Reducing Heavy-Haul Railcar Maintenance Costs and Improving Terminal Performance Using Technology: A Lean Production Approach

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Abstract
Railroad terminal performance directly affects network capacity and an important element of terminal efficiency is railcar inspection and repair. New technologies to automate railcar inspections can improve railroad terminal efficiency by reducing inspection times and improving operations. This research applies Lean Manufacturing methods to the railcar maintenance process and investigates potential means of eliminating waste and reducing variability by implementation of automated condition monitoring technologies. We consider the potential impact on unit-train inspections and quantify the delay costs resulting from railcar inspection. This analysis provides a basis for developing cost-effective inspection and maintenance strategies using automated technologies and evaluates potential benefits in terms of improved efficiency and increased capacity.

1. INTRODUCTION

Railway terminals have long been known to affect productivity in freight operations [1] and by the 1960s, terminal efficiency had become a major focus in railroad engineering research [2]. Meanwhile, management techniques were also evolving in other industries to improve production and manufacturing efficiency. In the 2000s, various production management techniques were applied to terminal operations through the introduction of Lean Railroading [3,4]. Lean Railroading eliminates operational waste in order to improve terminal capacity, efficiency and asset utilization. As railroads adopt new technologies and management strategies, Lean Railroading principles can be applied to railcar inspection and maintenance practices to further improve efficiency.

2. MOTIVATION AND BACKGROUND

2.1 Terminal Performance

Yards and terminals impact railroad productivity and reliability. Many railcars spend most of their time in terminals with as much as 64% of transit time spent in yards [3,4,5]. A common metric to measure this is terminal dwell, which is the average time a car resides in terminals [6]. Dirnberger found that average train speed, a common proxy for railroad performance [6], decreased linearly with terminal dwell [3,4]. In addition, Logan suggested that for every 15% reduction in systemwide average terminal dwell, carload traffic velocity would increase 2 mph [3,7]. Although the relationship between terminal dwell and train speed varies among railroads, reducing the former will generally increase the latter.

2.2 Lean Railroading

Lean Railroading was developed in the 2000s to improve efficiency in classification yards. According to Dirnberger, "Because classification terminals can be considered production systems, their performance can be improved by adapting an integrated approach consisting of three proven production management techniques: lean, theory of constraints (TOC), and statistical process control (SPC or Six Sigma)" [3,4]. The current research focuses on the concept of lean production, as applied to railroad terminal operations, in the form of Lean Railroading.

The term "Lean Manufacturing" was introduced in 1990 in a study that found Toyota production techniques to be superior to other automotive manufacturers [8]. This launched the use of lean methodology and other principles, among companies throughout the world [9]. The first formal application of lean techniques to a rail terminal environment was by Dirnberger and the Canadian Pacific Railway (CPR) Yard Operations Performance Group in the mid-2000s [3].

Lean is defined as the production of goods or services using minimal buffering costs [10]. Excessive buffering includes both direct waste and variability. Operations that are not needed represent direct waste, and in the rail yard setting include: rework, accidents, injuries, car damage, unnecessary motion, and unnecessary information collection [4]. However, most managers focus more on reducing direct waste than variability. Variability is a fundamental source of waste, as it necessitates buffering of extra inventory, capacity or time [10]. In rail yards, sources of excessive inventory buffering include: fueling requirements, the number of railcars or locomotives requiring maintenance, and the extent of the maintenance required. These buffers can come in the form of reserve fuel supplies, freight car and locomotive parts, etc. Variability in train arrivals and unexpected defects result in excess capacity buffers, which may include extra trackage, car inspectors, or repair personnel. Finally, variability in arrival times, inspection and repair times, or labor availability may be buffered by adding "slack time" in the train schedule. All of these buffers are a result of the uncertainty inherent to the various processes within the rail yard, leading to unnecessary costs in the form of indirect waste.

CPR adapted work from Hopp and Spearman [10] in their yards and saw dramatic improvements: average terminal dwell dropped by over 28%, average terminal capacity increased by 40%, and average train speed increased 3.6 mph [3]. Several other railroads are now applying aspects of Lean Railroading to improve terminal performance [4]. As railroads seek further improvements in terminal performance, new methods and technologies will be integrated to further eliminate waste and reduce variability including improving railcar inspection and maintenance practices.

