inspection Begin | Idle Time |
|---|---|---|---|
| (29) R67515 (d/o) | 5:30 | 16:00 | 630 minutes |
| (66) S67517 | 2:30 | 13:55 | 685 |
| (71) Q52017 (d/o) | 6:15 | 17:10 | 655 |

Figure 3-4: Test 1 out of control point.

An analysis was then performed to determine the causes for these three out of control points:

Train R67515 was actually a double-over. It was comprised of 28 cars, whereas the entire train was 149 cars. The train arrived at 0530, or five hours ahead of schedule. Therefore, 300 of the 630 idle minutes could be attributed to the fact it arrived early. Although the other 121 cars from train R67515 made their appropriate connection, as they were humped at 1540, these double-over cars missed their connections to outbound trains Q53118, Q53518, and R59218. Upon arrival, the double-over entered the inbound inspection queue second, but was inspected eighth. At the time of inspection two more double-overs had been added to the track, one at 0940 and one at 1040. A large queue of trains waiting for inspection built up after R67515's arrival as (1) the third shift inspected one train from 0455 to the end of the shift at 0800 and (2) three trains arrived in that same time frame. Additionally, three more trains were yarded as the first shift conducted their first inspections of the morning. Although the queue was growing, the long idle time R67515 experienced is attributable to inspection sequencing.

As train S67517 was a second section train and, therefore, did not have a scheduled arrival time, no idle time from train arrival and start of inbound inspection could be pinned to the train arriving early or late. Upon arrival at Radnor, S67517 became the second train in the queue for inbound inspection needed, yet was inspected seventh. At 0230, both inspection crews were free. One crew started inspecting Q64817 at 0325 (the first train in the queue). The second crew, however, did not start inspecting a train until 0440, and this was not S67517, but another train which arrived at the yard at 0345. From that point on it was a matter of inbound inspection sequencing as a queue of seven trains needing inspections was present when the first shift arrived (three trains arrived between 0615 and 0715). Since the train connections for the S, M, and G trains are not available, a summary of missed connections is not given.

Cut Q52017 was also a double-over and was comprised of 16 of the original 133 cars. One train and one double-over were added to this track before the inbound inspection took place, the train at 0905 and the double-over at 1220. The Q52017 double-over arrived at 0615, or 135 minutes early. At this time, it became the fifth train in the queue for inbound inspections (Q52017 with 117 cars was the fourth). Upon inspection, it was the seventh to be inspected. Therefore, a majority of the idle time was caused by the queue. The remaining 3 hours and 25 minutes was a result of inbound inspection sequencing. As this double-over was humped at 1710 (the rest of the train was humped at 1310), it missed connections to Q53120, R53320, and R59220.

In the three instances described above, a queue was the main cause of inbound inspection delay. The queue built up as trains arrived at the end of the third shift at a rate greater than the third shift was inspecting. In fact, from 0540-0830, exactly one train was inspected every day. Yet, on average, three trains arrived per day (this includes the cases where there were double-overs, meaning a double-over onto an empty track counted as two train arrivals, but a double-over onto an occupied track counted as one train arrival). While the first shift inspectors were inspecting their first trains of the day (usually a total of two trains, with the inspections ending at 1030), two additional trains would, on average, arrive. Therefore, the queue length would remain the same. The queue would get smaller throughout the rest of the day and the receiving yard generally would be caught up in its work at about 0500 every day as there was, on average, one train needing an inspection at that time. From 0500-0830, however, the queue would reformulate and long idle times would be experienced by the arriving trains.

### 3.4.2 Test 2: Two out of three points fall in Zone A or beyond

The control lines used in this test are derived in the following manner:

X bar +/- (2/3) * 2.66 * MR bar.

2/3 is used as a scaling factor because Zone A represents one-third of the top half of the graph.

Out of control points are identified as the second point in which two out of three successive points fall in Zone A or beyond (i.e., above or below the control limits). Zone A is defined as the regions between Test 2 (line A) and the upper and lower control limits. In this particular case, as line A for the bottom half of the graph is equivalent to the lower control limit, this test is not applicable to this part of the graph. Points are to be read from left to right, as the test is to be done on a real time basis, and can only be marked (i.e., labeled out of control) once.

| Train Id | Arrival Time | Inspection Begin | Idle Time |
|---|---|---|---|
| (67) Q59518 | 3:00 | 10:55 | 475 minutes |
| (72) S57318 | 7:00 | 13:55 | 415 |
| (74) R55718 | 9:05 | 17:10 | 485 |
| (86) Q52018 (d/o) | 6:00 | 13:25 | 445 |

Figure 3-5: Test 2 out of control point.

Again, an analysis was performed in order to find the causes for these points:

Train Q59518 arrived at 0300, or eight hours early. Although it was second in the inbound inspection queue upon arrival, other trains were given priority in inspections as these trains were arriving on time or late. The excessive idle time, therefore, is due to the early arrival.

S57318 arrived at 0700, while R55718 arrived at 0905. The trains entered the inspection queue sixth and fifth, respectively. As both S57318 and R55718 were inspected fifth after their arrivals, the long idle time was due to the inspection queue - the same queue experienced by S67517 in section 3.4.1. As a result of R55718 being humped late, two connections, to R52120 and R53320, were missed.

Q52018, however, was a double-over (19 of the 125 cars) and placed on a track that had both hump ready cars and cars needing inspection. Upon arrival (which was 2 1/2 hours early), the double-over was fourth in the queue for inspections needed (including the original Q52018). As it was the fifth train inspected, the idle time is primarily due to the inspection queue. The inspection queue was due to the fact that from 0300-0835, two trains were inspected while six trains arrived. Before this train was inspected, however, train Q64918 was inspected twice (see 3.6.1). As a result, Q52018 missed its connection to Q53121.

Once again, the difference in the inspection rate and the train arrival rate at the end of the third shift and beginning of the first shift was the cause for the build up of the long queue. This has occurred on two of the six days.

### 3.4.3 Test 3: Four out of five points fall in Zone B or beyond

Zone B is defined as the region between Test 2 (line A) and Test 3 and 4 (line B). Like Zone A, it comprises 1/3 of the area above and below the Mean. The formula for line B is:

X bar +/- (1/3) * 2.66 * MR bar.

Out of control points are defined as the fourth point in a series of five, where four of the five points lie in Zone B or beyond.

This test yielded the seven out of control points listed in Figure 3-6 (both tracks means that upon arrival, the train was yarded on two tracks, and that both tracks had the same starting and ending process times).

| Train Id | Arrival Time | Inspection Begin | Idle Time |
|---|---|---|---|
| (38) R53017 | 11:30 | 16:25 | 295 minutes |
| (75 & 76) R53019 (both tracks) | 12:20 | 17:10 | 290 |
| (101) Y33020 | 2:50 | 3:15 | 25 |
| (102) R57320 | 5:05 | 5:25 | 20 |
| (109 & 110) Q59520 (both tracks) | 17:30 | 18:00 | 30 |

Figure 3-6: Test 3 out of control point.

Train R53017 arrived two hours early and was placed on a track with another train in need of an inbound inspection. Upon arrival it was fourth in the inbound inspection queue. Since it was the third train inspected after arrival, the long idle time was due to the build up of the queue, as the inspectors were still trying to reduce the queue that was present for R67515 (d/o) in Section 3.4.1. R53017 had one missed connection, to R68517. This connection, however, is too tight (6 1/2 hours from scheduled arrival to scheduled departure) and could not have been made even if the train was humped upon arrival as the assembly for train R68517 began at 0925.

Train R53019 also arrived at the yard early (70 minutes) and became the fourth train in the inspection queue. The double-over for R53019, however, was placed on a track occupied by cars currently second in the queue. As the tracks holding R53019 and its double-over were inspected simultaneously (third and fourth after arrival), the excessive idle time was due to the inspection queue. The inspection queue was the same one faced by Q52017, S57318, and R55718 from previous sections. R53019 missed its scheduled connection to R68519. This is due to the tight connection of these trains, as described above (R53017 to R68517).

Y33020 arrived in the yard at 0250 and became second in the inspection queue. As this train was inspected next (along with the train first in the queue), the short idle time from arrival to inspection is attributed to the fact that the yard was caught up in its work. Likewise, R57320, despite arriving at the yard 55 minutes early, became the first train in the inspection queue upon entering the yard, and was inspected next. Despite this it missed its connection to train R68521. This is because the train was humped at 1145, while the assembly on train R68521 began at 0800.

Upon its arrival, train Q59520 was placed on tracks A5 and A6. The double-over and the original became first and second trains in the hump queue (as the double-over was placed on a track that had existing traffic). Because the yard was caught up, they became the next trains inspected and endured a small idle time, this despite being 6 1/2 hours late. As the end of the study came before the outbound connections were to be met, the connection performance for this inbound train is unknown.

Again, another example of how the (relative) inactivity of the third shift results in long idle times for arriving trains is shown. Additionally, an example of how trains are inspected quickly when the yard is caught up is presented. This illustrates the effectiveness of staggering arrival times for incoming trains at a particular yard.

#### 3.4.4 Test 4: Eight successive points fall in Zone C or beyond

Zone C is defined as the area between the Mean (or center) line and Line B. Again, Zone C comprises 1/3 of the area above and below the centerline. Out of control points are defined as the eighth in a series of eight, a series in which all eight points lie above or below the centerline. This particular process did not produce any points of this nature.

### 3.5 Inbound inspection process

The variable that is monitored in the inspection process is cars inspected per minute per inspector. The reason for using this statistic is that it more accurately reflects the performance of the inbound inspectors as trains were inspected with 1, 2, or 4 inspectors. This measure does, however, neglect the effects of the car inspectors fixing bad ordered cars in the receiving yard. The following figure presents a summary of the statistics for car inspections derived in this study.

| | |
|---|---|
| MR bar (average of the series) | 0.09 |
| X bar (cars inspected/minute per inspector) | 0.40 |
| Standard Deviation | 0.09 |
| Upper Control Limit | 0.65 |
| Test Two (A top) | 0.57 |
| Test Three and Four (B top) | 0.48 |
| Lower Control Limit | 0.14 |
| Test Two (A bottom) | 0.23 |
| Test Three and Four (B bottom) | 0.31 |

Figure 3-7: Summary statistics for inbound inspections.

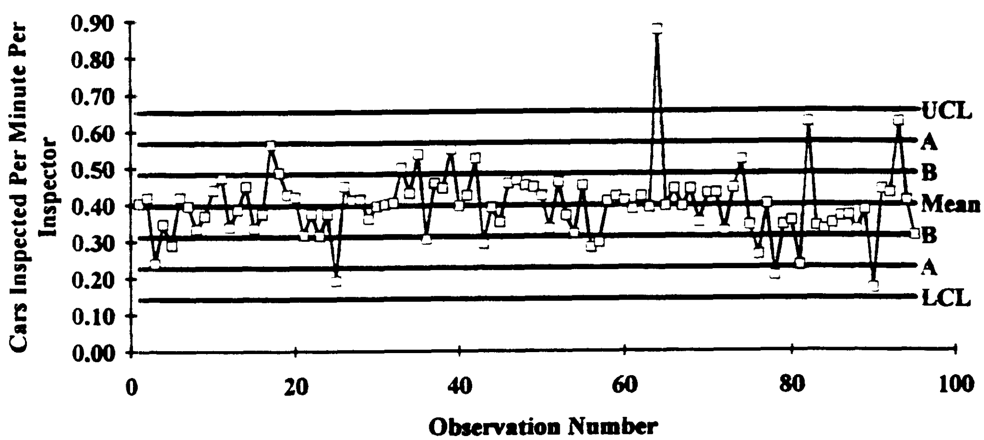


Figure 3-8: Control chart for the inbound inspection process.

3.5.1 Test 1

The tests used in the rest of this thesis are derived in the same manner as the tests used in Section 3.4.1 - 3.4.4. Therefore, only the out of control points will be identified and analyzed. To understand how these tests were conducted please refer back to the appropriate section.

For this particular process, analyzing the top half of the graph will highlight inspection times that are unusually fast, while the bottom half will exhibit points that are slower than average. The results of test 1 are presented below:

| Train Id | Inspection Time | # Cars | # Inspectors | Cars ins/min per inspector |
|---|---|---|---|---|
| (64) Q59519 | 64 | 112 | 2 | 0.88 |

Figure 3-9: Test 1 out of control point.

Research into train Q59519 revealed that it was the last train the inspection crew had to inspect before heading for home. Despite having one bad ordered car, the train was inspected relatively quickly.

### 3.5.2 Tests 2 and 3

These tests produced no out of control points for this particular process.

### 3.5.3 Test 4

| Train Id | Inspection Time | # Cars | # Inspectors | Cars ins/min per inspector |
|---|---|---|---|---|
| (90) R53021/Q59520 | 115 | 39 | 2 | 0.17 |

Figure 3-10: Test 4 out of control point.

Trains R53021 and Q59520 were on the same track, A5. Adjacent to this track, on A6, was another train in need of inspection. Track A6 had 101 cars, while A5 had 39. Despite this and the fact that A6 had three bad ordered cars, while A5 had one, the two crews working the tracks started and finished their job at the same time.

These two out of control points suggest that crews work faster when they are working close to quit time and work slower when they are inspecting trains while walking alongside other inspection crews. In general, though, the process is in control (as evident by only two out of control points) and the next step should be researching ways to get the process time under 123 minutes per train.

