Cost of Ownership Modeling for Support Equipment at Intermodal Transportation Terminals

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Project Abstract

Metropolitan planning organizations in the intermodal transportation business depend on many types of support equipment to effectively operate intermodal terminals. The acquisition, productive use and retirement of such equipment require the consideration of the reliability and maintainability (R&M) characteristics of the equipment. Through an industrial survey and literature review, we explore the types of support equipment used in intermodal terminals and the R&M characteristics of such equipment. We use the concept of a "performability index" (which has previously been applied only to manufacturing systems) to determine the robustness of a transportation system where support equipment is subject to failure and repair. We then use this knowledge to model an intermodal facility and characterize the loss in system performance caused by equipment breakdowns.

Evolution of Project Objectives

Originally, the focus of this research was on the development of a decision-support tool that managers of intermodal freight and/or passenger terminals could use to assist in making retirement decisions for support equipment. The original project objectives included an internet review of metropolitan planning organizations; a survey on support equipment reliability and maintainability data collection and the use of such data in decision-making at intermodal terminals; and the use of these data to develop a model which could be used to identify the appropriate age at which to retire units of equipment within the fleet.

While reviewing metropolitan planning organizations, it became clear that private corporations often owned the support equipment at intermodal terminals and outsourced most of their maintenance. Therefore, the R&M data of such equipment was not readily available for use. At this point, we shifted our research efforts to propose a model that could be used to evaluate the overall performance of an intermodal terminal using R&M data information that is more readily available.

Introduction

Intermodal transportation has grown tremendously in the new millennium. According to the National Center of Intermodal Transportation (NCIT), intermodal transportation can be generally defined as "the shipment of cargo and the movement of people involving more than one mode of transportation during a single, seamless journey" [3]. The phrase, "a single, seamless journey", means a smooth and coordinated transition between modes, i.e. the transportation of goods and/or people is done so efficiently that the changes in mode are hardly noticeable in the process. This is a primary goal of the intermodal transportation industry.

According to the U.S. Department of Transportation, the volume of intermodal containers moving through U.S. ports has grown 6% annually over the past decade [7]. Intermodal traffic on U.S. railroads tripled over the last two decades, and the volume of intermodal containers handled by railroads grew from 3 million to 8.7 million over the same period [2]. Additionally, the volume of cargo carried by all-cargo airlines grew 10% annually between 1991 and 1996. The volume of intermodal airfreight is expected to increase as more high-value commodities, including electrical equipment, food products, and textiles, travel by air [5]. Intermodal movements usually begin and end on trucks. The volume of intermodal freight moved by truck increases directly with the increase of marine, rail, and air intermodal freight volume [5].

Regardless of the exact nature of an intermodal facility, successful terminal operations require effective use of support equipment. This support equipment may include vehicles (aircraft, vessels, automobiles, locomotives, railcars, trailers, and chassis), material handling equipment (conveyors, cranes, forklifts, and tugs), passenger handling equipment (elevators, moving sidewalks, carts, and escalators), and also miscellaneous equipment such as computers, maintenance tools, and fuel trucks [3].

As with all equipment, the reliability and maintainability of intermodal support equipment is critical to maintaining acceptable levels of equipment operation at a reasonable cost. Unfortunately, equipment maintenance is often viewed as a necessary evil and, as a result, not given adequate attention in decision-making. For example, reliability and maintainability issues should be, and often are not, factors in making fleet-size and equipment replacement decisions. Therefore, there is a need for a methodology to evaluate the reliability of an intermodal terminal.

The purpose of this research project is to model an intermodal facility and characterize the loss in system performance caused by equipment breakdowns. The project consists of three phases.

- Phase I Facility Operation Overview
- Phase II Terminal Layout and Maintenance Issues
- Phase III Intermodal Facility Modeling Tool

In Phase I, we conducted an Internet review of metropolitan planning organizations that focus on intermodal terminals. In addition, we visited a local intermodal terminal, the Little Rock Port Authority, to determine the equipment necessary for facility operations. In Phase II, we provided typical terminal layouts and discussed general maintenance issues related to an intermodal facility. Finally in Phase III, we developed an intermodal facility modeling tool that can be used to determine system loss associated with equipment failures. This tool is based on the work of Usher and Biles [8] on material handling systems for manufacturing facilities.

Phase I: Facility Operation Overview

Phase I began with an Internet review of metropolitan planning organizations (MPO's). The Federal Highway Act of 1973 mandates that MPO's provide a cooperative, comprehensive, and continuing transportation planning and decision-making process. Today, many state and metropolitan transportation organizations are actively promoting and expanding the intermodal capabilities of their state or region. Most MPO's have long-term transportation plans to:

- Evaluate and consider improvement alternatives that enhance intermodal linkages
- Improve intermodal connections
- Accommodate efficient movement of goods and freight
- Support legislation that improves intermodal connections
- Develop transportation systems that integrate all modes of transportation

We focused our attention on the types of support equipment used to effectively operate intermodal freight terminals and attempt to gain insight into the reliability and maintenance issues associated with that support equipment. Due to the large number of state and metropolitan planning organizations and the fact that most of the research team is located at the University of Arkansas, we focused our attention on intermodal freight terminals within the state of Arkansas.

Intermodalism in Arkansas

Arkansas's central location within the United States is ideal for both domestic and international freight shipment. While trucking is the state's primary mode for freight transportation, barge and rail traffic are also important when considering freight tonnage. Figures 1 and 2 summarize the modes of transportation for the import and export of goods within Arkansas [6].