2.3 Current Railcar Inspection Practices

U.S. regulations require that each railcar receives a mechanical inspection before departing a yard or terminal (FRA Class I Inspection) [11]. In addition, trains must be stopped en-route for inspections if they travel beyond specified distances (FRA Class IA inspection). To meet these requirements, current railcar inspection practices require an inspector to visually inspect the mechanical components on both sides of each car in a train. Inspection efficiency and effectiveness varies depending on conditions and capability of inspectors so technologies have been developed to augment manual inspection.

2.4 Automated Condition Monitoring Technology (ACMT)

US railroads have invested over $70 million on the development, installation and maintenance of new wayside detection systems to monitor the condition of freight car components [12]. These automated condition monitoring technologies (ACMT) use various sensing mechanisms to measure heat, force, sound, and visual parameters to monitor railcar component condition.

Condition monitoring of railcar components allows trending analysis and early detection of deteriorating components. Technologies such as acoustic bearing detectors (ABDs) and truck performance detectors (TPDs) provide mechanical departments with information enabling removal of faulty journal bearings or truck components prior to failure. Other wayside detection systems include wheel impact load detectors (WILDs), hot wheel detectors (HWDs), cold wheel detectors (CWDs), truck hunting detectors (THDs), and wheel profile monitoring (WPM) systems. Several reviews of these new wayside technologies have been published [12,13,14,15,16,17]. ACMT will provide immediate returns through the reduction of equipment-caused derailments and in-service failures, and longer-term benefits through improved yard efficiency and increased asset utilization.

3. METHODOLOGY: APPLYING LEAN TO RAILCAR INSPECTION

Using the four step Lean Railroading process [3] the following principles were applied to railcar inspection and maintenance practices: 1) eliminate direct waste, 2) swap buffers, 3) reduce variability, and 4) perform continuous improvement. Data from a major US Class I railroad terminal were used to assess the potential benefits of using ACMT in conjunction with lean techniques.

3.1 Eliminate Direct Waste

The first step in eliminating waste is to separate the value-adding operations from the non-value adding operations. Unavoidable actions that create no value are considered Type I waste, whereas steps that create no value and can be avoided are considered Type II waste [9].

3.1.1. Type I Waste: Inherent but Unavoidable Waste

Tagging of bad order cars is an example of Type I waste. When a railcar needs major repair, a bad order card must be completed and affixed to each side of the railcar. This is Type I waste because there is no technology to automate this process. Data from empty coal train inspections indicated an increase of 9.9 minutes in inspection time for each bad ordered car (Figure 1).

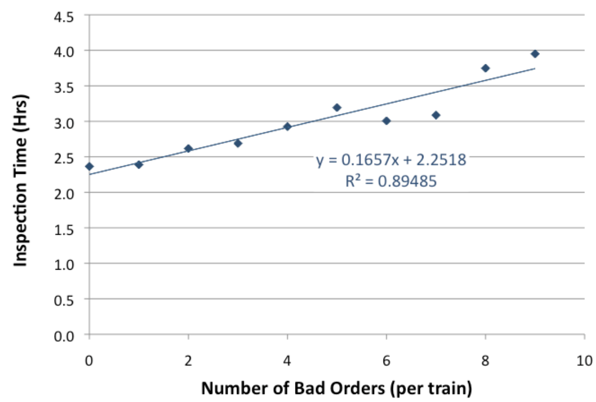

FIGURE 1. Average coal train inspection times as a function of the number of bad orders found per train

These data suggest that it takes approximately 10 minutes to: 1) identify an FRA-reportable defect, 2) complete required documentation, and 3) attach a bad order card to each side of the car. Steps 2 and 3 are Type I waste, because they do not improve the train's condition. If appropriate technology was available the time needed for this process could be greatly reduced. Hundreds of thousands of freight cars are bad ordered each year so such technology would enable railroads to realize substantial savings. This could be accomplished by linking wayside detection systems and automatic equipment identification (AEI) data with handheld devices in the yard, allowing car inspectors to electronically bad order cars.