3.6 Idle time from hump ready to hump start

This section examines the idle time spent by trains on the receiving track, from hump ready to hump start. Trains used in this analysis were sequenced in the order of their hump ready times. As defined above hump ready is when the train's receiving track is unflagged at the completion of the inbound inspection, while hump start is the time when the cut reached the hump crest.

| | |
|---|---|
| MR bar (average of the series) | 118 minutes |
| X bar (average idle time) | 257 |
| Standard Deviation | 142 |
| Upper Control Limit | 571 |
| Test Two (A top) | 464 |
| Test Three and Four (B top) | 361 |
| Lower Control Limit | 0 |
| Test Two (A bottom) | 51 |
| Test Three and Four (B bottom) | 154 |

Figure 3-11: Summary statistics for idle time between hump ready and hump start.

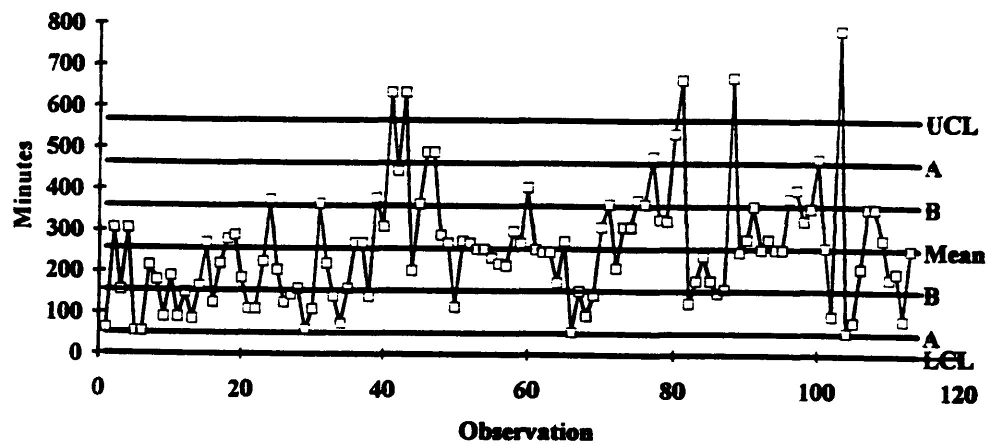


Figure 3-12: Control chart for the idle time from hump ready to hump start.

3.6.1 Test 1

Out of control points from the top half of the graph will be instances where trains that were ready to be humped sat idle for an extraordinarily long time. The bottom half of the graph will exhibit data points corresponding to trains that were humped soon after the inbound inspection process was completed. The table below presents the out of control points, as defined by Test 1:

| Train Id | Hump Ready | Hump Start | Idle Time |
|---|---|---|---|
| (41) M71917 | 23:55 | 10:30 | 635 minutes |
| (43) R53217 | 23:55 | 10:30 | 635 |
| (81) Q64918 | 5:20 | 16:25 | 665 |
| (88) S57519 | 15:30 | 2:40 | 670 |
| (103) M78621 | 12:55 | 2:00 | 785 |

Figure 3-13: Test 1 out of control point.

Upon completion of the inbound inspection, Trains M71917 and R53217 were fifth in the hump queue (they were on the same track), and were humped sixth (not including cars humped from the hold track and new shop). Therefore, the majority of the idle time was due to the hump queue. The hump queue built up as a result of only three trains being humped from 1725 to 2310. During this time period the hump was free for 145 minutes, or 42% of the time, and six inspections were completed. This combination led to the development of the hump queue. As a result, R53217 missed its connection to R53418.

Train Q64918 was finished with inspection and hump ready at 0520, placing it sixth in the hump queue. However, the train was inspected again at 1055. This inspection lasted until 1300. Upon completion of the second inspection, the train was fourth in the queue. It waited an additional 205 minutes until it was humped (which was fourth). Therefore, the long idle time here is attributable to an error causing the train to be inspected twice.

When declared hump ready, S57519 was second in the hump queue. It was humped sixth, though. Also, during this period the hump was not utilized at all from 1900 to 2300. Since maintenance reports are unavailable, it is unclear if the hump was shut down. Therefore, the causes of delay to this train are the gap in humping (long hump idle time) and the hump sequence. Because connections for S trains are unavailable, it is not known how the hump sequencing effected its connection performance.

Train M78621 was hump ready at 1255 and was second in the queue. From 1225 to 1330 the hump was free and not being utilized. At 1330, however, a double-over (R53021) was placed on the same track as M78621. Another double-over was placed on the track at 1730 (Q59520). Therefore, the track was not hump ready again until 2005. These double-overs were placed on this track despite five other free tracks available in the receiving yard. Upon the new hump ready time, the track was first (along with another track) in the queue. It was then the second track humped. Therefore the hump sequence was not at fault. As the hump was again free for an extended period of time, from 2005 to 0045, the long idle time is due to the inactivity of the hump and the decision to place non-inspected double-overs on to the hump ready track.

From this test, it is evident that the hump sequencing leads to the greatest delays to hump ready trains. Also, the decision to place double-overs on a hump ready track led to the delay of M78621. Since M trains' connections are unavailable, it is unknown as to how many missed connections this decision caused.

3.6.2 Test 2

| Train Id | Hump Ready | Hump Start | Idle Time |
|---|---|---|---|
| (47) Q52016 (d/o) | 5:40 | 13:50 | 490 minutes |

Figure 3-14: Test 2 out of control point.

The double-over portion of train Q52016 was ready to be humped at 0540. At this time it entered the queue fifth. It was the seventh train humped, however. Because the train arrived at the yard 4 1/2 hours early, no outbound connections were missed. This could be the reason for the deviation from the first in first out (FIFO) hump rule. The hump queue was a result of only one train being humped from 0420-0753, while three additional trains became hump ready.

3.6.3 Test 3

| Train Id | Hump Ready | Hump Start | Idle Time |
|---|---|---|---|
| (30) S59515 | 10:35 | 12:25 | 110 minutes |
| (45) Q68416 | 3:10 | 9:15 | 365 |
| (46) Q57517 | 5:40 | 13:50 | 490 |

Figure 3-15: Test 3 out of control point.

S59515 was ready to be humped at 1035. Upon completion of the inbound inspection, it was (tied) first in the hump ready queue. As there were no other trains ready to be humped, it was humped second. The yard was pretty full as four tracks were awaiting inspection, but only two trains were ready to be humped.

Train Q64816 arrived 2 3/4 hours early and was inspected 20 minutes after arrival. It entered the hump ready queue fourth and was humped fourth. Therefore, the hump queue was the reason for delay. This is the same queue faced by trains M71917 and R53217. Similarly is the case for Q57517, which arrived at 0300, six hours late. A double-over cut (Q52016) was placed on the tracks with it. The track was hump ready at 0540, but humped at 1350. It entered the queue fifth, but was humped seventh. Therefore, the hump queue and hump sequencing were the causes for this delay. No connections, however, were missed.

### 3.6.4 Test 4

| Train Id | Hump Ready | Hump Start | Idle Time |
|---|---|---|---|
| (12) Q52014 | 10:30 | 13:00 | 150 minutes |
| (13) R58215 | 12:55 | 14:20 | 85 |
| (14) Q53615 | 12:55 | 15:40 | 165 |
| (80) R53219 | 2:50 | 11:45 | 535 |

Figure 3-16: Test 4 out of control point.

Q52014 was hump ready at 1030, (tied) first in the queue and was humped second, as the yard was caught up and there was nothing else hump ready. As a result, Q52014 had no missed connections. Similarly, R58215 entered the hump ready queue (tied) second, and was humped second. Q53615 entered the hump ready queue (tied) second and was humped third. The missed connections for this inbound train were from the double-over, not this particular cut. The three data points above are examples of how efficiently the hump works when two crews are working in tandem, as the hump was only free for 125 minutes from 0935-1620 (31% of the time).

Train R53219 was hump ready at 0250 and entered the queue fourth, but was humped seventh. From 2349-0400, only two tracks were humped while the hump was idle for 161 minutes (or 64% of the time). Additionally, the hump was inactive from 0435-0608, while one more train became hump ready. Therefore, the main cause to the development of the hump queue was the inactivity of the hump. Although the decision not to hump it fourth at 0945 resulted in an extra 120 minutes of idle time, no connections were missed by R53219.

## 3.7 Summary

From the control charts, one can conclude that the inbound inspection process time is generally steady (i.e., the same) and almost in complete control, while the idle times spent by incoming trains in the receiving yard are enormous and vary widely. The wide distributions of idle times leads to the unreliability of train connections, while the magnitude of these times leads to missed connections. If these idle times could be controlled, then methods to reduce them could be invoked. Controlling and reducing idle times will lead to more predictable and reliable train connection performance. Continuing to monitor control charts will tell you if the changes made to the system have resulted in improved performance.

Queues of trains waiting for inbound inspection developed during the end of the third shift/beginning of first shift as more trains arrived than were being inspected. This was due to either bunched train arrivals or inspector inactivity, or a combination of both. The yard would generally be caught up in the middle of the third shift. As this queue build up was a problem during the entire study period, train schedules should be closely looked at, as well as the starting and ending times of shifts. It does not make sense to have a lot of trains arrive in a two hour window every morning, as this contributes to the build up of queues. Likewise, starting the first shift at 0600 instead of 0800 could aid in reducing queue build up as the maximum number of inspections possible in a day would increase.

The long idle times from hump ready until hump start experienced by trains were mainly a result of (1) hump inactivity and (2) hump sequencing decisions. The periods of inactivity at the hump resulted in a hump ready queue build up on the receiving tracks, while deviations from the FIFO principle generally adhered to at the yard also led to longer idle times. The following figures summarize the causes for delay and the causes for efficient process times, in the pre-classification process.

| Reason for out of control point (delay) | Number of occurrences |
|---|---|
| 1. Inspection queue | 6 |
| 2. Hump queue | 4 |
| 3. Hump sequencing | 4 |
| 4. Inspection sequencing | 3 |
| 5. Early arrival | 2 |
| 6. Slow inspection | 1 |
| 7. Placement of double-overs | 1 |
| 8. Inspected twice | 1 |

Figure 3-17: Delay causality analysis for the receiving yard.

| Reason for out of control point (efficient) | Number of occurrences |
|---|---|
| 1. Yard caught up in work | 7 |
| 2. Fast inspection | 1 |

Figure 3-18: Efficient causality analysis for the receiving yard.

Out of the 114 trains analyzed, 85 were in control (i.e., no out of control processes associated with them). Of the 29 trains that were out of control (one train was out of control in two different processes), 8 were due to fast, or efficient, yard times while 21 were due to slow yard process times. These 21 out of control points had 12 missed connections, or 24% of the week's total. Although all of the missed connections are not entirely attributable to these out of control points (see Chapter 6), enough of them are to warrant the needed improvements in the pre-classification process.

## IV. Analysis of Hump Utilization

A control chart for time between hump jobs (hump utilization) was constructed in the same manner as those previously discussed. As defined earlier, hump start is the time when the cut reached the hump crest, while hump end is the time when the last car is pushed over the crest and into the bowl. This type of control chart is utilized for the hump for the following reasons: (1) Hump speeds for cars traveling down the hump are (generally) limited to under 5 miles per hour; (2) the time between hump jobs will better highlight the productivity differences between two hump crews working in tandem on a shift and a single crew working the hump; and (3) the inactivity of the hump forces hump ready queues to develop and the receiving yard to become full. Consequently, it is more important to monitor the utilization of the hump than the hump rates cars humped per minute or per shift.

The control chart presented below is based on the average hump idle time for the entire week. However, there are two separate performance measures for the hump: one for when two crews are working and one for when one crew is working. The processing times for these two separate cases are presented in Figure 4-1. Although incorporated into the control charts, idle times at the end and beginning of a shift are not included in the calculations for Figure 4-1. Also, idle times that are excessive (100 minutes and above) were not included, as this table was constructed in order to demonstrate the different processing capabilities of one crew as compared to two.

| Number of hump crews | Average time between jobs | Average length of job |
|---|---|---|
| 1 | 54 minutes | 43 minutes |
| 2 | 21 | 45 |

Figure 4-1: Difference in hump utilization between one and two crews.

From this table, the conclusion that the productivity of two hump crews (hump utilized 45 out of 66 minutes, or 68% of the time) far exceeds that of one crew (44%) can be made. Therefore, the maximum amount of cars that can be humped in a shift should be based on two crews working at 68% hump utilization (less the idle time at the beginning and end of the shift), and not on a simple cars per minute calculation.

Figure 4-2 presents the statistics used in constructing the control chart for hump utilization. Here, the hump activity for the entire week is incorporated.

| | |
|---|---|
| MR bar (average of the series) | 44 minutes |
| X bar (average hump idle time) | 44 |
| Standard Deviation | 48 |
| Upper Control Limit | 160 |
| Test Two (A top) | 121 |
| Test Three and Four (B top) | 83 |
| Lower Control Limit | 0 |
| Test Two (A bottom) | 0 |
| Test Three and Four (B bottom) | 5 |

Figure 4-2: Summary statistics for hump utilization.

Since the average processing time for humping a train is 45 minutes (see Figure 6-1), the hump is utilized (on average) 51% of the day (45 out of every 89 minutes). Even with two crews working a shift, large idle times are present at both the beginning of the shift and at the end. These idle times can be reduced by staggering the start times of the crews (i.e., have one crew come in at 0700 and one at 0800). Therefore, the third shift hump crew can be working while one of the first shift crews receives their safety briefing. Likewise, this first shift crew will be working the hump when the second hump crew reports at 0800.