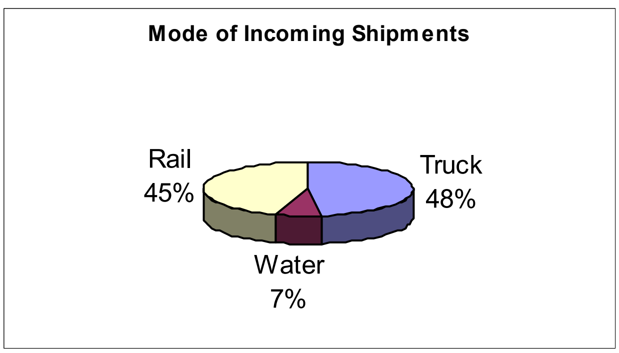


Figure 1. Incoming Shipments

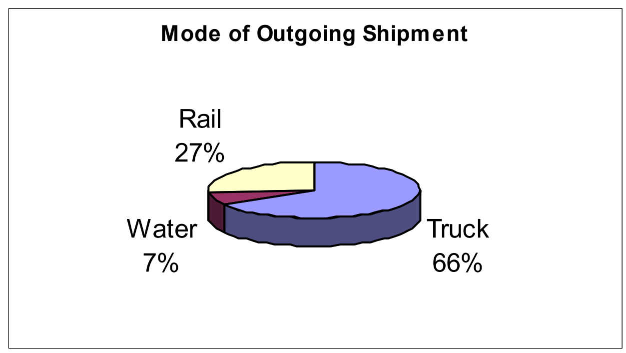


Figure 2. Outgoing Shipments

In 1996, the Arkansas Highway Commission implemented a Strategic Plan for the Arkansas State Highway and Transportation Department. The goals of this plan are as follows [1]:

- Provide a safe and efficient Intermodal Transportation System
- Maximize external and internal customer satisfaction
- Strive for continual improvement
- Enhance the social, economic and environmental qualities of Arkansas

Furthermore, federal regulations require that urbanized areas (a population of 50,000 or more and a specific density) prepare a 2025 Long-Range Plan Update. Prior to the 2000 Census, Arkansas contained six urbanized areas (see Figure 3) [1].

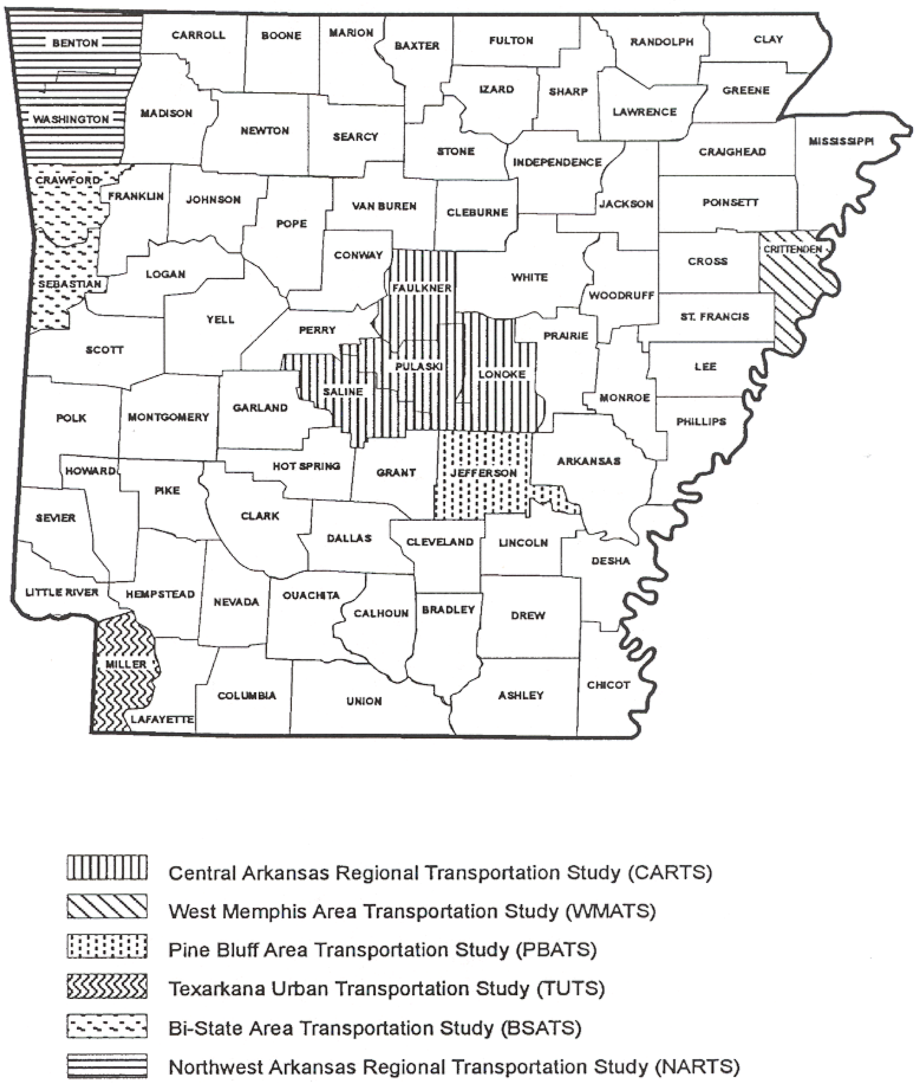


Figure 3. Urban Areas in Arkansas

Intermodal Facilities in Arkansas

We visited the Little Rock Port Authority, a cargo terminal, in April, 2002, and met with the assistant general manager of operations, Duane Hawkins. The Little Rock Port Authority was completed in December, 1968, with the hopes of creating local jobs. Today, the facility operates with 19 salaried employees and hires temporary employees during busy periods.

