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IMPROVING EMPTY CONTAINER DEPOT LAYOUTS: COMBINING EFFICIENCY AND SAFETY USING SIMULATION

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ABSTRACT

Layout decisions in empty-container depot affect both efficiency and safety, but prior studies rarely evaluate them together. This work presents an integrated discrete-event simulation framework that quantifies truck turnaround times, lifting equipment travel distances, and potential collision risks. A case study in a Chilean multipurpose terminal shows the value of the proposed framework, revealing critical workload imbalances and traffic bottlenecks, particularly for reefer operations. Statistical analyses show significant performance degradation under high truck arrival frequencies and confirm that traditional efficiency metrics only partially explain safety risks. Managerial insights include layout redesign, targeted equipment allocation, and automated gate operations. The study highlights the necessity of balancing operational efficiency and safety in space-constrained terminals to improve overall performance.

1 INTRODUCTION

Empty container depots are crucial for mid-size maritime terminals because they handle large volumes and directly influence yard productivity. Designing these depots is challenging due to limited space, dynamic workflows, and increasing competitive pressure (Baştuğ et al. 2022). Previous research often focuses on improving efficiency using simulation or mathematical models, measuring indicators such as truck turnaround times and equipment utilization (Zhang et al. 2023). However, most studies do not include safety as a measurable performance criterion, even though it can have significant operational and economic impacts.

This study addresses that gap by proposing a discrete-event simulation framework that evaluates efficiency and safety together. The framework considers three indicators: truck turnaround times, total distances traveled by lifting equipment, and the number of potential collisions at identified conflict points. Using a case study of a real depot, the work shows how different yard configurations and operational conditions affect both efficiency and safety, helping terminals make more balanced design decisions.

2 METHODS

We followed six main steps to develop and apply the simulation framework, adapted from Law and Kelton (1999). First, we documented all depot processes through field visits and interviews with staff to understand real operations. Second, we mapped operational flows, including truck movements, container handling and equipment interactions. Third, we collected and analyzed data from the terminal's system and direct measurements to set realistic model parameters. Fourth, we built a discrete-event simulation model in SIMIO, replicating the yard layout, equipment schedules and traffic patterns. Fifth, we designed experiments combining three truck arrival frequencies (low, regular, high) and two reefer-to-total container ratios (low and high), creating six scenarios; each scenario involved one-day simulations with 30 replications. Finally, we analyzed results statistically, using ANOVA and Poisson regression to explore how operational factors affect efficiency and collision risks.

3 RESULTS

The process documentation and operational flow mapping identified four key conflict zones where collisions can occur, especially near the gate. Data analysis showed that reefer trucks have longer service times and that reefer-dedicated equipment travels much more. The simulation model reproduced these patterns. Under high arrival frequencies, reefer truck turnaround times increased by up to 35%, while dry trucks were less affected. Equipment results showed a clear imbalance: dry-dedicated machines traveled less than 10 km per day, while reefer-dedicated equipment covered from 24 km to over 33 km. Collision analysis found that the number of potential collisions rises sharply at the gate when traffic is heavy, making it the most critical risk area. ANOVA confirmed significant differences across scenarios, and Poisson regression showed that longer truck times and higher equipment travel distances are linked to more collisions, although the strength of this relationship changes by location.

4 DISCUSSION

Our findings highlight that looking only at efficiency misses important safety problems. The study shows that collision risk depends strongly on traffic and yard configuration, and that equipment use is highly unbalanced. Based on these results, several managerial actions are suggested. First, adding more equipment or redistributing tasks can reduce pressure on reefer-dedicated machines. Second, redesigning the yard layout and truck routes, for example by relocating inspection processes and improving road design, can lower congestion and risk. Third, automating gate operations can reduce delays and help keep traffic flowing evenly. Together, these measures help balance efficiency and safety, supporting better decisions in yard design and daily operations.

5 CONCLUSION

This study shows that evaluating empty container depot layouts must include both efficiency and safety to reflect real operational challenges. The simulation results reveal how reefer trucks face bigger delays under high traffic and how reefer-dedicated equipment works much harder than dry-dedicated units, creating clear workload imbalances. The collision analysis identifies the gate area as the most critical risk point, and statistical tests confirmed that longer truck times and more equipment movement can raise collision risk. These findings support practical recommendations such as redesigning yard flows, reallocating equipment, and automating gate operations. By combining operational and safety indicators in the same framework, terminals can make better design and planning decisions to improve performance and reduce risks.

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