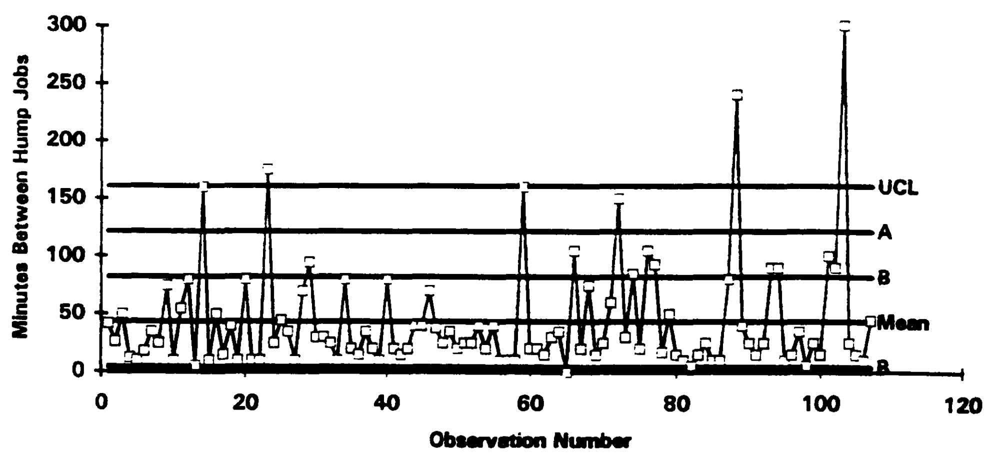


Figure 4-3: Control chart for the utilization of the hump.

What follows is an analysis of the out of control points present in Figure 4-3.

4.1.1 Test 1

| Day | Time Hump Job End | Time Next Hump Job Start | Hump Idle Time |
|---|---|---|---|
| (14) 16th | 6:55 | 9:35 | 160 minutes |
| (23) 16th | 20:15 | 23:10 | 175 |
| (59) 18th | 21:10 | 23:50 | 160 |
| (88) 20th | 19:00 | 23:00 | 240 |
| (103) 21st | 19:45 | 0:45 | 300 |

Figure 4-4: Test 1 out of control point.

An analysis similar to that of the previous section was then performed to determine the causes of these long hump idle times and the effects they had on the hump ready queues:

Job Y34015 finished his hump job at 0655 on the 16th. The next hump job was Y14116 beginning at 0935. The 3rd shift was due to end at 0800, so Y34015 had an hour and five minutes until his shift ended. At the time, there were four trains sitting in the receiving yard, one (Y33015) of which had been inspected and, therefore, was ready to be humped. During this idle time the hump ready queue increased from one train to two, as the hump crews on the first shift did not begin to hump trains until 0935.

Y24016 finished his job at 2015, but Y24116 did not start his next job until 2310. At 2015 there were four trains in the receiving yard, two of which had been inspected and were ready to be humped. At 2310, when Y24116 began to hump one of these two trains, the hump ready queue had increased to three.

Y24018 finished his job at 2110, while Y24118 started at 2350. At the time there were six trains in the receiving yard, two of which were ready to be humped. At 2350, one of these trains was humped (Y24118 had to stay past the end of his shift to finish the hump job) and the hump ready queue was up to five trains.

Y24020 finished his job at 1900, while no trains were humped until Y24020 humped a train beginning at 2300. At 1900, there were five trains sitting in the receiving yard, three of which had been inspected and were ready to be humped. When Y24020 began humping one of these trains at 2300, the queue was up to five.

Y24021 ended his job at 1945, but Y34021 did not start humping trains until 0045. At 1945 there were four trains in the receiving yard, two of which were ready to be humped at 2000. By the time one of these trains was humped at 0045, the queue had grown to four trains.

Two of the five out of control points presented above were a result of the idle time between the end of one shift and the start of another. As mentioned before, this idle time could be reduced by staggering the start times of the hump crews. Also, the effect these hump idle times have on the hump ready queues are presented. The hump ready queues have a direct effect on cars meeting their appropriate outbound connection, and should also be reduced.

4.1.2 Tests 2 and 3

These tests produced no out of control points for this particular process.

4.1.3 Test 4

| Day | Time Hump Job End | Time Next Hump Job Start | Hump Idle Time |
|---|---|---|---|
| (54) 18th | 16:10 | 16:30 | 20 minutes |
| (55) 18th | 16:50 | 17:30 | 40 |
| (56) 18th | 18:15 | 18:25 | 10 |
| (57) 18th | 19:25 | 19:35 | 10 |
| (58) 18th | 20:10 | 20:20 | 10 |

Figure 4-5: Test 4 out of control point.

The out of control points above are from the lower part of the control chart - points where the hump was not idle long. As the points are consecutive on the chart, they demonstrate how effectively the hump can be utilized if two hump crews are working in tandem. This efficient utilization of the hump enabled the yard to get caught up in its work load.

4.2 Summary

The utilization of the hump is a key ingredient in cars making their scheduled connections. When the hump is idle, hump ready queues build up in the receiving yard. These queues not only effect train connection performance, but also effect the decisions made by yardmasters on where to place an arriving train. For example, a yardmaster may have a hi-rail truck he would like to use for light repairs on bad ordered cars found during the inbound inspection. If this is the case, trains are, ideally, yarded on every other receiving track. If these tracks are full of trains waiting to be humped, then the hi-rail truck cannot be effectively used. Also, the hump ready queue may cause the "long" receiving tracks to be full, forcing 100 car trains to be doubled over. These double-over cars may be placed on tracks with hump ready cars, causing unnecessary delays to those hump ready cars (as seen in the previous section). The figure below lists the causes for the excessive hump idle times identified in this chapter.

| Reason for out of control point (long hump idle time) | Number of occurrences |
|---|---|
| 1. Hump idle during shift with two crews working | 2 |
| 2. Hump idle from end of one shift to start of next shift | 2 |
| 3. Hump idle during shift with one crew working | 1 |

Figure 4-6: Causality analysis for long hump idle times.

The difference in productivity between two crew shifts and one crew shifts is highlighted, as two crews in tandem were the cause for the out of control points associated with short hump idle times (see Figure 4-7). This type of analysis should be utilized when determining the maximum amount of cars that can be humped in a shift or day and when conducting what if analyses on the effects of adding a hump engine to yard productivity. Additionally, the effects of staggering crew starts should be looked at as some of the out of control points were a result of the hump idle time caused by one shift ending and another starting.

| Reason for out of control point (short hump idle time) | Number of occurrences |
|---|---|
| 1. Two crews working in tandem during shift | 5 |

Figure 4-7: Causality analysis for short hump idle times.

## V: Analysis of Preparation for Train Departure

The preparation for train departure process is defined as the time the assembly for an outbound train starts until the actual train departure. The sub-processes involved occur in the departure yard and are: train assembly, outbound inspection, brake test, and train departure. This chapter will apply the methodology presented in previous chapters to this end of the yard. The same tests will also be utilized in order to determine the out of control points on the control charts. Elimination of the out of control points present in the departure yard will aid in improving the performance and reliability of rail terminals.

As in the pre-classification process, four processes were monitored. These four processes were chosen as they are correctable and are the processes that departing trains must go through. The four processes to be monitored are:

1. Time to assemble outbound train

2. Idle time from assembly done to start of outbound inspection

3. Outbound inspection

4. Idle time from outbound inspection complete until actual train departure.

The process time for assembling a train is influenced by whether or not the cars in the bowl are coupled and ready to be pulled, the number of bowl tracks to pull, the physical location of the blocks, and which pullout leads (or throats) are to be used. A yardmaster can have a trim engine spend time coupling cars in the bowl. While this will reduce the train assembly time, it could adversely effect yard operations as other jobs are left undone. Also, trim engines using the same pullout leads will negatively effect each other's performance. Proper planning and scheduling of train assemblies and classification track assignments can alleviate this potential problem.

The idle time from assembly done to start of inbound inspection is a result of decisions by the yard master as to what time to build the train and the order in which the inbound inspections will occur. Building a train far in advance of the train departure time will lead to long idle times in the departure yard as long inspection needed queues build up, while inspection sequencing decisions can lead to short, or long, idle times.

The idle time from outbound inspection complete until actual train departure, though, is a function of two variables. As with the idle time before the start of the inbound inspection process, the time the yardmaster decides to assemble a train effects the idle time spent in the departure yard. Secondly, is the adherence to running the trains according to schedule. Deviations from the schedule will cause outbound trains to experience longer, or shorter, delays than average.

As stated earlier, the data used in this chapter was organized sequentially. For the assembly process, times were ordered according to the time the train assembly was completed. The idle time trains spent on the departure tracks were ordered according to the completion of the previous process (either the assembly or inspection), while the inspection process was ordered according to when the inspections were initiated. The organization of the data in this manner was necessary as moving range control charts were to be used.

In analyzing the departure yard processes, 124 train departures were examined. 22 trains, however, were not analyzed completely as they were either missing inspection data or were not inspected.

## 5.1 Definition of variables

The variables used in this process are:

1. Time assembly starts
2. Time assembly ends
3. Time outbound inspection started
4. Time to complete outbound inspection
5. Time train depart ready
6. Number of cars inspected
7. Number of inspectors performing inspection
8. Scheduled train departure time
9. Actual train departure time

The time assembly starts is defined as the time the yard job is given their instructions to build the outbound train. The time assembly ends is the time the yard job calls the bowl tower when they are done building the train and are looking for something to do next.

The outbound inspection process is defined in the same manner as the inbound inspection process, starting and ending with the flagging and unflagging of the tracks. The ten minute fixed time from the flagging process is not included in the cars per minute calculations, as it would skew the data. When the train has finished the outbound inspection process, it is declared departure ready. After completion of the outbound train inspection and before the train leaves the yard, however, there is a three minute set and release process (brake test) that is conducted. This was performed on all departing trains and was a constant three minutes for the study period. Therefore, it is not included in any of the control charts presented below.

Lastly, the scheduled departure time is the time listed in the time tables for the railroad for that particular train, while the actual departure time is when the wheels on the departing train begin to turn.

5.2 Time to assemble train

The train assembly process involves pulling blocks of cars from the bowl tracks and placing them on the departure track. Generally, the engines must couple the cars waiting on the bowl tracks before pulling them, as cars rolling over the hump do not always make it to the end of the classification track. Proper throat coordination is important as two trim engines using the same pull out leads could cause unnecessary delays to one another. Additionally, coordination may be needed with intermodal or arriving trains as throat tracks may be utilized by these trains. Unnecessary delays here could arise as the intermodal or arriving train may block the trim engine and the train being assembled.

The statistics used in the formulation of the control chart are presented in Figure 5-1.

| | |
|---|---|
| MR bar (average of the series) | 56 minutes |
| X bar (average time for assembly) | 141 |
| Standard Deviation | 62 |
| Upper Control Limit | 288 |
| Test Two (A top) | 239 |
| Test Three and Four (B top) | 190 |
| Lower Control Limit | 0 |
| Test Two (A bottom) | 42 |
| Test Three and Four (B bottom) | 91 |

Figure 5-1: Summary statistics for the assembly process.

From the control chart, out of control points will be identified. Out of control points on the top half of the control chart will highlight the factors that caused the assembly process to be longer than normal, while points on the bottom half will illustrate periods of time when the assembly process was proceeding in an orderly manner. Analyses will then be conducted to understand the characteristics of each point.

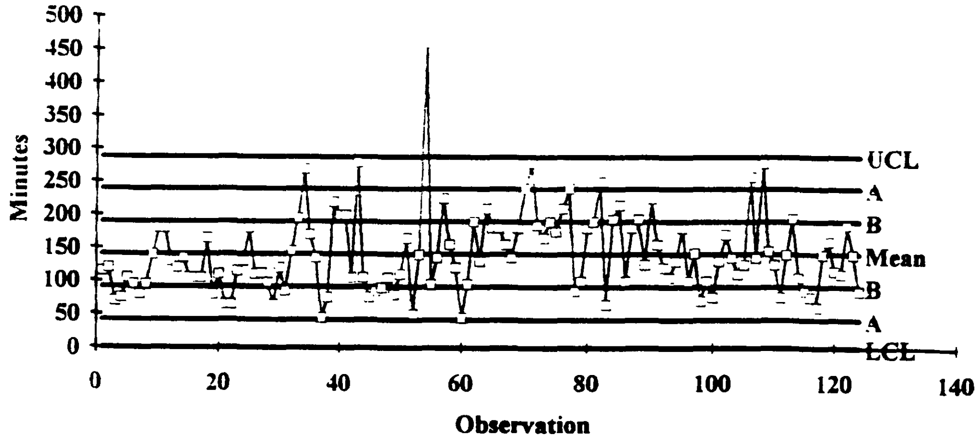


Figure 5-2: Control chart for the assembly process.

5.2.1 Test 1

| Train Id | Time Assembly Start | Time Assembly End | Time |
|---|---|---|---|
| (54) R53318 | 23:35 | 7:15 | 460 minutes |

Figure 5-3: Test 1 out of control point.

Four bowl tracks were pulled in order to make up train R53318, with the car count equal to 120 cars. Although another train assembly used the same throat as the assembly of R53318, it was not the cause of the excessive processing time as the 0715 assembly end time is thought to be a data error.

5.2.2 Test 2

| Train Id | Time Assembly Start | Time Assembly End | Time |
|---|---|---|---|
| (71) R59619 | 0:01 | 4:40 | 279 minutes |
| (108) M71921 | 23:37 | 4:15 | 278 |

Figure 5-4: Test 2 out of control point.

During the time R59619 was being assembled, six other outbound train assemblies occurred. As R59619 was comprised of bowl tracks 21, 4, and 20, the trim engine had to work its way around the bowl. With three other assemblies using the same pullout leads as R59619, there was idle time as R59619 had to occasionally wait for the lead to be free.

Five bowl tracks had to be pulled in order to assemble train M71921. These tracks were 21, 7, 13, 44, and 54, causing the trim engine to work most of the bowl and resulting in some complicated coupling. As five other trains were assembled during this time, and train M71921 was made up of 87 cars, periods of conflict would arise and idle time would occur.