The facility has access to over 448 miles of navigational waters. It has one main dock area that can accommodate the unloading of two barges at one time during peak operation. The facility mainly handles bulk and break-bulk cargo. Bulk cargo is typically not packaged and includes products such as grain, gravel, and cement (see Figure 4). Break bulk cargo includes large separable units such as steel coils or metal bars (see Figure 5).

Figure 4. Bulk cargo

Figure 5. Break bulk cargo

Typical products transported include outbound rock, cement (80,000 tons/yr), and bauxite (120,000 tons/yr). The average throughput is approximately 400,000 to 450,000 tons per year. The maximum throughput occurred in 1998 with 560,000 short tons being shipped. The shipping rates for the facility vary and are determined by the speed of the operation, labor costs, equipment utilization, supplies, and overhead. Incoming revenues from freight shipments are relatively small; therefore the facility manages a packing operation to supplement their revenues. The facility currently packages roofing granules for 3M (see Figure 6), and they have the capability to package aluminum bauxite (see Figure 7).

Figure 6. Packaged 3M roofing granules

Figure 7. Aluminum bauxite packaging operation

The equipment used to support facility operations includes cranes, front-end loaders, railcars, forklifts and conveyors (see Figures 8-16). Logistic Services Inc. owns the equipment used at the facility and is responsible for all maintenance actions.

Figure 8. 175-ton capacity crane

Figure 9. 125-ton capacity crane

Figure 10.Barge crane

Figure 11. Rail-mounted gantry crane

Figure 12. Front end loaders

Figure 13. Front end loader

Figure 14. Conveyor system for packaging operation

Figure 15. River conveyor system

Figure 16. Rail cars

Phase II: Terminal Layout and Maintenance Issues

In 1998, the Arkansas Highway & Transportation Department published a report describing the intermodal transportation needs of the Arkansas River Valley [6]. This report indicates that consideration should be given to the development of a new transportation center, which could include an intermodal truck/rail terminal, a freight handling terminal, and a slack water harbor. In this report, typical terminal layouts were provided (see Figures 17, 18, 19). The Little Rock Port Authority facility has a layout similar to that of Figure 19 but also includes break-bulk warehousing.