3.1.2 Type II Waste: Immediately Avoidable Waste

Inspection processes in and of themselves, do not add value and therefore generate operational waste; however, they are often necessary due to imperfections in manufacturing. Terminals produce outbound trains comprised of locomotives and railcars that may contain defects. Inspection allows value to be added by facilitating repairs and improved train operation. Train inspections do not add value unless they result in a repair or some other improvement, thus, a rail industry goal is to "turn finders into fixers" [18]. By using ACMT to find defects, railroad personnel can spend more time adding value.

An example of Type II waste is the redundancy that occurs when railcars are repeatedly inspected. Non-defective railcars are inspected numerous times between origin and destination but there is no system to record the results. This is inefficient in terms of finding and repairing defects. Inspectors do not know if a component was in satisfactory condition at a previous inspection so they must inspect all components again. This is repeated frequently with the result that components that are quickly inspected are over-monitored, whereas components or conditions that are difficult to assess may be less frequently observed. This is a direct outcome of regulations emphasizing inspection frequency rather than defect detection and repair. There have been recent efforts to reduce the inspection of non-defective railcars. In 2008 the FRA amended the regulations pertaining to freight equipment to allow trains equipped with electronically controlled pneumatic (ECP) brakes to travel up to 3,500 miles before stopping for an air-brake inspection [11]. Implementation of ECP brakes will enable Type II waste to be reduced, the cost of excessive car inspections recovered and safety benefits achieved.

Inspections at one terminal took between 80 and 140 minutes (1.33 to 2.33 hours) per train, depending on train type (Figure 2). Procedures on most Class I railroads involve two car inspectors with one on each side of the train, thus a 140-minute coal train inspection requires 4.66 person-hours of labor. These times are consistent with observations at other terminals.

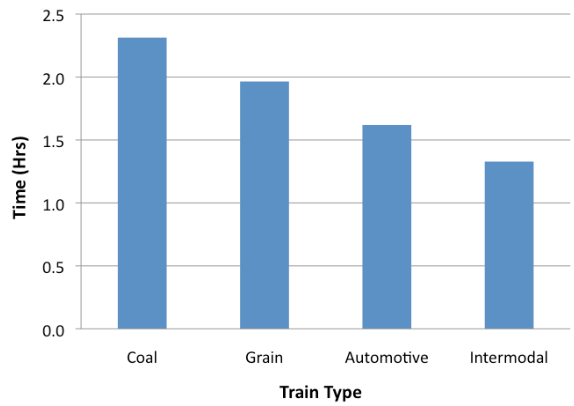

FIGURE 2. Average train inspection times for various train types

Inspection times are affected by train length and the priorities for different train types, with intermodal trains having the highest priority. Most inspections require one car inspector to be positioned on each side of the train, resulting in 2.67 to 4.67 person-hours of labor per train. Most trains contain only a few defects, so most of this time is spent inspecting cars that have none. By equipping trains with ECP brakes, railroads could run unit-trains 3.5 times farther between inspections, resulting in elimination of one or two Class IA inspections. The reduction in Type II waste alone would not be enough to justify the cost of retrofitting an entire train with ECP brakes; however, it is a major factor to be considered when assessing their benefits. As more ACMT systems are validated, additional regulatory relief may be forthcoming.

3.2 Swap Buffers

Buffers can be swapped to eliminate indirect waste. When one buffer is reduced, another buffer must be increased. A common practice of Lean Railroading is to decrease the time buffer (dwell time) by increasing either the inventory or capacity buffer [4]. Buffers can be swapped as a result of ACMT by shifting mechanical personnel from inspection tasks to repair activities. As ACMT is used to augment inspections, less labor will be required and personnel can be shifted from the inspection yard to the repair facility, reducing the time buffer and increasing the capacity buffer. This increase in the capacity buffer will allow more cars to be repaired, eliminating waste and adding value. However, the extent to which the capacity buffer can be increased may be constrained by the size of the repair facility or the number of repair tracks. Railroads must incorporate a system-wide view of all the processes so appropriate buffers can be determined.

3.3 Reduce Variability

Variability is a subtle but important source of waste. Maintenance of railcars is subject to considerable variability because bad orders of varying severity may be encountered. This leads to waste because parts and labor resources are limited, and if there are only a few bad orders the extra parts remain unused and repair personnel sit idle. Conversely, if there are more bad orders than usual, there may be insufficient repair personnel, replacement parts, or space in the repair facility. Thus, variability in car inspection leads to variability in the car repair process and an increase in the time buffer, reducing the efficiency of the more important, value-adding activities.