The above two examples illustrate how heavy periods of train assemblies cause longer than average processing times, especially when an outbound train is made up of bowl tracks not next to each other. Better coordination in assigning assembly jobs and better utilization of the bowl (i.e., placing blocks destined for the same outbound train on tracks next to each other) will help alleviate these periods of congestion.

### 5.2.3 Test 3

| Train Id | Time Assembly Start | Time Assembly End | Time |
|---|---|---|---|
| (43) S53417 | 10:00 | 14:40 | 280 minutes |
| (49) R52117 | 21:00 | 22:20 | 80 |
| (85) Q52620 | 19:25 | 23:00 | 215 |

Figure 5-5: Test 3 out of control point.

The assembly for train S53417 began at 1000. At 1020, however, the instructions for the yard crew building S53417 changed. The crew had to assemble R18517 and was not finished until 1120. At that time, the crew resumed assembling S53417 and was finished at 1440. Therefore, the excessive assemble time is due to the crew's orders changing part way into the job.

Train R52117 was made up of three bowl tracks, 48, 49, and 44. As these tracks were adjacent to one another and only one other trim engine was building a train at the time, from tracks 13, 7, and 24, the train was assembled relatively quickly.

Train Q52620 was made up of four bowl tracks: 20, 14, 8, and 17. Another train being assembled at the time was made up of tracks 35, 37, and 47. Therefore, throat conflicts between the two trim engines was not the cause for the excessive assembly time. Instead, as this was the last train assembled by the crew (their shift ended at 2300), the long processing time is thought to be related to the crew quit time.

The above out of control points exhibit three qualities: first, poor planning caused one train assembly to be halted in favor of another. This led to a long period of idle time to a train that was partially made up. It is not known if any train connections were effected by this, but it is possible that cars sitting in the receiving yard were destined for the semi-assembled train, yet had to be sent to other bowl tracks as a result of tracks 12, 15, 10, and 9 being locked out (as the assembly process had begun). Secondly, the assembly process moves faster when the outbound train is made up of tracks adjacent to one another. And thirdly, only one new train assembly start out of a crew could be expected in the last four hours of their shift. Only six times (out of 64 possibilities) did a crew begin assembling two different trains in the last four hours of their shift.

5.2.4 Test 4

| Train Id | Time Assembly Start | Time Assembly End | Time |
|---|---|---|---|
| (8) R53316 | 21:05 | 22:40 | 95 minutes |
| (9) R59616 | 0:10 | 2:30 | 140 |
| (76) Q67619 | 8:00 | 11:30 | 210 |
| (77) R68519 | 7:30 | 11:30 | 240 |

Figure 5-6: Test 4 out of control point.

Train R53316 was assembled at the end of the second shift and was made up of three bowl tracks: 28, 30, and 40. It was eighth train in a row to be assembled in a swift manner. This was partially a result of staggered train assembly start times. Staggering the assembly start times would allow one train to couple its traffic while the other trim engine utilized the throat. Also, the outbound trains being assembled were not very long, resulting in smaller coupling times. Likewise, train R59616 was only made up of 25 cars. Although there were four bowl tracks to be pulled, they were close to one another (21, 8, 9, and 13) and no other trim engines were using throat three in their train assemblies.

Train Q67619 was made up of bowl tracks 28, 25, 20, and 28 (separate blocks) and the trim engine utilized throat four during the construction of the train. Two other large assemblies occurred during this time period, including R68519. R68519 was comprised of bowl tracks 49, 43, 45, 44, and 36. The other train was made up of tracks 10, 13 , 18, and 22. Therefore, the heavy activity in the bowl contributed to the excessive assembly times faced by these train makeups.

These four out of control points highlight the differences between a couple of short trains and three long trains being assembled at a time. The switch engines assembling the short trains are able to maneuver the yard more efficiently while those assembling the long trains tie up the pull leads when going from track to track.

5.3 Idle time from those done assembling to start of outbound inspection

The data for this process was organized sequentially according to assembly complete times. The control chart was constructed using the information in Figure 5-7.

| | |
|---|---|
| MR bar (average of the series) | 86 minutes |
| X bar (average idle time) | 94 |
| Standard Deviation | 88 |
| Upper Control Limit | 322 |
| Test Two (A top) | 246 |
| Test Three and Four (B top) | 170 |
| Lower Control Limit | 0 |
| Test Two (A bottom) | 0 |
| Test Three and Four (B bottom) | 18 |

Figure 5-7: Summary of statistics for the idle time between train inspection ready and inspection start.

As in the inbound inspection case, out of control points on the top and bottom halves of the control chart will offer different insight into the yard operations. The top of this graph will highlight times in the yard when trains were experiencing long idle times between inspection ready and start of inspection. The bottom half, on the other hand, will illustrate periods of time when trains were being inspected in an orderly and relatively swift manner.

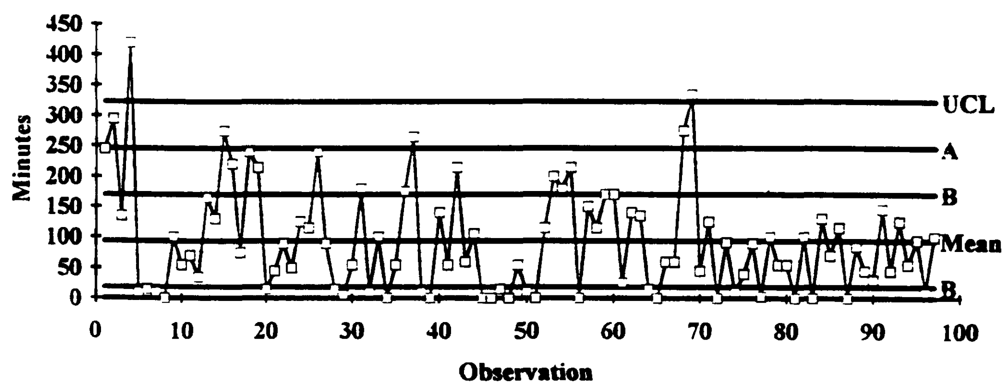


Figure 5-8: Control chart for those done assembling to start of inspection.

5.3.1 Test 1

Figure 5-9 presents the data points which were labelled out of control for Test 1, as defined in Chapter 3. Following the figure is an analysis of why each point occurred.

| Train Id | Time Assembly End | Time Inspection Start | Idle Time |
|---|---|---|---|
| (4) R53316 | 22:40 | 5:40 | 420 minutes |
| (69) M78619 | 13:15 | 18:50 | 335 |

Figure 5-9: Test 1 out of control point.

Train R53316 was on the departure tracks awaiting inspection at 2240. At the time it was fifth in the inspection queue, yet was inspected seventh. Therefore, while some idle time can be attributed to the inspection sequencing, a majority of the time is due to the inspection queue. The queue built up as five trains were assembled from 2020-2240. As the outbound inspection data for this time window is unavailable, it is not known how many trains were inspected. There were three trains, however, already on the departure tracks at 2020. As the connections for this train are unavailable, it is not known how the long idle time effected the connection performance for R53316.

M78619 entered the inspection queue second and was inspected second. The long idle time was due to the fact that no inspections occurred from 1500-1630, while only one was started before 1850. Connections for M trains are not available.

These two examples illustrate that causes for the idle time waiting for the outbound inspection are similar to those in the inbound inspection process. The first out of control data point was caused by the inspection queue and inspection sequencing, while the second point was caused by the inbound inspection inactivity. As the train connections for these two departures were unavailable, a connection analysis could not be performed.

5.3.2 Test 2

This test produced no out of control points for this particular process.

### 5.3.3 Test 3

| Train Id | Time Assembly End | Time Inspection Start | Idle Time |
|---|---|---|---|
| (8) R53416 | 6:30 | 6:30 | 0 minutes |
| (19) Q52617 | 17:40 | 21:15 | 215 |
| (48) R53318 | 7:15 | 7:15 | 0 |

Figure 5-10: Test 3 out of control point.

Train R53416 entered the inspection queue third, but was inspected first. A second cut for this train was then inspected immediately after it, and the train departed at 1057, or three minutes early. The train started assembly at 0430, 115 minutes after its connections were in the bowl. Therefore, the short idle time could be attributed to the fact that the yardmaster wanted to both depart the train on time and hold train makeup until its connections were in the bowl.

After Q52617 was assembled, it entered the inspection needed queue second. As Q52617 was inspected fourth, the excessive idle time was caused by the inspection sequencing. The outbound connection from inbound train Q53615 was missed. Q53615, humped and in the bowl at 2015, had an hump ready idle time of 270 minutes. As the hump was free for 80 of those minutes, some coordination and communication between the hump tower and the trim end of the yard could have resulted in this connection being met.

R53318 had an excessive assembly time (see 5.2.1), which contributed to the zero idle time between inspection ready and inspection start. As the train was scheduled to leave at 0900, it had to be inspected quickly (it entered the queue second and was inspected first) for it to leave on time (it departed at 0915).

This test for out of control points highlights the effects of inspection sequencing. Inspection sequencing decisions can lead to short idle times, as is the case with R53416 and R53318, or to excessive ones, like Q52617. If a train is not going to be inspected until a period of time after it is assembled, then the assembly of that train should be delayed so that the yard resources may be utilized in a more efficient manner.

### 5.3.4 Test 4

This test also produced no out of control points for this process.

The main causes leading to out of control data points on the above control charts are inspection queues and sequencing decisions. Unlike the build up of the inbound inspection queues. the outbound inspection queues can be controlled by the yardmaster. In the receiving yard. the queues. in part. are effected by the arriving train schedules, something not controlled by the yard. In the departure yard. however. decisions of when to assemble trains directly effect the build up of the queue. as does the number of car inspection crews working a particular shift. Proper scheduling of these two events will reduce this idle time.

## 5.4 Outbound inspection

Like the inbound inspection process, the outbound inspection process was monitored using the cars inspected per minute per inspector variable. Comparisons of Figure 3-9 and 5-11 show that X bar is similar in both cases (0.40 for the inbound process and 0.41 for the outbound). While this is somewhat surprising as the inbound inspectors tend to fix more bad ordered cars than the outbound inspectors, it does show that the inspection process (inbound and outbound) is in control and that methods to make the process faster should be undertaken.

| | |
|---|---|
| MR bar (average of the series) | 0.11 cars per inspector per minute |
| X bar (cars inspected per minute per inspector) | 0.41 |
| Standard Deviation | 0.11 |
| Upper Control Limit | 0.69 |
| Test Two (A top) | 0.60 |
| Test Three and Four (B top) | 0.50 |
| Lower Control Limit | 0.13 |
| Test Two (A bottom) | 0.22 |
| Test Three and Four (B bottom) | 0.32 |

Figure 5-11: Summary statistics for outbound inspections.

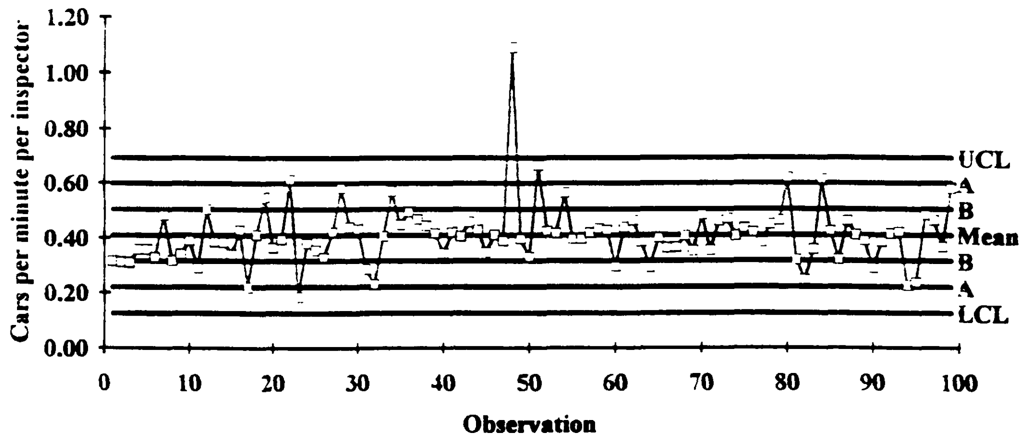


Figure 5-12: Control chart for the outbound inspection process.

5.4.1 Test 1

| Train Id | Time to inspect train | # cars | # inspectors | Cars per inspector per minute |
|---|---|---|---|---|
| (48) R53318 | 55 minutes | 120 | 2 | 1.09 |

Figure 5-13: Test 1 out of control point.

This train was inspected quickly as it had a departure time of 0900. The train had an excessive assembly time, and was an out of control point in the two previous sections.

5.4.2 Tests 2, 3, and 4

These tests produced no out of control points for this process.

As in the inbound inspection case, the outbound inspection process is (almost) in a complete state of control, as it had only one out of control point. Therefore, the next step in improving this process would be to reduce the average time of 118 minutes needed to inspect outbound trains.

5.5 Idle time from outbound inspection complete until actual train departure

This section examines the idle time spent by trains ready to depart until they actually depart. The out of control points present in this section will highlight the causes of outbound train delay. The statistics used in construction of the control chart are presented in Figure 5-14.

| | |
|---|---|
| MR bar (average of the series) | 141 minutes |
| X bar (average idle time) | 207 |
| Standard Deviation | 135 |
| Upper Control Limit | 581 |
| Test Two (A top) | 456 |
| Test Three and Four (B top) | 331 |
| Lower Control Limit | 0 |
| Test Two (A bottom) | 0 |
| Test Three and Four (B bottom) | 82 |

Figure 5-14: Summary statistics for the idle time between train depart ready and train depart.