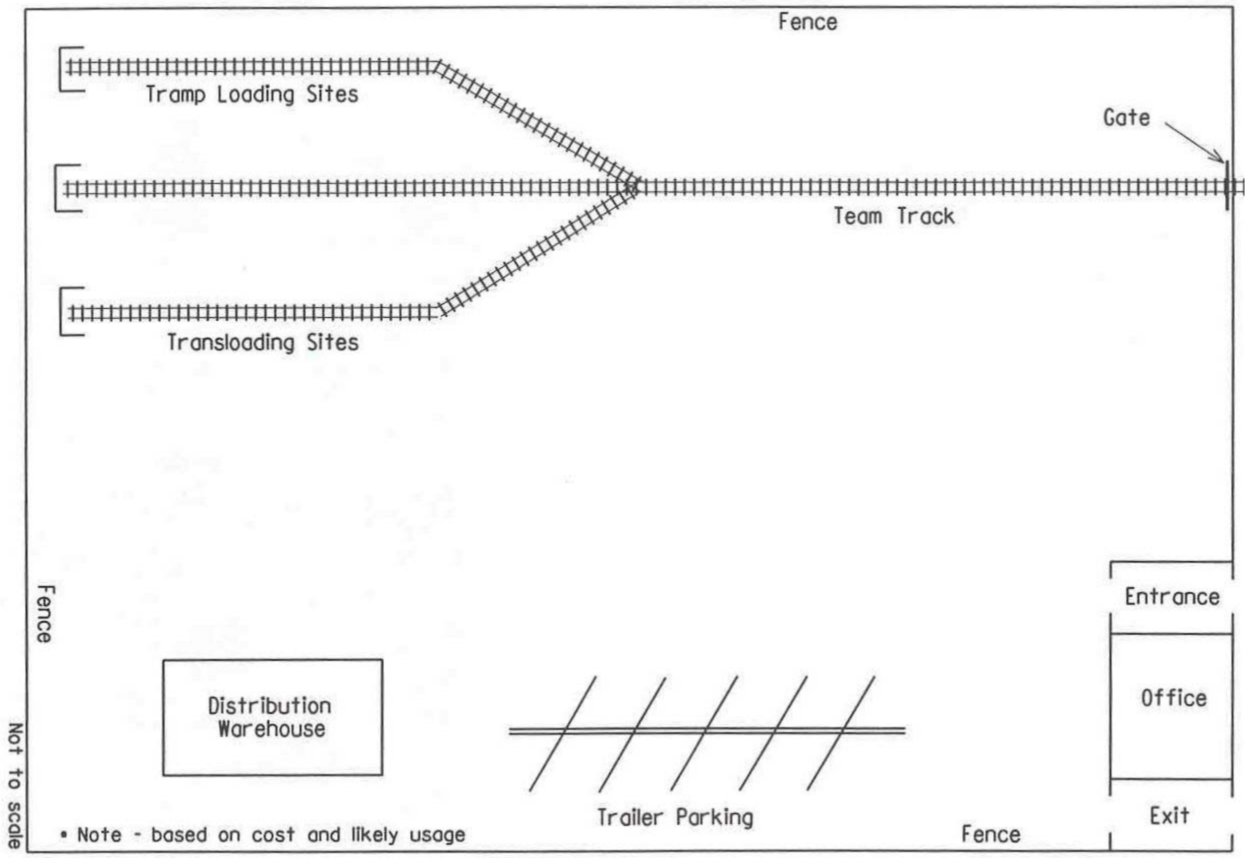


Figure 17. Typical Truck/Rail Intermodal Terminal in Arkansas

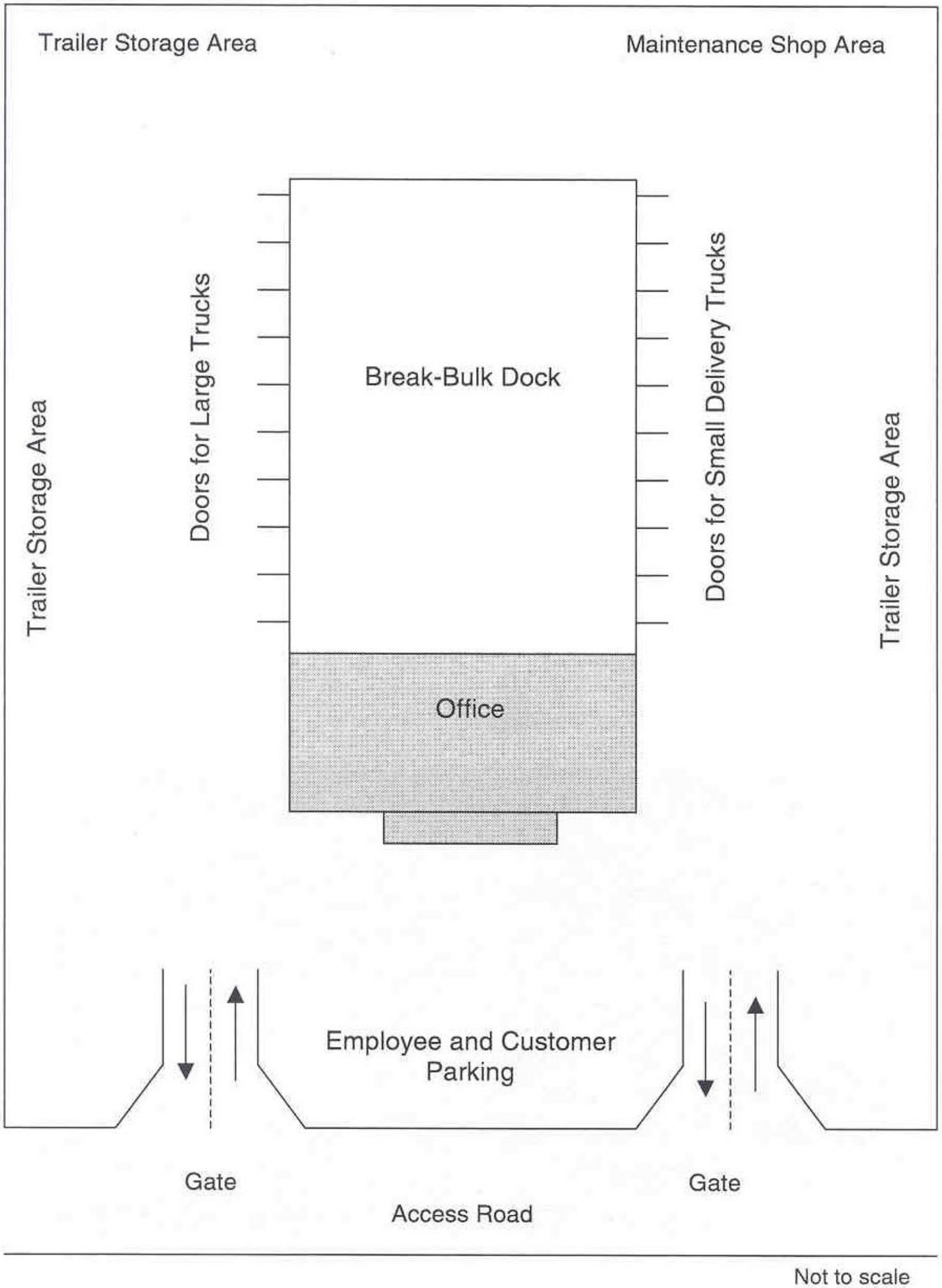
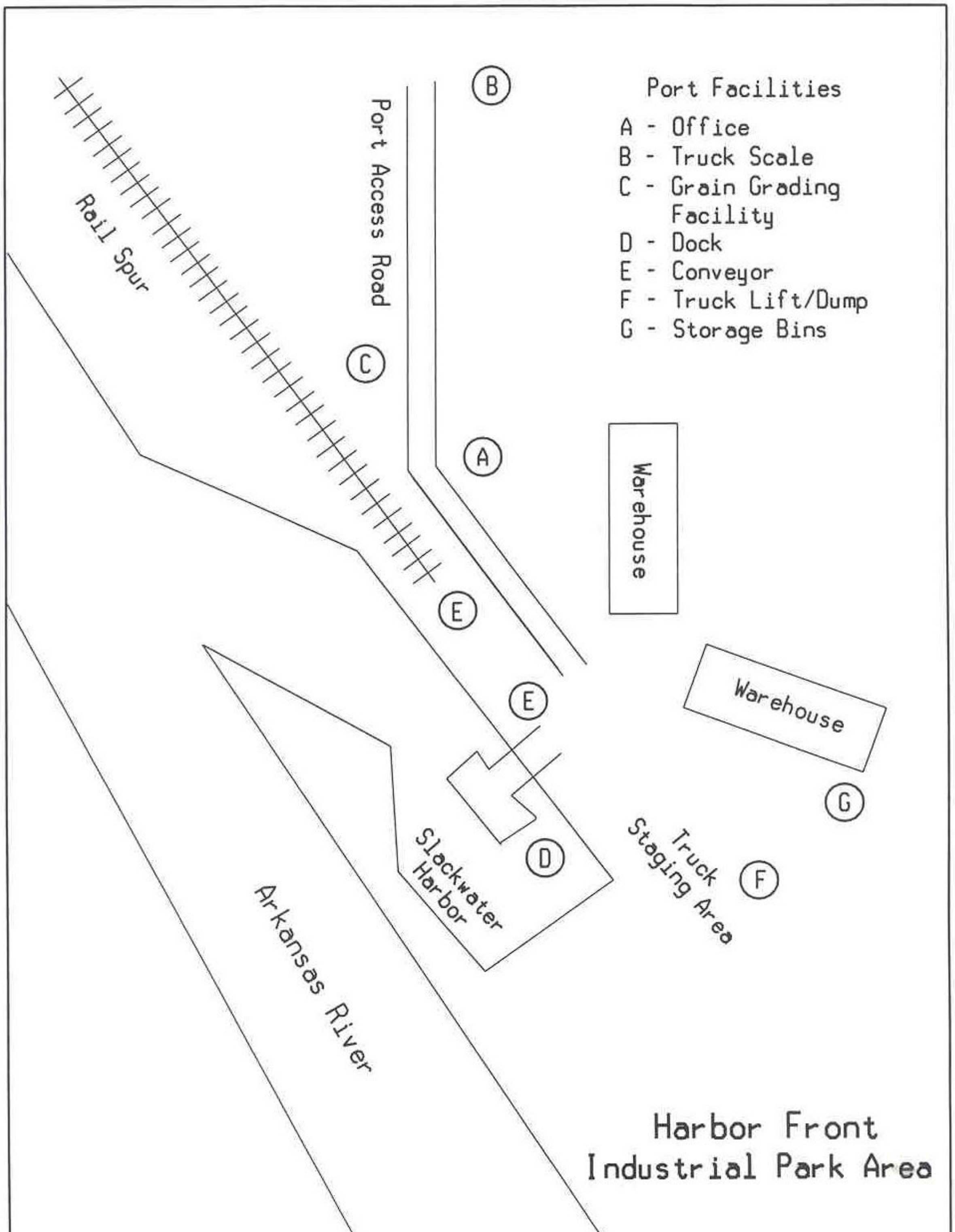