When a train contains more defective railcars than normal, there is a negative impact on productivity. Repair time for wheelset replacement increases non-linearly as the number of bad orders increases (Figure 3), suggesting a loss in efficiency as bad orders increase.

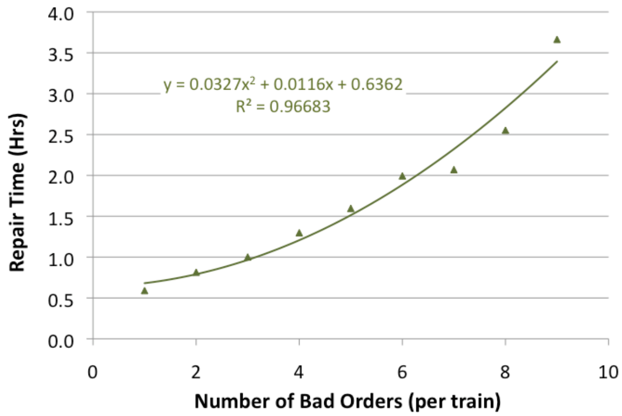

FIGURE 3. Average wheelset replacement times at a major US Class I railroad terminal, 2008-2009

A lean production method to reduce variability is to regulate work-in-process (WIP) levels. WIP is the amount of unfinished product moving through the system. Condition-based railcar maintenance can help regulate WIP and reduce variability. Condition-based maintenance is a form of preventive maintenance based on vehicle performance and/or parameter monitoring and involves taking corrective action prior to component failure [19]. Wayside detection can identify component deterioration at early stages and maintenance can be planned more efficiently resulting in WIP levels regulated to reduce system variability. Railcar component condition can be monitored such that a "window-of-opportunity" is identified for repair types and managers can select an optimal workload. Defects requiring immediate attention would have the highest priority, but less severe defects within their window-of-opportunity would not have to be repaired unless there were sufficient resources. Using Statistical Process Control (SPC) techniques, wayside detector thresholds could be set to reduce car maintenance variability while ensuring that critical defects are repaired. This would enable maximization of workforce efficiency and reduce time and inventory buffers.

3.4 Continuous Improvement

As new inspection technologies are developed and implemented, the railcar maintenance process should be continually evaluated. Regardless of how diligently managers reduce variability, it will always exist in the system [10]. Railroads need to balance time, inventory, and capacity buffers. As railcar maintenance becomes more predictive, new parts can be ordered as needed, rather than keeping large inventories. In addition, as railcars are maintained more efficiently, car availability and asset utilization will improve. This will allow railroads and customers to recover capital investments by liquidating underutilized railcars, or seek new business using the existing fleet. If railroads reduce their rolling stock fleets it will enable removal or consolidation of storage tracks, reducing the capacity buffer. Thus, improvements using lean principles can have efficiency impacts over the entire railroad network.

4. RESULTS

4.1 Calculation of Current Waste Due to 1,000-Mile Unit-Train Inspections

The largest portion of waste associated with railcar maintenance is manual inspection of railcars without defects. ACMT will provide comprehensive and automated inspection of all aspects of the railcar, leaving inspection personnel with responsibility to verify the defects identified and to make necessary repairs. Waste will be reduced from the time required to inspect an entire train, to the time required to inspect several potentially defective cars per train.

The greatest initial benefit, in terms of waste reduction, will be reduced labor during the inspection of unit-trains. Since these trains often travel long distances, they must stop for FRA Class IA, 1,000-mile air brake inspections. Unless the locomotives need refueling or a new train crew, this inspection is the only reason for the stop. In addition, unit-trains will be the first to benefit from ACMT that incorporates machine vision technology, since many of the first-generation computer algorithms for these systems were developed to inspect cars that are similar in design. In the preliminary analysis, the savings for unit-train inspections are calculated using data from one Class I rail terminal that inspects a large number of unit-coal trains each year (Table 1). In order to quantify the savings due to waste reduction, the annual labor cost required for a hybridized ACMT approach is subtracted from the labor costs for the conventional, manual inspection.