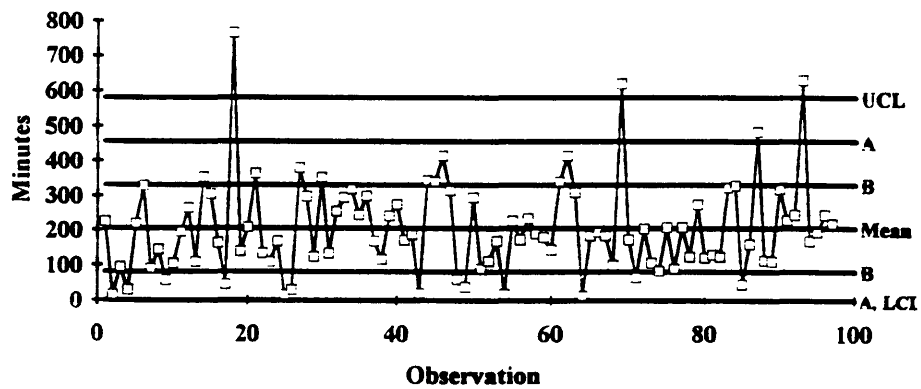


Figure 5-15: Control chart for the idle time between train depart ready and train depart.

5.5.1 Test 1

| Train Id | Time Inspection End | Train Departure Time | Idle Time |
|---|---|---|---|
| (18) R67416 | 20:15 | 9:00 | 765 minutes |
| (67) M78619 | 20:35 | 6:55 | 620 |
| (91) R67421 | 19:55 | 6:25 | 630 |

Figure 5-16: Test 1 out of control point.

R67416 was finished with assembly at 1430, inspection at 2015, and departed at 0900. Therefore, it sat in the departure yard for 18 1/2 hours. Since it had a scheduled departure time of 0130, 450 of 765 idle minutes are attributable to the late departure. This late departure was a result of the engines arriving late off of inbound train R57316, which arrived at 0705, an hour and five minutes late (the engines were not serviced but pulled right to the departure yard). Therefore, waiting for power accounted for this delay.

M78619, with a scheduled departure of 0300, left the yard at 0655. Therefore, 235 of the 620 minutes are attributable to the late departure time. The engines for this outbound train left the service area at 0415, yet were not coupled to the train until 0600. They left the service at 0415 even though the last engine had completed being serviced at 0300 and the pit knew the outbound train assignment for the engines at 0005. Therefore, the late train departure is due to the engines leaving the service area late and not being coupled to the outbound train until 0600.

Likewise, R67421 had a scheduled departure time of 0130, but departed almost five hours late (at 0625). The engines for train R67421 were ready for departure at 0255 and left the pit area at 0330. As no couple times are available for this outbound train, the only conclusion drawn is that the engines being serviced late caused the late departure.

The above three points all had actual departure times that were over three and a half hours past the scheduled time, with power not available a major contributor. An analysis of the connection performance of these trains upon arriving at the next terminal would be beneficial so as to determine the effects of late departures on downstream connections.

5.5.2 Tests 2, 3, and 4

These tests produced no out of control points for this process.

An additional test performed in order to help monitor the idle time between train depart ready and actual train departure was to chart the difference between the scheduled and actual train departure times. A control chart of this nature illustrates how much of the idle time in the departure yard is due to trains deviating from schedule by departing early or late. As mentioned previously, schedule adherence is important for not only the terminating yard (train arrivals), but for the originating yard (train departures) as well. With estimated times of arrival (ETA's) at a downstream terminal partly based on the time a train leaves the previous terminal, it is important that trains leave the yard on time. Lack of accurate train schedules hurts any yard operation scheduling a yardmaster may have done.

Additionally, this type of chart highlights times in the yard when power available is the reason for late departures. If this problem is cyclical, it will show up on the chart. Likewise, if some outbound trains are always waiting for certain inbound connections, then trip planning and scheduling needs to be examined. Adequate power for outbound trains, however, depends on having timely and accurate tonnage estimates for the departing trains. This can be done with a more predictable, and reliable, yard. If the power required on an outbound train is underestimated, initial terminal delay or on line of road delay can occur, while overestimating power needed will waste resources. Therefore, an accurate schedule of yard operation events that will occur over the next 8-10 hours will aid in the forecasting of outbound train tonnage and, therefore, power requirements.

A chart listing the causes for outbound train delay that occurred during this study period was made and is presented in the below figure. Of the 124 train departures occurring in the study period, 46 of them left late (37%). The numbers below do not add to 46 as some outbound trains had more than one source of delay while others have unknown causes for delay.

| Cause of departure delay | Number of occurrences | Average delay |
|---|---|---|
| 1. Engines late off pit/arriving at yard | 8 | 216 minutes |
| 2. Engine trouble | 8 | 184 |
| 3. Late on call figure | 7 | 161 |
| 4. Mechanical (cars) | 6 | 101 |
| 5. Train held for connection | 4 | 78 |
| 6. Train called on crew's rest | 4 | 89 |
| 7. Train blocked by other departure/arrival | 3 | 45 |
| 8. Engines headed in wrong direction | 3 | 62 |
| 9. Hotel van late in picking up crews | 2 | - |
| 10. Train underpowered | 1 | - |
| 11. EOT problem | 1 | 131 |
| 12. Train not blocked properly (long/short car combination) | 1 | - |
| 13. Inspection late | 1 | - |

Figure 5-17: Causality analysis for trains not departing on time.

In the above figure, some categories do not have average delay times as their trains (i.e., second section, or extra, trains) did not have a scheduled departure time. Although the trains did not have a scheduled departure time, they were recorded as being delayed in leaving the yard due to the listed cause. The engine troubles category included: sander not functioning correctly, defective speed recorder, headlights not working, toilet smelled, engine would not stay running, and change of engine. Mechanical included bad ordered cars that were switched out and shopped. Eliminating the causes found on the above list will aid in departing trains in a reliable manner, which, in turn, will aid in the connection performance of terminals downstream.

Lastly, a control chart could be constructed for the time between when the assembly process started and the scheduled departure of that train. This chart would highlight the time differences between the two, as train assemblies occurring far in advance of their scheduled departure contribute to cars missing their appropriate connections and account for the excessive idle times present in the departure end of the yard. The scheduled departure time is used over the actual departure time as delays to outbound trains are not known until the hours, or minutes, immediately preceding the scheduled departure. Consequently, assembly schedules are made assuming that all trains are leaving the yard on time.

As an example, the building of an outbound train (the assembly process) could start at a time equivalent to:

Average time to assemble a train + 2 * average inspection time for a train

Therefore, if trains are being inspected when the newly assembled train is inspection ready, the train would have some built in buffer time to allow for it to be inspected next and still make its scheduled departure time. For example, the above formula for this yard would result in a time of 6 hours and 17 minutes. If all trains were built within seven hours of their scheduled departure (to allow for some additional buffer time), instead of the average of 9 hours and 8 minutes (see Figure 5-18), 27% (14/51) of the missed connections listed in Chapter 6 would not have occurred. This type of analysis suggests that train make up should not be started any earlier than a preset time limit (i.e., hours before scheduled departure), with the time limit based on the average times of the processes involved in getting a train departure ready. Adherence to this type of time limit will improve train connection performance.

| | |
|---|---|
| Mean time assembly started before scheduled departure time | 548 minutes |
| Standard Deviation | 165 |

Figure 5-18: Statistics for time between train assembly start and scheduled train departure.

## 5.6 Summary

As was the case in the pre-classification process, the inspection process within the preparation for train departure process is in control while the other processes are not. Train assemblies and train idle times are often excessive and need to be controlled, as long inspection needed queues and late train departures are two items leading to the unpredictability of the departure yard.

An argument for communication between the hump and trim ends of the yard was also made. Another example highlighting the lack of communication between the two resulting in a missed connection is found in the connection from inbound train R22916 to outbound train Q52619. Train R22916 completed humping at 1650, while the assembly for train Q52619 began at 1630, 11 1/2 hours before its scheduled departure. As a result R22916 missed its connection to Q52619 by 20 minutes (hump done - assembly start). With any communication between the two ends of the yard, the departure yard could have delayed building the train in favor of getting more connections.

The following figures summarize the causes for the out of control points presented in this chapter.

| Reason for out of control point (excessive process time) | Number of occurrences |
|---|---|
| 1. Periods of heavy train assemblies | 4 |
| 2. Outbound train waiting for power | 3 |
| 3. Inspection sequencing | 2 |
| 4. Last train assembled on shift | 1 |
| 5. Inspection queue | 1 |
| 6. Inactivity of inspection crew | 1 |
| 7. Switch engine's crew orders changed | 1 |
| 8. Data error | 1 |

Figure 5-19: Causality analysis for excessive process times in the departure yard.

| Reason for out of control point (short process time) | Number of occurrences |
|---|---|
| 1. Priority in inspection sequencing | 2 |
| 2. Short train assembly | 2 |
| 3. Train needed to depart on time | 1 |
| 4. Bowl tracks being pulled were adjacent to one another | 1 |

Figure 5-20: Causality analysis for short process times in the departure yard.

## VI. Actual Missed Connections

This chapter identifies and analyzes the 51 missed connections (out of 428 scheduled connections) that occurred during the course of the study and offers insight into why each happened. As the connection data for the M and S trains is not available, only the missed connections for the Q and R trains are presented. The analysis of the missed connections led them to being grouped into eight separate categories. The mutually exclusive categories are missed connections due to: out of control points, out of control points with tight connections, out of control points with late arrivals, out of control points with late arrivals and tight connections, tight connections, late arrivals, late arrivals with tight connections, and other reasons.

The "out of control points" category contains train connections in which one of the processes involved in getting a car from the inbound train to the outbound train (i.e., one of the processes presented in Chapters 3, 4, and 5) was out of control. Additionally, the trains making up the connection did not have late arrivals or tight connections associated with them. The out of control process identified for the connection can be on the inbound side, the outbound side, or both.

Tight connections are defined as connections that have scheduled yard times less than the average total process time it takes a car to move through the yard (from train arrival to train departure). The average total process time for this yard is presented in Figure 6-1 and includes all the processes described in previous chapters. Any connection with a scheduled yard time less than 19 hours and 2 minutes (1142 minutes) is, therefore, labelled a tight connection. This does not mean that the connection cannot be met, but that special attention (i.e., priority in sequencing decisions) may be needed in order to meet the scheduled connection. As the idle times in the yard are reduced, this process time will decrease. It should be noted that this yard process time does not include any time that a car may spend sitting in the bowl.

In the Figure 6-1, the inbound inspection mean time was determined from the actual inspections that occurred, as was the outbound inspection time. Therefore, the fixed time of 10 minutes, as well as the variable time dependent on train length (used in determining the cars per minute calculations), is included in the process time. The average hump time is also taken from actual data and is the time it took trains to complete the hump process, as defined in Chapter 4. The total predicted and total actual times are given to illustrate that the individual processes are nearly independent and that the individual process times can be summed together in order to get an average (total) yard process time. The predictions assume that the processes have normal probability distributions. For the processes to be independent, the summation of the variances for each process would produce a number equivalent to the variance of the entire process. As seen in Figure 6-1 the predicted standard deviations (square root of the variance) are within 10% of the actual standard deviations.

Late arrivals are defined as trains that arrive at the yard more than two hours after the scheduled arrival time. The two hours is used as this is the standard reporting measurement for this particular yard. Lastly, the "others" category is a listing of connections that did not have out of control process points, late arrivals, or tight connections. Instead, other factors contributed to these connections being missed. An analysis of why these train connections were missed is also presented.

| Process | Mean Time | Standard Deviation |
|---|---|---|
| Pre-Classification Process | | |
| Idle time: train arrival to start of inspection | 154 minutes | 154 |
| Inbound inspection | 123 | 26 |
| Idle time: train hump ready to hump start | 257 | 142 |
| Hump train | 45 | 16 |
| Total: predicted | 579 | 212 |
| Total: actual (omitting trains uninspected) | 581 | 202 |
| | | |
| Preparation for Train Departure | | |
| Train assembly | 141 | 62 |
| Idle time: assembly done to start of inspection | 94 | 88 |
| Outbound inspection | 118 | 29 |
| Brake test | 3 | 0 |
| Idle time: train ready to train departure | 207 | 135 |
| Total: predicted | 563 | 175 |
| Total: actual (omitting trains uninspected) | 562 | 158 |
| | | |
| Total predicted yard process time | 1142 | 652 |

Figure 6-1: Mean and standard deviation of process times.

From the table, it is determined that 712 of the 1142 minutes (62%) a car spends in the yard is spent sitting idle, including 71% of the time spent in the receiving yard

(411 of the 579 minutes). Elimination of this non-value added process time will improve both the performance and the reliability of the terminal.

### 6.1 Missed connections with out of control process points

This section presents the connections that have out of control processes associated with them. The connections are classified into four groups: out of control points, out of control points with tight connections, out of control points with late arrivals, and out of control points with late arrivals and tight connections. For an in depth analysis into why these data points were out of control refer back to the appropriate chapter.

#### 6.1.1 Out of control points

The connections listed below had neither a late train arrival nor a tight connection, only an out of control process that occurred while classifying the inbound train or building the outbound train.

| Train Connection | Out of Control Process |
|---|---|
| 1. Q52017 to Q53120 | idle time from train arrival to inbound inspection |
| 2. Q52017 to R53320 | idle time from train arrival to inbound inspection |
| 3. Q52017 to R59220 | idle time from train arrival to inbound inspection |
| 4. Q52018 to Q53121 | idle time from train arrival to inbound inspection |
| 5. R55718 to R53320 | idle time from train arrival to inbound inspection |
| 6. R57319 to R67421 | idle time from outbound inspection to train depart |
| 7. R67515 to R59218 | idle time from train arrival to inbound inspection |

Figure 6-2: Missed connections due to out of control processes.