Figure 18. Typical Break-Bulk Terminal in Arkansas



Not to Scale

Figure 19. Typical Slack Water Harbor/Intermodal Terminal in Arkansas

As mentioned earlier, Logistics Services, Inc. owns and maintains all equipment at the Little Rock facility. The facility receives monthly PM (preventive maintenance) reports, which follow manufacturer-recommended PM intervals. All PM and corrective maintenance actions are outsourced, and the facility has a maintenance technician "on call" at all times. Since the maintenance actions are outsourced, data on equipment failures and duration of repairs is not readily available at the facility.

Phase III: Intermodal Facility Modeling Tool

Traditional reliability approaches fail to accurately characterize the effect of component failures and repairs on overall system performance. Often, system performance is measured by availability or uptime. However, in a complex material handling system, such as an intermodal terminal, the terminal may continue to function even though units of equipment have failed. In Phase III, we define an approach for characterizing the "performability" of an intermodal terminal by evaluating system performance based on realistic equipment failure and repair rates.

This approach is based on the work of Usher and Biles [8]. They proposed the use of a "performability index" to evaluate the effects of component failures on the performance of a material handling system in a manufacturing facility. They suggested that a discrete-event simulation model of the system be built and evaluated under two different scenarios:

1. Run the simulation model with no component failures and evaluate the performance of the facility
2. Run the simulation model with realistic component failures and collect data on system performance

For an intermodal terminal, several performance measures are of interest. These include machine and/or labor utilization, availability of equipment, cargo cycle time, and throughput. For this project, we used cargo cycle time as the main performance measure in our simulation model.

With the data collected from the simulation model, the performability index was calculated as follows:

$$PI = \frac{E(L_1)}{E(L_2)} \tag{1}$$

where $E(L_1)$ represents the expected loss associated with a system when there are no equipment failures, and $E(L_2)$ represents system loss when component failure and repair are considered. Values of PI close to 1 indicate a robust system (insensitive to component failures), while values close to 0 indicate that the system incurs heavy losses when equipment fails [8]. In this project, we make the widely-accepted assumption that the loss functions are quadratic expressions. Furthermore, we use a "smaller-is-better" performance measure (cargo cycle time). Therefore, PI can be calculated based on the mean and variance of the performance measure

$$PI = \frac{\sigma_1^2 + \mu_1^2}{\sigma_2^2 + \mu_2^2} \tag{2}$$

where μ_1 denotes the mean cargo cycle time when there are no equipment failures, μ_2 denotes the mean cargo cycle time when equipment is subject to failure and repair, σ_1 denotes the standard deviation of cargo cycle time without failures, and σ_2 denotes the standard deviation of cargo cycle time with failures and repairs.