TABLE 1. Unit-train Inspection Data for an Example Class I Railroad Terminal

	Train Type				
	Coal	Grain	Automotive	Intermodal	Total
Average Inspection Time (hrs)	2.31	1.96	1.62	1.33	2.16*
Number of Trains Inspected per year	10,600	650	770	1,320	13,340
Percentage of Trains Inspected per year (%)	79	5	6	10	100

*Weighted average

4.1.1 Manual Inspection Cost

Annual labor costs for manual Class IA unit-train inspections are calculated as follows:

$$C_{manual} = 2 \times T_{manual} \times N \times S \qquad (1)$$

where,

C_{manual} = total annual labor cost for manual inspections, in US dollars

T_{manual} = average manual inspection time (weighted by train type), in hours

N = number of 1,000-mile inspections per year

S = average hourly compensation for car inspectors, including benefits in US dollars

The average inspection time, T_{manual}, is the weighted average of inspection times for each train type in Table 1, resulting in 2.16 hours per train. For this terminal, N is equal to 13,340 unit-train inspections per year. The average annual salary of a car inspector is $81,400 (including benefits) corresponding to an hourly rate, S = $39.13 [20]. This is a conservative estimate, as mechanical department manager salaries are not included. These values are multiplied by two because most train inspections involve two inspectors so total C_{manual} for this terminal is approximately $2,255,000.

4.1.2 Hybrid ACMT Inspection Cost

We assumed a hybrid inspection system in which ACMT identifies component defects and flags potentially defective cars before a train arrives in the yard. Upon arrival, only the flagged cars are inspected and decisions are made regarding whether they should be repaired or bad ordered, or are deemed satisfactory for continued operation. Annual labor costs for hybridized unit-train inspections are calculated as follows:

$$C_{hybrid} = (D \times A_{automated} + F_{\mathrm{automated}}) \times T_{hybrid} \times N \times S \qquad (2)$$

where,

C_{hybrid} = total annual labor cost for hybrid inspections, in US dollars

D = average number of detectable FRA defects per train inspection

$A_{automated}$ = average correct identification percentage for automated wayside detectors

$F_{automated}$ = average false alarm rate for automated wayside detectors

T_{hybrid} = average inspection time to verify a single component defect, in hours

Current wayside inspection technologies have accuracies ranging from 90% to 99% [13, 21, 22, 23], so an average of 95% was used for $A_{automated}$. Although false alarm rates vary widely, an average of 10% was used for $F_{automated}$. We assumed that 5 out of 100 trains containing a component defect will pass the wayside detectors without being flagged (95% accuracy) and an additional 10 out of 100 healthy (non-defective) trains will be incorrectly flagged by the wayside detectors (10% false alarm rate). The average inspection time required for an inspector to verify a flagged railcar, T_{hybrid}, was assumed to be 10 minutes, regardless of train type, and D is assumed to be 5 [23]. The total labor cost associated with a hybridized inspection process,

C_{hybrid}, is $422,000 per year. Subtracting this from the labor costs required for the current manual inspection process results in $1,833,000 of annual labor savings for this terminal.

These costs are sensitive to both the number of inspections considered, *N*, and the overall condition of the railcar fleet, represented in this model by *D*. The introduction of ACMT will increase *D* because more defects can be detected using a hybrid inspection system than with pure manual inspection. However, as railcar maintenance improves and becomes more preventive due to ACMT, *D* should decrease over time. To better understand the expected labor costs at varying magnitudes of *N* and *D*, a sensitivity analysis was performed (Figure 4).

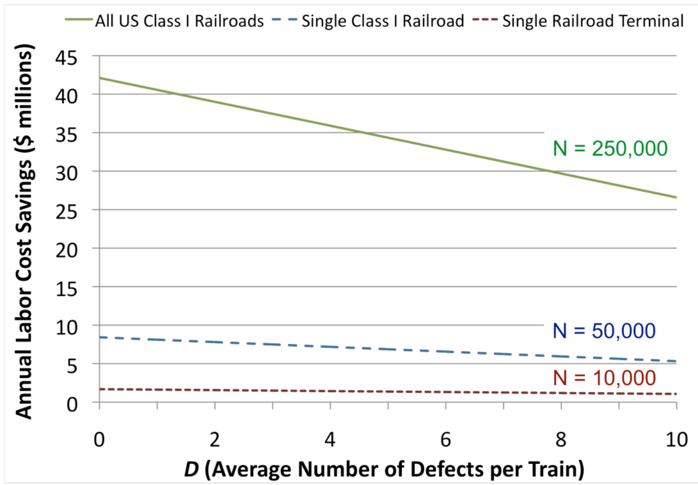

FIGURE 4. Sensitivity analysis showing labor cost savings for varying levels of railcar fleet size (*N*) and railcar condition (*D*)