From above, 7 of the 51 missed connections are a result of excessive idle times faced by the inbound or departing train, with six of these as a result of waiting for the inbound inspection. As Q52017, Q52018, and R67515 were all double-overs off the original train, the decisions on outbound train length and where to yard arriving trains are deemed important ones. Trains that are longer than the longest receiving track in the next yard will need to be doubled over upon arrival. In this particular study, doubled over tracks were generally given the lowest priority during inspection and hump sequencing. Therefore, holding a departing train for a connection could be counterproductive if that train becomes so long that it will need to be doubled over at the next terminal. Likewise, yarding a train on a track whose capacity exceeds its necessary space requirements (e.g., a 50 car train onto an 100 car track) is a poor utilization of resources as there may be a

90 car train arriving in a hour that will now have to be yarded on two tracks of 60 car train lengths.

### 6.1.2 Out of control points with tight connections

The connections listed below not only had an out of control process in classifying the inbound train or building the outbound train, but also had a tight connection associated with it.

| Train Connection | Out of Control Process | Scheduled Yard Time |
|---|---|---|
| 1. Q53615 to Q52617 | time idle: assemble end to inspection | 17:00 hours |
| 2. Q53619 to R67421 | time idle: inspection end to depart | 14:30 |
| 3. R53017 to R68517 | time idle: train arrival to inspection | 6:00 |
| 4. R53018 to R68518 | time idle: train arrival to inspection | 6:00 |
| 5. R53019 to R68519 | time idle: train arrival to inspection and outbound train assembly | 6:00 |
| 6. R53021 to R68521 | inbound inspection | 6:00 |
| 7. R55718 to R52120 | time idle: train arrival to inspection | 18:45 |
| 8. R57318 to R68519 | outbound train assembly | 13:30 |
| 9. R67515 to Q53118 | time idle: train arrival to inspection | 17:30 |
| 10. R67515 to Q53518 | time idle: train arrival to inspection | 13:45 |

Figure 6-3: Missed connections due to out of control processes coupled with tight connections.

Although long idle and process times in a yard at any time are not desirable, it is especially important to keep these times to a minimum when servicing trains with tight connections. If anything, special attention should be given to the trains with tight connections. The above connections represent 20% of the missed connections for the week.

### 6.1.3 Out of control points with late arrivals

The connection from inbound train R67516 to outbound train R59619 had both an excessive assembly time and a 3 hour 50 minute late arrival. The combination of the late arrival of R67516 and the long assembly for R59619 resulted in this connection being missed.

#### 6.1.4 Out of control points with late arrivals and tight connections

The connection from inbound train R53217 to outbound train R53418 experienced the following problems: (1) a 2 1/4 hour late arrival, (2) an excessive hump ready to hump start idle time, and (3) a 15 1/2 hour connection. As mentioned previously, long idle times spent by trains with tight connections are undesirable, especially if the train arrives at the yard late. The late arrival of R53217 reduced the scheduled yard available time to 13 1/4 hours, while the 10 hours and 35 minutes idle time spent by R53217 from hump ready to hump start assured that the connection would be missed.

## 6.2 Analysis of the remaining missed connections

### 6.2.1 Tight connections

The missed connections below had tight connections, as defined earlier.

| Train Connections | Scheduled Yard Time | Train Connections | Scheduled Yard Time |
|---|---|---|---|
| 1. R53016 to R68516 | 6:00 | 12. Q53618 to R67420 | 14:30 |
| 2. R53020 to R68520 | 6:00 | 13. R22913 to Q52616 | 15:00 |
| 3. Q57516 to Q53117 | 7:00 | 14. R22916 to Q52619 | 15:00 |
| 4. Q57520 to Q53121 | 7:00 | 15. R53218 to R53419 | 15:30 |
| 5. R57315 to R68516 | 13:30 | 16. Q53615 to R52117 | 16:00 |
| 6. R57316 to R68517 | 13:30 | 17. Q53616 to R52118 | 16:00 |
| 7. R57319 to R68520 | 13:30 | 18. Q53617 to R52119 | 16:00 |
| 8. R57320 to R68521 | 13:30 | 19. Q59516 to R52118 | 16:00 |
| 9. Q53615 to R67417 | 14:30 | 20. Q53616 to Q52618 | 17:00 |
| 10. Q53616 to R67418 | 14:30 | 21. Q53617 to Q52619 | 17 00 |
| 11. Q53617 to R67419 | 14:30 | 22. R57319 to Q53521 | 18:15 |

Figure 6-4: Missed connections due to tight connections.

In the connection reports for the yard, every connection from the inbound R582 to the outbound R592 trains were listed as missed as each had - 1 1/2 hour connections (the scheduled arrival for the inbound R582 trains are an hour and a half after the scheduled departure of the R592 trains). As this is thought to be a data error (wrong connections listed), an analysis of these connections is not presented.

Realistically, the first four connections listed in Figure 6-4 could not have been met, as the pure processing time (i.e., processing times less the idle time) for the yard is 7 hours and 10 minutes (from Figure 6-1). The other connections could have been met only with special attention provided to them. This could be accomplished if either the inbound train was given priority in the inspection needed and hump ready queues or the outbound trains were assembled closer to their scheduled departure times, or a combination of both. But this would be done at the expense of other connections and might have resulted in a poorer yard performance.

### 6.2.2 Late arrivals

The missed connections below had inbound connections that were a part of a late train arrival.

| Train Connection | Hours arrived late |
|---|---|
| 1. R67516 to R59219 | 3:50 |
| 2. R58217 to R53419 | 10:30 |

Figure 6-5: Missed connections due to late arrival.

These two connections had scheduled yard times greater than 19 hours and faced no out of control processes while moving through the yard. The late arrivals of the trains, however, reduced the available yard time and were the reason the connections were missed.

### 6.2.3 Late arrivals with tight connections

The following missed connections had late inbound train arrivals coupled with tight connections. The late arrivals reduced the scheduled available yard times by at least 30%, resulting in little hope for making the scheduled connection.

| Outbound Train | Hours Arrived Late | Scheduled Yard Time |
|---|---|---|
| 1. R58216 to Q53518 | 5:00 | 16:45 hours |
| 2. R58220 to Q53522 | 5:20 | 16:45 |
| 3. R57314 to Q53516 | 9:55 | 18:15 |
| 4. R58217 to Q53519 | 10:30 | 16:45 |
| 5. R57317 to R68518 | 11:30 | 13:30 |
| 6. R57317 to Q53519 | 11:30 | 18:15 |

Figure 6-6: Missed connections due to trains with late inbound train arrivals coupled with tight outbound connections.

### 6.2.4 Others

The two connections below fell into none of the above categories and were analyzed in order to determine why the connection was missed:

(1) R57319 to Q53121: Train R57319 finished being humped 13 1/2 hours after arrival, assembly began on Q53121 12 1/2 hours before the scheduled departure time, and the scheduled yard time for the connection was 22 hours. Of the 13 1/2 hours spent in the receiving yard, R57319 had an idle time from train arrival to inbound inspection start of 475 minutes. Although this point was not labelled out of control, it was part of an out of control sequence (the next point, train Q52018 (d/o), was labelled out of control). Combined with the three hours of idle time from hump ready to hump start, R57319 sat idle in the receiving yard for nearly 11 hours. As the inspection data for Q53121 is missing, an analysis of the idle time spent in the departure yard by Q53121 is not presented. However, the excessive idle time spent by R57319 in the receiving yard (due to entering both the inspection needed and the hump ready queues fourth) combined with the early begin assemble time for Q53121 is concluded to be the reason for this missed connection.

(2) R53218 to Q55619: The double-over for R53218 finished humping 11 hours 50 minutes after arrival. assembly began on outbound train Q55619 11 hours 50 minutes before scheduled departure time, while the scheduled yard time for this connection was 19 1/2 hours. R53218 spent 590 of its 690 (86%) minutes in the receiving yard sitting idle. Although Q55619 departed only 35 minutes late, it still spent 445 of its 560 (79%) minutes in the departure yard sitting idle, with 310 of these after the train was depart ready. Although none of the processes associated with these two trains are out of control, the summation of the high individual idle times experienced by R53218 and Q55619 led to the missed connection.

## 6.3 Summary

The following figure summarizes the 51 missed connections that occurred during this study period (numbers to not add to 100% due to rounding). The tight connections are categorized into two groups. Group (a) represents the tight connections missed due to a scheduled yard time less than the pure process time. while group (b) is the tight connections missed due to a scheduled yard time less than the average process time (as presented in Figure 6-1).

| Reason for missed connection | Percentage of missed connections |
|---|---|
| 1. Tight connections (total) | 43 |
| a: Connection time < Average process time | 35 |
| b: Connection time < Pure process time | 8 |
| 2. Out of control points with tight connections | 20 |
| 3. Out of control points | 14 |
| 4. Late arrivals with tight connections | 12 |
| 5. Late arrivals | 4 |
| 6. Other | 4 |
| 7. Out of control point with a late arrival | 2 |
| 8. Out of control point with a late arrival and a tight connection | 2 |

Figure 6-7: Summary of missed connections.

From the figure, it is concluded that tight connections are the biggest cause for missed connections, with out of control points being second. Train connections in a yard should be based on the actual process time for that particular yard, not on a system goal. As the process times in that yard become lower, train connection tables can be revised. Likewise, elimination of the out of control points presented previously will result in, at least, 14% more of the train connections being met.

## VII. Summary and Conclusions

### 7.1 Thesis summary

In order to improve rail reliability and, therefore, increase rail profitability, rail terminals need to become more than just a "black box." Train connection standards within terminals need to improve (i.e., a reduction in average yard times) and become more reliable. As studies have placed the probability of an inbound car meeting its appropriate outbound connection anywhere from 70-90% for a given terminal [Martland, Little, Kwon, and Dontula, 1992], cars traveling through three or more terminals have less than a 75% chance of being on the appropriate train upon reaching their final destination. In the world of just in time manufacturing and lean production systems, this unreliability often causes inventory conscious customers to utilize other modes of transportation when shipping their freight.

Using the need for increased terminal reliability as an underlying theme, this thesis, and the research presented within, has accomplished the following:

1. It has detailed the operations involved in taking a car off of an inbound train and placing it on its outbound connection. Before improving a particular process, a thorough understanding of that process is needed. A possible reason for bad yard performance is that terminals are poorly understood. Understanding the complexity of terminal operations is necessary before any "fool proof" methods for improving the yards can be invoked. Otherwise, improving one area of the terminal may actually hurt yard performance as it was done at the expense of a different process.

2. A methodology to pinpoint causes of poor performance within a yard was presented. This methodology utilizes a manufacturing quality control technique known as statistical process control (SPC). SPC charts the individual yard process times on a graph and utilizes the mean and an approximation for the standard deviation of each process in order to highlight out of control points. The out of control points identify periods of time in which the yard was running efficiently, as well as times when there were excessive processing times. The points are associated with the processing times of one of the processes necessary in moving a car through the yard. A Pareto analysis was then performed to get to the root cause of each out of control point as understanding the reasons for excessive, as well as efficient, process times will aid in improving yard performance.

Eight "correctable" processes were monitored. A correctable process means that the yard master has the ability to make changes in yard operations that will aid in improving the yard performance. The eight processes are: idle time from arrival to start of inbound inspection, inbound inspection time, idle time from train hump ready to hump start, hump utilization, outbound train assembly time, idle time from train done assembly to outbound inspection start, outbound inspection time, and idle time from train depart ready to train depart.

3. After highlighting the yard processes that contribute to the unreliability of train connections, an analysis on why each missed train connection occurred was performed. This assigned the appropriate cause to each missed connection. The missed connections were then placed in to one of the following eight groups: missed connections due to out of control points, out of control points with tight connections, out of control points with late arrivals, out of control points with late arrivals and tight connections, late arrivals, tight connections, late arrivals with tight connections, or other reasons.

## 7.2 Results

The research presented in this thesis was performed using data gathered from Radnor Yard. Radnor Yard, located in Nashville, Tennessee, is a major hump yard on the CSX system. As part of improving their service reliability in the Nashville-Chicago corridor, CSX spent considerable time and resources collecting data from Radnor, data which is used in this research. The data was collected during the week of September 15-21, 1993. The following subsections are summaries of the major results generated by the research presented in this thesis.

### 7.2.1 Yard process times

The average total process time for this yard is presented in Figure 7-1 and includes all the processes described in previous chapters. The total predicted and total actual times are given to illustrate that the individual processes are nearly independent and that the individual process times can be summed together in order to get an average (total) yard process time. The predictions assume that the processes have normal probability distributions. For the processes to be independent, the summation of the variances for each process would produce a number equivalent to the variance of the entire process. As seen in Figure 7-1 the predicted standard deviations (square root of the variance) are within 10% of the actual standard deviations. The notion of independence among individual yard processes is important as formulas for predicting yard performance, such as the process PMAKE approach developed by Tykulsker, can then be used.

From the table, it is determined that 712 of the 1142 minutes (62%) a car spends in Radnor yard is spent sitting idle, including 71% of the time spent in the receiving yard (411 of the 579 minutes).

| Process | Mean Time | Standard Deviation |
|---|---|---|
| Pre-Classification Process | | |
| Idle time: train arrival to start of inspection | 154 minutes | 154 |
| Inbound inspection | 123 | 26 |
| Idle time: train hump ready to hump start | 257 | 142 |
| Hump train | 45 | 16 |
| Total: predicted | 579 | 212 |
| Total: actual (omitting trains uninspected) | 581 | 202 |
| | | |
| Preparation for Train Departure | | |
| Train assembly | 141 | 62 |
| Idle time: assembly done to start of inspection | 94 | 88 |
| Outbound inspection | 118 | 29 |
| Brake test | 3 | 0 |
| Idle time: train ready to train departure | 207 | 135 |
| Total: predicted | 563 | 175 |
| Total: actual (omitting trains uninspected) | 562 | 158 |
| | | |
| Total predicted yard process time | 1142 | 652 |

Figure 7-1: Mean and standard deviation of process times.