The Simulation Model

Using ARENA, a simulation model of a hypothetical intermodal freight terminal (similar to the Little Rock Port Authority) is constructed based on the following assumptions:

- All cargo enters the terminal by barge and leaves by either truck or rail
- Cargo may arrive as bulk cargo or break bulk cargo
- Equipment considered for failure includes cranes, forklifts, and gantry cranes
- No preventive maintenance actions are performed
- The terminal operates continuously for 30 days

When freight arrives to the terminal, it is classified as either bulk or break bulk cargo. The arrival time of the freight is recorded, and a crane is used to unload the freight. The user defines the *time between arrivals* and *entities per arrival* for each type of freight. Additionally, the *number of cranes available* and the *delay time* required for the crane to unload each entity are defined and entered into the model (Figure 20).

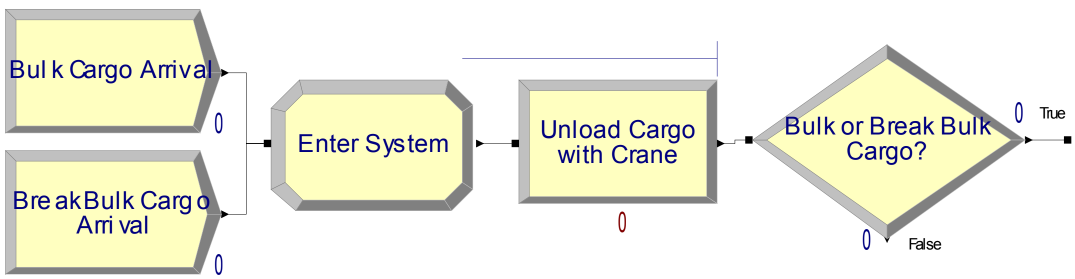


Figure 20. Cargo arrival and unload

Once the freight is unloaded, it is processed through the system and leaves by either truck or rail. Bulk cargo that leaves the facility by rail is loaded directly into a rail car to be shipped to its destination. The user of the model inputs the *percentage of bulk cargo leaving the terminal by rail* and the number of entities required to form a *rail car load*. Bulk cargo that leaves the facility by truck is packaged and palletized upon arrival (this was incorporated to more closely model the Little Rock Port Authority). The pallets are transferred to trucks using forklifts. The following parameters are input by the user (Figure 21):

- *Number of forklifts available*
- *Forklift delay time*
- *Packaging delay time*
- *Pallet size*
- Number of pallets required to form a *truckload*

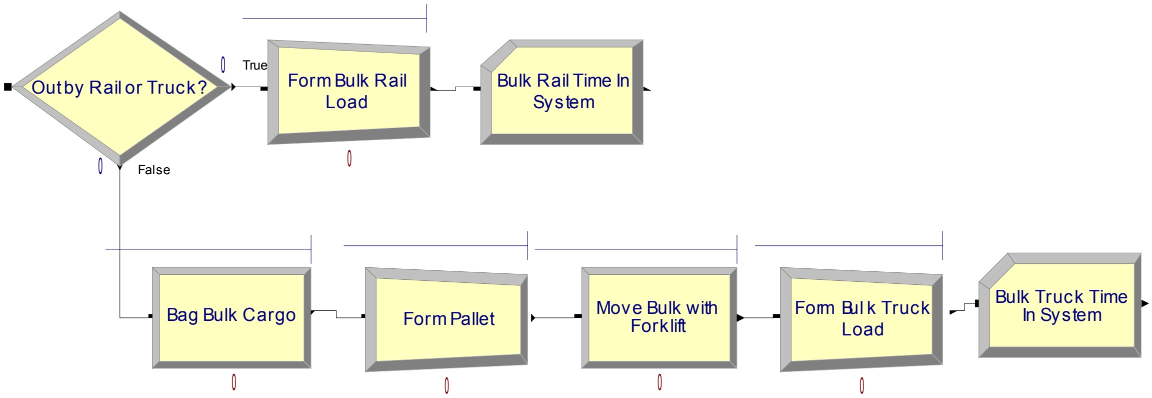


Figure 21. Bulk cargo

Similarly, break bulk cargo leaves the terminal by truck or rail. The user of the model determines the *percentage of break bulk cargo leaving the facility by truck* as well as the amount of freight required to form a *truckload*. Break bulk cargo leaving the terminal by rail is moved using a gantry crane. Again, the user specifies the number of gantry cranes available, the delay time required to load the rail car, and the amount of freight to *form a rail car load* (Figure 22). The model calculates the cargo cycle time (time in system) for each type of freight, as well as the mean cargo cycle time for all types of freight.