In all cases, labor cost savings decrease linearly with *D*. Therefore, as maintenance practices improve, *D* will decrease and cost savings will increase. Values for *N* are representative of a major Class I railroad terminal (*N* = 10,000), an entire Class I railroad (*N* = 50,000) and all US Class I railroads (*N* = 250,000). These are approximate estimates, but they enable comparisons among various magnitudes of *N*. Assuming approximately 250,000 Class IA train inspections per year and less than five detectable FRA defects per train inspection, Class 1 railroads would save over $35 million per year in labor costs. Although not considered in this analysis, ACMT can provide additional savings as preventive maintenance strategies increase car utilization rates due to more efficient maintenance. Railcar cycle times will decrease and fewer cars would be needed for the same level of service. This increase in the capacity buffer will result in various options: 1) liquidate rolling stock assets and recover capital investment costs, 2) consolidate or remove storage tracks to recover capital investment and maintenance costs associated with underutilized infrastructure, or 3) absorb the additional capacity by pursuing new business. Thus, application of lean principles through use of ACMT can have additional economic benefits.

4.2 Summary of Results

This economic analysis indicates that a hybrid, machine-search, human-decision inspection process, is over five times more efficient, than manual inspection (i.e. C_{manual} / C_{hybrid} = 5.3). These results demonstrate the potential for significant reduction in operational waste. Although ACMT is not yet implemented to the level where every railroad terminal could benefit from the hybrid process, the efficiency of many inspections could be improved by eliminating manual inspection of healthy cars. In addition to these savings, other costs can be reduced through the elimination of other forms of waste, the appropriate allocation of buffers, and the reduction of variability.

5. CONCLUSION AND DISCUSSION

Railroad yards, like other manufacturing systems, can benefit from lean production methods. A methodology has been presented for the application of Lean Railroading to railcar inspection and maintenance practices using the four-step approach of: 1) eliminating waste, 2) swapping buffers,

3) reducing variability, and 4) performing continuous improvement. An example Class I railroad terminal was used to calculate the potential reduction in waste with an estimated annual savings of approximately $1.8 million for a single terminal. Extrapolating to all Class I railroads, implementation of the first step of Lean Railroading could save over $35 million per year and further savings realized through implementation of steps 2 through 4.

Elimination of operational waste in railcar inspection practices through ACMT will require achieving two objectives. First, ACMT systems capable of monitoring all safety-critical railcar components must be fully developed and integrated. This requires development of reliable and robust condition monitoring systems capable of addressing all aspects of FRA Class 1A, 1,000-mile air-brake inspections. Then, regulatory changes allowing automated technology to augment manual inspection will enable more effective and efficient hybrid systems that will reduce cost and improve safety. Industry and government have begun to move in this direction; regulations have been introduced that allow extended-haul trains to travel up to 1,500 miles before stopping for a required inspection [11]. In addition, trains equipped with ECP brakes may travel up to 3,500 miles before a required air brake inspection [11]. As wayside detection systems are further incorporated into railroad mechanical practices, the distance between inspections may be increased and/or the labor requirements for individual inspections reduced.

6. FUTURE RESEARCH

This paper is part of a larger analysis considering new ACMT technologies and the costs and benefits of their implementation, including an economic analysis of train accidents and mainline delays due to defective railcar components [23, 24, 25]. Track and equipment damages were calculated and train delay costs were estimated using results from dispatch simulation software. Future research should consider the costs of implementing ACMT including research and development, installation, and maintenance and institutional costs of technology integration.

To better understand the waste involved in railcar inspection practices, value stream mapping [3] can be performed to determine other Type I and Type II waste. This will involve an assessment of the entire railcar maintenance process to identify each individual inspection sub-process, and determine the value and/or waste associated with each. Variability in the railcar maintenance process can also be further investigated and methodologies developed to reduce variability using SPC and Six Sigma techniques. The robustness and generality of the results can be enhanced by collection of additional data that will improve the cost estimates for the entire US rail network.

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