### 7.2.2 The receiving yard

From the control charts associated with the processes involved in yarding a train and making it hump ready (see Chapter 3), one can conclude that the inbound inspection process time is almost in complete control, while the idle times spent by incoming trains in the receiving yard are enormous and vary widely. Additionally, long queues of trains waiting for inbound inspection developed during the end of the third shift/beginning of first shift as more trains arrived than were being inspected. This was due to either bunched train arrivals or inspector inactivity, or a combination of both.

Lastly, the long idle times from hump ready until hump start experienced by trains were mainly a result of (1) hump inactivity and (2) hump sequencing decisions. The periods of inactivity at the hump resulted in a queue build up of hump ready cars on the receiving tracks. while deviations from the first in-first out (FIFO) principle generally adhered to at the yard also led to longer idle times. The following figures summarize the causes for delay and the causes for efficient process times in the pre-classification process.

| Reason for out of control point (delay) | Number of occurrences |
|---|---|
| 1. Inspection queue | 6 |
| 2. Hump queue | 4 |
| 3. Hump sequencing | 4 |
| 4. Inspection sequencing | 3 |
| 5. Early arrival | 2 |
| 6. Slow inspection | 1 |
| 7. Placement of double-overs | 1 |
| 8. Inspected twice | 1 |

Figure 7-2: Delay causality analysis for the receiving yard.

| Reason for out of control point (efficient) | Number of occurrences |
|---|---|
| 1. Yard caught up in work | 7 |
| 2. Fast inspection | 1 |

Figure 7-3: Efficient causality analysis for the receiving yard.

Out of the 114 inbound trains analyzed, 85 were in control (i.e., no out of control processes associated with them). Of the 29 trains that were out of control (one train was out of control in two different processes), 8 were due to fast, or efficient, yard times while 21 were due to slow yard process times. These 21 out of control points had 12 missed connections, or 24% of the week's total. Although all of the missed connections are not entirely attributable to these out of control points, enough of them are to warrant the needed improvements in the pre-classification process.

### 7.2.3 Hump utilization

The utilization of the hump is a key ingredient in cars making their scheduled connections. When the hump is idle, hump ready queues build up in the receiving yard. These queues not only effect train connection performance, but also effect the decisions made by yardmasters on where to place an arriving train. For example, a yardmaster may have a hi-rail truck he would like to use for light repairs on bad ordered cars found during the inbound inspection. If this is the case, trains are, ideally, yarded on every other receiving track. If these tracks are full of trains waiting to be humped, then the hi-rail truck cannot be effectively used. Also, the hump ready queue may cause the "long" receiving tracks to be full, forcing 100 car trains to be doubled over. These double-over cars may be placed on tracks with hump ready cars, causing unnecessary delays to those hump ready cars. The figures below list the causes for the excessive and short hump idle times identified in Chapter 4.

| Reason for out of control point (long hump idle time) | Number of occurrences |
|---|---|
| 1. Hump idle during shift with two crews working | 2 |
| 2. Hump idle from end of one shift to start of next shift | 2 |
| 3. Hump idle during shift with one crew working | 1 |

Figure 7-4: Causality analysis for long hump idle times.

| Reason for out of control point (short hump idle time) | Number of occurrences |
|---|---|
| 1. Two crews working in tandem during shift | 5 |

Figure 7-5: Causality analysis for short hump idle times.

In Figure 7-6, the difference in productivity between two crew shifts and one crew shifts is highlighted, as two crews working in tandem were the cause for the out of control points associated with short hump idle times.

| Number of hump crews | Average time between jobs | Average length of job |
|---|---|---|
| 1 | 54 minutes | 43 minutes |
| 2 | 21 | 45 |

Figure 7-6: Difference in hump utilization between one and two crews.

### 7.2.4 The departure yard

As was the case in the pre-classification process, the inspection process within the preparation for train departure process is in control while the other processes are not. Train assemblies and train idle times are often excessive and need to be controlled, as long inspection needed queues and late train departures are two items leading to the unpredictability of the departure yard.

| Reason for out of control point (excessive process time) | Number of occurrences |
|---|---|
| 1. Periods of heavy train assemblies | 4 |
| 2. Outbound train waiting for power | 3 |
| 3. Inspection sequencing | 2 |
| 4. Last train assembled on shift | 1 |
| 5. Inspection queue | 1 |
| 6. Inactivity of inspection crew | 1 |
| 7. Switch engine's crew orders changed | 1 |
| 8. Data error | 1 |

Figure 7-7: Causality analysis for excessive process times in the departure yard.

| Reason for out of control point (short process time) | Number of occurrences |
|---|---|
| 1. Priority in inspection sequencing | 2 |
| 2. Short train assembly | 2 |
| 3. Train needed to depart on time | 1 |
| 4. Bowl tracks being pulled were adjacent to one another | 1 |

Figure 7-8: Causality analysis for short process times in the departure yard.

An additional test performed in order to help monitor the idle time between train depart ready and actual train departure was to chart the difference between the scheduled and actual train departure times. This chart illustrated how much of the idle time in the departure yard was due to trains deviating from schedule by departing early or late.

Additionally, this type of chart highlights times in the yard when power available is the reason for a late departure. If this problem is cyclical, it will show up on the chart. Adequate power for outbound trains, however, also depends on having timely and accurate tonnage estimates for the departing trains. This can be done with a more predictable, and reliable, yard. If the power required on an outbound train is underestimated, initial terminal delay or on line of road delay can occur, while overestimating power needed will waste resources. Likewise, if some outbound trains are always waiting for certain inbound connections, then trip planning and scheduling needs to be examined.

A chart listing the causes for outbound train delay that occurred during this study period was made and is presented in the below figure. Of the 124 train departures occurring in the study period, 46 of them left late (37%). The numbers below do not add to 46 as some outbound trains had more than one source of delay while others have unknown causes for delay.

| Cause of departure delay | Number of occurrences | Average delay |
|---|---|---|
| 1. Engines late off pit/arriving at yard | 8 | 216 minutes |
| 2. Engine trouble | 8 | 184 |
| 3. Late on call figure | 7 | 161 |
| 4. Mechanical (cars) | 6 | 101 |
| 5. Train held for connection | 4 | 78 |
| 6. Train called on crew's rest | 4 | 89 |
| 7. Train blocked by other train departure/arrival | 3 | 45 |
| 8. Engines headed in wrong direction | 3 | 62 |
| 9. Hotel van late in picking up crews | 2 | - |
| 10. Train underpowered | 1 | - |
| 11. EOT problem | 1 | 131 |
| 12. Train not blocked properly (long/short car combination) | 1 | - |
| 13. Inspection late | 1 | - |

Figure 7-9: Causality analysis for trains not departing on time.

In the above figure, some categories do not have average delay times as their trains (i.e., second section, or extra, trains) did not have a scheduled departure time. Although the trains did not have a scheduled departure time, they were recorded as being delayed in leaving the yard due to the listed cause. The engine troubles category included: sander not functioning correctly, defective speed recorder, headlights not working, toilet smelled, engine would not stay running, and change of engine. Mechanical included bad ordered cars that were switched out and shopped.

### 7.2.5 Actual missed connections

The following figure summarizes the 51 missed connections (out of 428 possible) that occurred during this study period (numbers to not add to 100% due to rounding). The tight connections are categorized into two groups. Group (a) represents the tight connections missed due to a scheduled yard time less than the pure process time, while group (b) is the tight connections missed due to a scheduled yard time less than the average process time (as presented in Figure 7-1).

| Reason for missed connection | Percentage of missed connections |
|---|---|
| 1. Tight connections (total) | 43 |
| a: Connection time < Average process time | 35 |
| b: Connection time < Pure process time | 8 |
| 2. Out of control points with tight connections | 20 |
| 3. Out of control points | 14 |
| 4. Late arrivals with tight connections | 12 |
| 5. Late arrivals | 4 |
| 6. Other | 4 |
| 7. Out of control point with a late arrival | 2 |
| 8. Out of control point with a late arrival and a tight connection | 2 |

Figure 7-10: Summary of missed connections.

### 7.2.6 Summary

The following table presents the number of out of control points that occurred during the study period. The number of trains that arrived and were analyzed in the receiving yard is given. Next, the number of out of control points that were identified (due to both long and short process times) with these trains is listed. Finally, the number of missed connections associated with the out of control points is also presented. These out of control points, however, may not be solely responsible for the missed connection. For a discussion of the reasons train connections were missed, please refer back to Chapter 6. Similarly, the departure yard is also listed in the figure.

| Yard location | # of trains | # of out of control points | | # of missed connections |
|---|---|---|---|---|
| | | delay | efficient | |
| Receiving Yard | 114 | 21 | 8 | 12 |
| Departure Yard | 102 | 14 | 6 | 6 |

Figure 7-11: Summary of trains with out of control points.

## 7.3 Conclusions

The major conclusions from this research are presented below. They are characterized into two groups: General and Radnor Yard. The general conclusions are methodology conclusions that can be applied industry wide. With each general conclusion, an example from the results generated in the Radnor study is given. The Radnor Yard conclusions, however, are specific conclusions as related to Radnor Yard and are derived from the research conducted in this thesis.

### 7.3.1 General conclusions

1. SPC offers insight into the causes of poor terminal performance and can be effectively used in the railroad industry for terminal analyses. Construction of the appropriate control charts are useful in performing terminal causality analyses that are as thorough as previous line performance studies.

> Example: As some of the out of control points in the receiving yard were a result of the hump idle time caused by one shift ending and another starting, the effects of staggering hump crew starts should be examined. Instead of having both hump crews report to work at 0700, have one report at 0600 and the other at 0700.

2. Processing capabilities of the yard can be defined from the results of an SPC analysis. Rather than simply give the average yard time for a car, an SPC analysis will give the mean and standard deviations of each individual process faced by a car when going through a particular yard. From here, industrial engineering techniques can be used to determine the maximum processing capabilities of the yard.

> Example: Determining the hump capacity of Radnor Yard. From Figure 7-6, the hump utilization of one hump crew shifts is 44% (43 of 97 minutes), while two crew shifts utilize the hump 68% of the time. Over the entire course of the study, when the hump was utilized an average of 1.96 cars per minute were humped. Using these numbers, the hump capacity for Radnor Yard is 1,242 for strictly one crew shifts on the hump (44% * 24 hours * 60 minutes * 1.96 cars per minute), and 1,919 for strictly two crew hump shifts. Therefore, one of three things must happen for Radnor to increase the hump capacity: use two hump crews around the clock, decrease the average time between hump jobs (i.e., increase the hump utilization percentage), or increase the average number of cars humped per minute (i.e., speed of cars rolling down the hill).

3. SPC is useful in monitoring freight terminal performance. Achieving a state of control for each yard process through the use of SPC will have three advantages. First, a controlled state will give more predictable outcomes. Secondly, methods to tighten the control limits can be invoked. Tighter control limits will improve reliability as there will be less variability associated with that particular process. And, lastly, operational changes that lead to reductions in individual mean process times can be applied. Lower average mean times for each process will lead to lower average yard times.

> Example: 77% of the missed connections at Radnor Yard were due to tight connections, out of control points, or a combination of the two. These variables are all related to excessive process times, times which can be controlled with SPC.

### 7.3.2 Radnor Yard conclusions

1. The control charts formulated in this thesis showed that both the inbound and outbound inspection process were in control. This being the case, methods to reduce the long inspection processing times need to be undertaken.

2. The long idle times experienced by the trains in the receiving yard led to missed connections, while the variability in processing time from train to train contributed to the unreliability of the yard.

3. As the queue for inbound inspections was a problem during the entire study period, train schedules should be closely looked at, as well as the starting and ending times of shifts. It does not make sense to have a lot of trains arrive in a two hour window every morning, as this contributes to the build up of queues. Likewise, starting

the first shift at 0600 instead of 0800 could aid in reducing queue build up as the maximum number of inspections possible in a day would increase.

4. Outbound train assemblies need to be performed in a set manner. They should occur at a predescribed time before the scheduled departure of the train. With the start of assembly for an outbound train known in advance. efforts to classify trains sitting in the receiving yard with a large number of connections to that outbound train can be made. As an example, if all trains were built within seven hours of their scheduled departure, instead of the average of 9 hours and 8 minutes (see Figure 5-18), 27% (14/51) of the missed connections listed in Figure 7-11 would not have occurred.

5. Outbound train assemblies need to be coordinated. Train assemblies in which the outbound trains being built had blocks on bowl tracks close to other outbound train's blocks caused assembly times to be greater than average (e.g., tracks 9, 10, and 15 for one outbound train and 7, 11, and 18 for another). Times, however, in which bowl tracks being pulled for the outbound trains were at different locations in the bowl (e.g., 9, 10, 15 and 34, 37, 40) allowed for quicker assembly times.

6. Engines were the biggest reason trains departed the yard late. Engines arriving at the yard late or arriving at the departure yard late from the pit combined with engine troubles (mostly mechanical) to account for 35% of the delays to outbound trains. This is important as schedule adherence is important for not only the terminating yard (train arrivals), but for the originating yard (train departures) as well. With estimated times of arrival (ETA's) at a downstream terminal partly based on the time a train leaves the previous terminal, it is important that trains leave the yard on time. Lack of accurate ETA's disrupts any yard operation scheduling a yardmaster may have done.