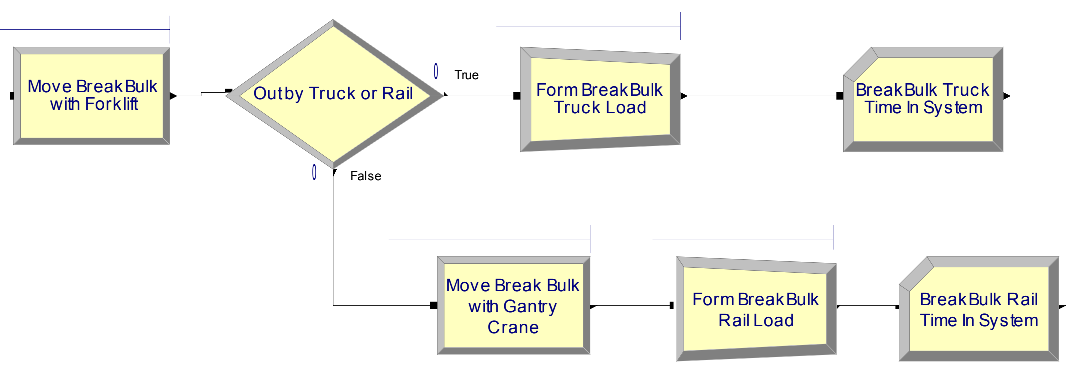


Figure 22. Break bulk cargo

Using the schedule module for single units of equipment or the failure element for sets of two or more resources, the user defines failure and repair intervals that coincide with historical data. A picture of the ARENA simulation model is located in Figure 23.

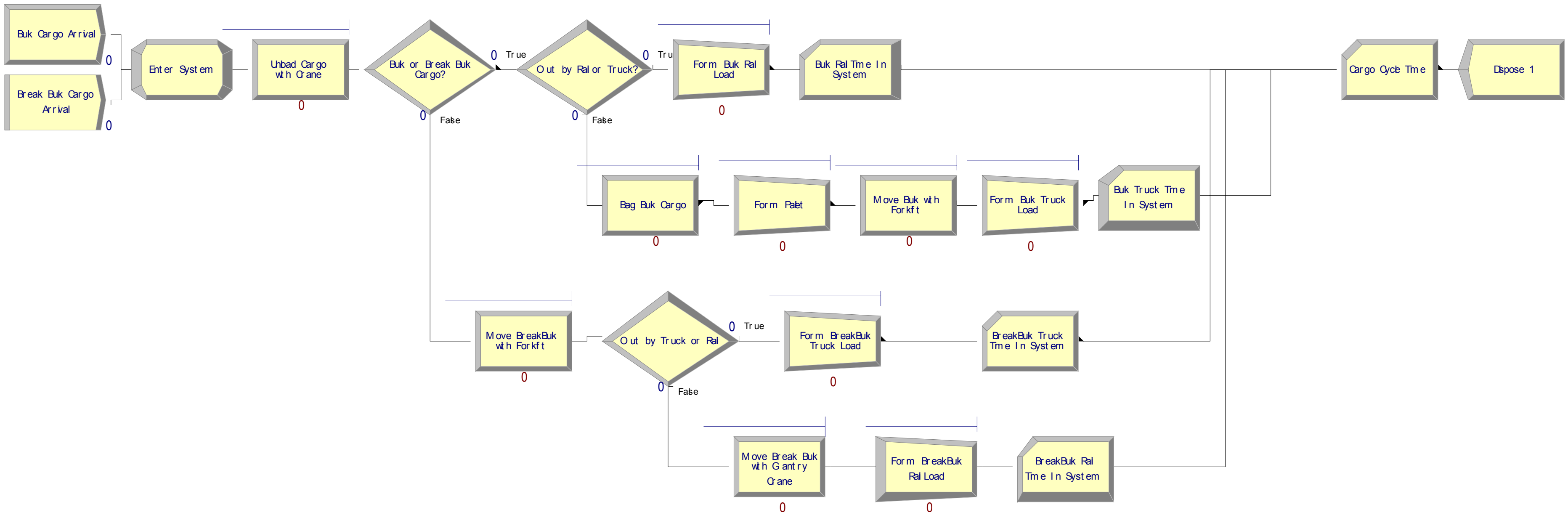


Figure 23. ARENA simulation model

Several scenarios were developed for the model. These scenarios varied in the duration of repairs and the number of units of equipment available for use. The user of the model must only approximate the failure rate and duration of repair. Managers and operators familiar with the terminal should be able to approximate these values without data.

The baseline scenario incorporates constant equipment failure rates and stochastic durations of repair. The second scenario explores the impact of reducing repair times, and the third scenario incorporates the use of additional equipment. Finally, the fourth scenario integrates additional equipment with reduced repair times.

Numerical Example

Consider the baseline scenario where equipment failure rates are constant (time to failure is exponentially distributed) and the duration of corrective maintenance actions are exponentially distributed (Table 1).

Table 1. Time to Failure and Duration of Repairs for Baseline Scenario

Equipment	Time To Failure (mean in hours)	Duration of Repair (mean in hours)
Crane	Expon (60)	Expon (5)
Gantry Crane	Expon (90)	Expon (7)
Forklift	Expon (30)	Expon (2)

When the model is run without failures, the mean cycle time of the system, μ_1, is 174 hours with a standard deviation, σ_1, of 39.6 hours. With failures, the mean cycle time of the system, μ_2, increases to 178.4 hours with a standard deviation, σ_2, of 44.4 hours. This gives a performability index of 0.94, which indicates this system is robust and continues to function well even with equipment failures.

In scenario 2, the durations of equipment repair are reduced. This may be done by increasing the number of maintenance technicians available or increasing the skill set of existing technicians. Again, the equipment is subject to constant failure rates and the durations of repair are exponentially distributed (Table 2).