7. Although known prior to the study (as this was a reason Radnor was chosen for an in depth analysis), the performance of Radnor Yard was poor relative to industry benchmarks. The average processing time of 19 hours is excessive, as other yards have exhibited average yard times much lower than that. For example, Martland and Smith [1989] found that the average yard time for Burlington Northern's Cherokee Yard in Tulsa, Oklahoma, was 17.6 hours. Note the distinction that the 17.6 hours was the average yard time for cars travelling through Cherokee, while the average process time for Radnor, which excludes any time a car may have spent in the bowl, was 19 hours. The average yard time for cars going through Radnor averaged 28 hours during the course of the study.

## 7.4 Recommendations

### 7.4.1 Sequencing rules

Inspection and hump sequencing decisions caused 11 of the out of control points presented in Figures 7-2 and 7-3. An analysis into the effects these decisions made by the yardmaster had on the connection performance should be done. This would enable a researcher to both examine the consequences of different hump sequencing rules (first in first out, priority of train, etc.) on actual connection performance and to update the hump sequencing work done by Deloitte Haskins & Sells in 1978. Likewise, rules for inbound train inspection sequencing could be developed.

### 7.4.2 Applying SPC

SPC control charts should be used to monitor the performance of each yard process. The charts will aid in bettering terminal performance by highlighting the areas of yard operations that are in need of improvement. This type of yard process monitoring builds on Tykulsker's conclusion that tracking yard component processing performance relative to standards will help improve terminal control.

Secondly, besides using SPC charts for each individual process, an SPC chart for the entire yard process time could also be made. This chart would be based on the cumulative time a car spends in the yard, from train arrival to train departure, and would better exhibit the distribution of time that cars spend in a yard. If the control limits from this chart were to be outside the specifications for the yard (i.e., the connection standards) on the lower end and inside the specs on the high end, then the reliability of the yard would increase.

For example, assume that the average processing time of a particular yard is 25 hours, with the lower control limit equal to 12 hours, and the upper limit at 38 hours. Using the information gathered from the control chart, any connections with a scheduled yard time of 9 hours would not be expected to make it. On the other hand, if a train has a scheduled yard time of 33 hours, there is still a possibility that the connection would be missed, as the upper control limit is equal to 38 hours. However, through the methods presented in this thesis, improvements in the yard may move the lower control limit to 8 and the upper to 32. Now, the connections with scheduled yard times of 9 and 33 would have a higher probability of making their appropriate outbound connection (in fact, the 33 hour connection would be expected to make it), provided the trains arrive and depart the terminal as scheduled.

Lastly, Figures 7-13 and 7-14 present examples of different ways to monitor trains sitting in a rail yard. For the receiving yard (Figure 7-13), the times to monitor are the same as presented in this thesis: idle time from arrival to start of inbound inspection (represented by "////" in the figure), inbound inspection time (represented by the train number), and idle time from hump ready (inspection complete) to hump start ("\\\\" in the figure).

| Receiving Yard | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Track #/Time | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
| 1 | ////////// TRAIN ONE \\\\\\ | | | | | | | | | | | | | | | |
| 2 | | / TRAIN TWO \\ | | | | | | | | | | | | | | |
| 3 | | | | | | | // TRAIN THREE \ | | | | | | | | | |
| 4 | | | | | | //////////// TRAIN FOUR \\\ | | | | | | | | | | |
| 5 | | ///////////// TRAIN FIVE \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\ | | | | | | | | | | | | | | |

Figure 7-12: Schematic of a receiving yard.

Likewise, the departure yard could be exhibited in the same manner. The processes to be monitored would be: idle time from assembly done to start of outbound inspection (////), outbound inspection time (train number), and idle time from train departure ready to actual train departure (\\\\).

| Departure Yard | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Track #/Time | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
| 1 | | | | | | | | | | //////// TRAIN ONE \\\\\\ | | | | | | |
| 2 | | / TRAIN TWO \\ | | | | | | | | | | | | | | |
| 3 | | | / TRAIN THREE \\\\\\ | | | | | | | | | | | | | |
| 4 | | | | | | | | | | /////////// TRAIN FOUR \\ | | | | | | |
| 5 | | ///////////////////////// TRAIN FIVE \\\\\\\\\\\\\\\\\\\\\\ | | | | | | | | | | | | | | |

Figure 7-13: Schematic of a departure yard.

These types of charts present a better way of understanding what actually happened in the yard over the last 24 hours than the traditional morning reports, which tell how many cars were humped the day before or how many cars having been sitting in the yard for more than 24 hours. These charts show where the cars have been spending all of their time and offer clues as to why. Appendix B presents some actual charts that were derived using data gathered during this study.

### 7.4.3 Further terminal studies

Using the methodology presented in this thesis, similar studies should be conducted at other rail yards on different rail systems. Using the results generated from additional studies, industry benchmarks for each of the eight processes described earlier can be formulated. From these studies, yard masters seeking methods to reduce times spent by cars in their yard can see how the "best" yard keeps their process times low.

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## Appendix A: Glossary

blue-flagged: receiving or departure yard track that is closed to additional traffic due to an inspection being done. The process of blue-flagging a track is simply to close the track to additional traffic.

couple: connecting cars together.

double-over: arriving trains that are too long for available receiving yard tracks are yarded onto two receiving yard tracks, with the "original train" being placed on one receiving track and the double-over (or over flow cars) placed on another.

locked: a classification, or bowl, track that is closed to additional cars due to the track being coupled or pulled.

pure processing time: time for inbound inspection, hump process, assembly of outbound train, outbound inspection, and brake test. Does not include any of the idle time a car may face in a yard.

second section train: an extra train run out of a yard.

throat: pull out lead. Used in assembling outbound trains.

Appendix B: Examples of receiving and departure yard reporting sheets

The next two pages are actual reporting sheets for the receiving and departure yard at Radnor for one day of the study period. The receiving yard sheet has the following information:

(1) Track number (e.g., A13)
(2) Time train arrived (time associated with left most vertical line)
(3) Time inspection process started (time associated with the beginning of the shaded area)
(4) Time train being inspected (time associated with shaded region)
(5) Time train finished being inspected (time associated with the end of the shaded region)
(6) Time track humped (time associated with right most vertical line)
(7) Train number (e.g., R58217)
(8) Number of cars on train - in parentheses

The departure yard sheet displays the following information (note: the whole departure yard is not depicted in this example):

(1) Time outbound train assembly complete (time associated with left most vertical line)
(2) Time inspection process started (time associated with the beginning of the shaded area)
(3) Time train being inspected (time associated with shaded region)
(4) Time train finished being inspected (time associated with the end of the shaded region)
(5) Time locomotives coupled to train (time associated with hashmark in between time train inspection end and train depart)
(6) Time train departed (time associated with right most vertical line)
(7) Train number (e.g., R58217)
(8) Number of cars on train - in parentheses

Visually, the two sheets also display important information. When read from left to right, the sheets display individual track utilization, individual process times, queues present, and train idle time. When read from top to bottom, however, the sheets display the yard status at any point in time.

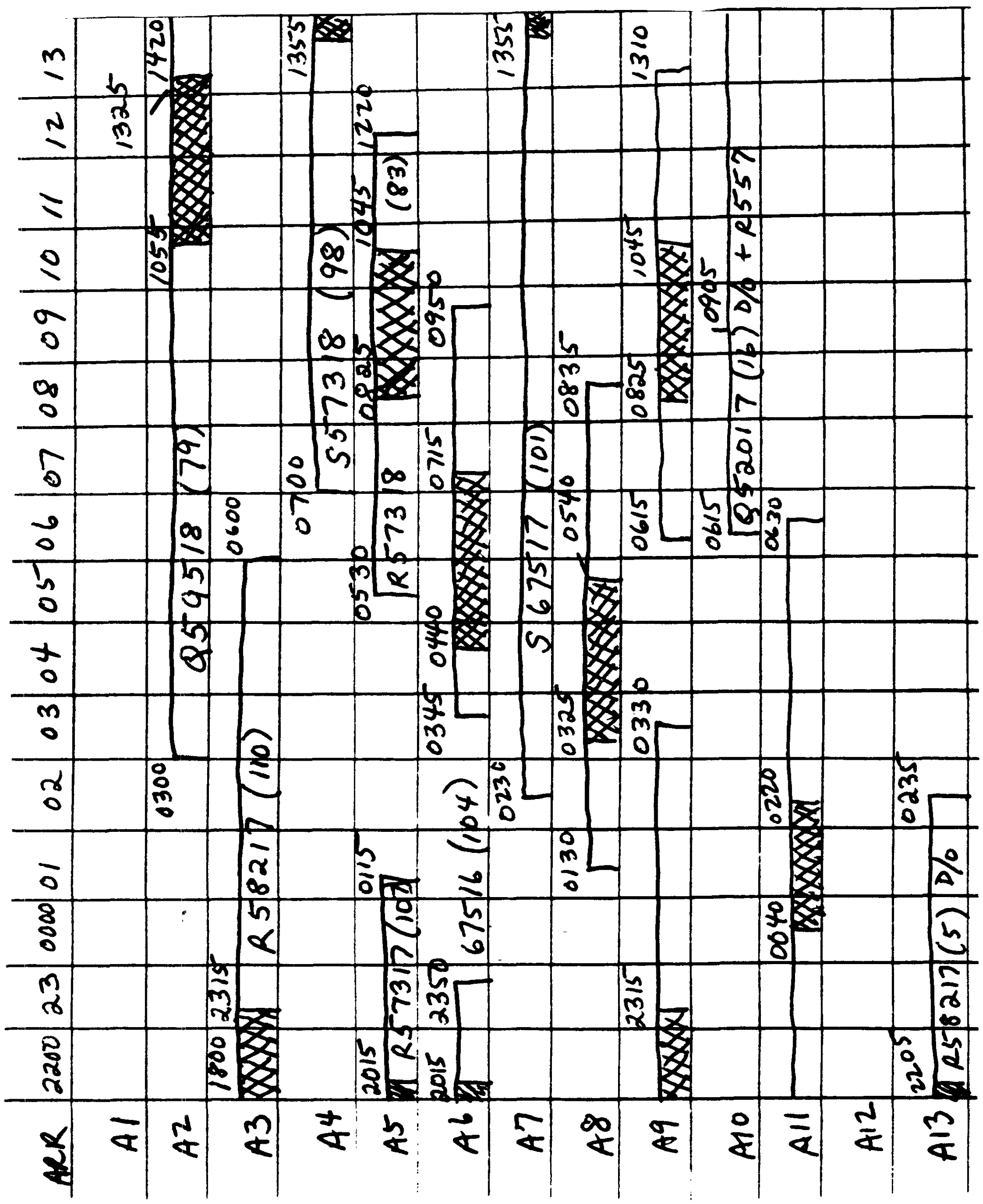

Figure B-1: Receiving yard.

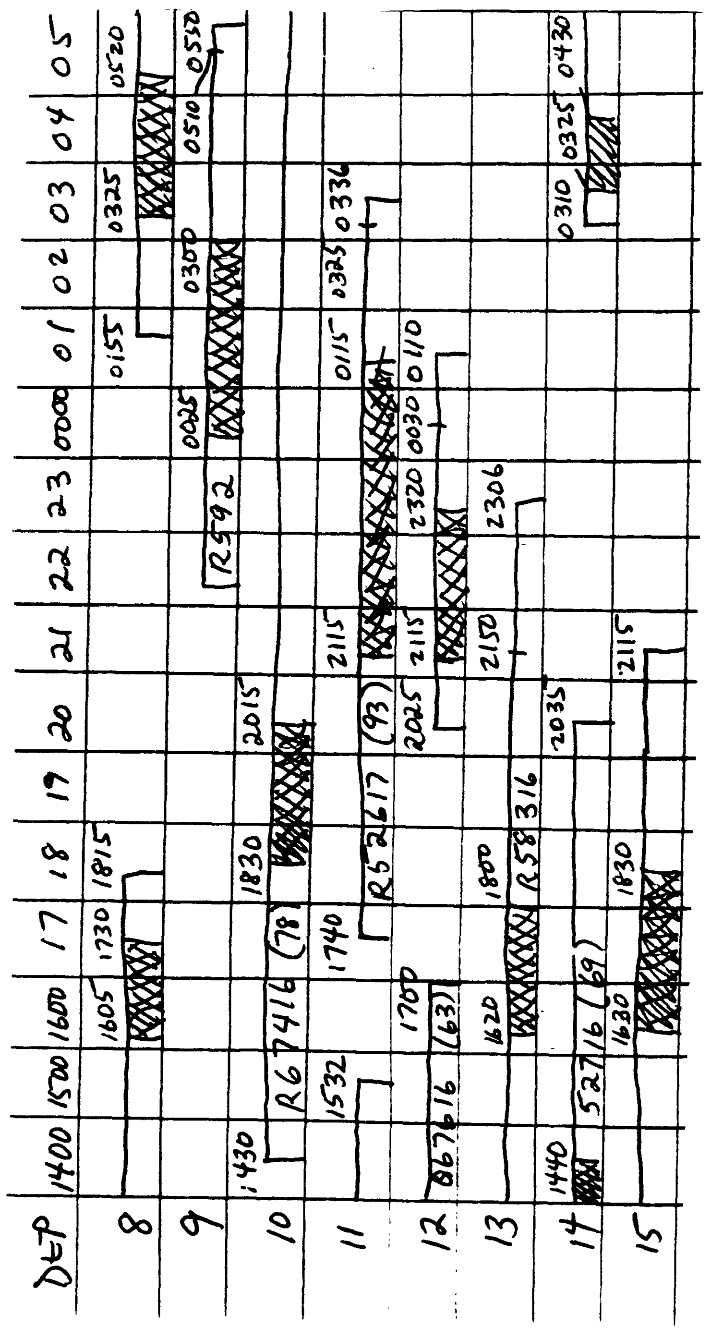


Figure B-2: Departure yard.