Table 2. Time to Failure and Duration of Repairs for Scenario 2

Equipment	Time To Failure (mean in hours)	Duration of Repair (mean in hours)
Crane	Expon (60)	Expon (3)
Gantry Crane	Expon (90)	Expon (4)
Forklift	Expon (30)	Expon (1)

When the model is run without failures, the mean cycle time of the system, μ_1, and the standard deviation, σ_1, are identical to Scenario 1. With failures, the mean cycle time of the system, μ_2, is 178 hours with a standard deviation, σ_2, of 42.9 hours. This increases the performability index to 0.95. However, in both of these scenarios, the cargo spends over a week within the facility.

In scenario 3 and 4, the equipment from the baseline scenario is supplemented with additional, newer units of equipment. In particular, the facility has access to two cranes and forklifts. In the fourth scenario, reduced maintenance times are incorporated with the additional equipment. The equipment failure rates and durations of repair for these scenarios are detailed in Table 3.

Table 3. Time to Failure and Duration of Repairs for Scenario 3 and 4

Equipment	Time To Failure (mean in hours)	Scenario 3 Duration of Repair (mean in hours)	Scenario 4 Duration of Repair (mean in hours)
Crane 1	Expon (60)	Expon (5)	Expon (3)
Crane 2	Expon (125)	Expon (3.5)	Expon (2)
Gantry Crane	Expon (90)	Expon (7)	Expon (4)
Forklift 1	Expon (30)	Expon (2)	Expon (1)
Forklift 2	Expon (75)	Expon (2)	Expon (1)

Again, the model is run both with and without failures and data on the mean cycle time is collected. When the model is run without failures for both scenarios 3 and 4, the mean cycle time of the system, μ_1, is 32.4 hours and the standard deviation, σ_1, is 13.9 hours. The with-failure results for scenarios 3 and 4 are detailed in Table 4.

Table 4. Results for Scenarios 3 and 4

Scenario	μ_2	σ_2	*PI*
3	43.0	20.7	0.55
4	38.6	19.8	0.66

Now, cargo spends less than two days within the facility, and the effects of equipment failure on facility operation have been quantified. Reducing the time required to perform repairs provides a significant increase in the performability of the facility. Therefore, it may be beneficial for the facility to increase size of the staff or implement additional training for maintenance technicians or equipment operators.

Other Applications

As mentioned earlier, several performance measures may be of interest to managers of an intermodal freight terminal. Initially, we chose cargo cycle time and stated that "smaller-is-better" best describes this performance measure. Other performance measures such as throughput are described as "larger-is-better" while equipment utilization may be described as "target-is-best." In either case, we would still use equation (1) to calculate *PI*, but the equations for expected loss would change. For a "larger-is-better" measure, PI is given by

$$PI = \frac{\mu_2^4\left(\mu_1^2 + 3\sigma_1^2\right)}{\mu_1^4\left(\mu_2^2 + 3\sigma_2^2\right)} \tag{3}$$

and for a "target-is-best" measure, *PI* is given by

$$PI = \frac{\sigma_1^2 + \left(\mu_1 - m\right)^2}{\sigma_2^2 + \left(\mu_2 - m\right)^2} \tag{4}$$

where *m* is the target value of the performance measure.

Since intermodal terminals have different facility layouts and support equipment, the simulation model may need to be modified to more accurately portray a particular facility's operations. If the following assumptions are not met, the model may require significant changes:

- All cargo enters the terminal by barge and leaves by either truck or rail
- Cargo may arrive as bulk cargo or break bulk cargo
- Equipment considered for failure includes cranes, forklifts, and gantry cranes

However, the model does allow the following parameters to be modified without major changes to the model.

- Arrival and departure rates of cargo
- Quantities, processing times, failure rates, and repair times of support equipment
- Storage and processing times of cargo

Once the simulation model has been modified and run, port managers can use the *PI* values to determine the effect of equipment breakdown on facility operations. This tool can be used to determine the appropriate quantities of support equipment needed for effective facility operation. For example, with a simulation model, a manager can see the impact of additional equipment without the expense of actually purchasing such equipment. Furthermore, the model can be used to determine the impact on overall facility operations of more efficient repair procedures.

Conclusions

After reviewing many state and metropolitan planning organizations and visiting a local intermodal terminal, we have provided a tool to assess the reliability of an intermodal terminal. By applying the concept of a "performability index" to a complex intermodal transportation system, port managers have a tool for assessing the overall effectiveness of an intermodal terminal based on the reliability of its support equipment. Further research in the area could include more complex modeling of intermodal facilities. Additionally, preventive maintenance policies for systems that experience an increasing failure rate could be incorporated to more accurately assess a terminal's performance.

References

1. Arkansas Highway and Transportation Department website, www.ahtd.state.ar.us

2. Association of American Railroads website, www.aar.org

3. Graham, D.W., C.R. Cassady, R.O. Bowden, and S.A. LeMay (2000), "Modeling Intermodal Transportation Systems: Establishing a Common Language", *Transportation Law Journal*, pp. 55-68.

4. *The Impacts of Changes in Ship Design on Transportation Infrastructure and Operations* (1998), U.S. Department of Transportation, Office of Intermodalism.

5. The Intermodal Network, Intermodal Association of North America (1998).

6. *Intermodal Transportation Needs/Economic Development – Russellville, Arkansas* (1998), Arkansas Highway and Transportation Department.

7. Pentimonit, Eugene (1998), Speaker at the I-95 Intermodal Leadership Summit, Princeton, NJ.

8. Usher, J.S. and W.E. Biles, "Evaluation of Material Handling System Reliability", Department of Industrial Engineering, University of Louisville.

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