Simulation and Analysis of Container Transport Operations for Chifeng Gold

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***Abstract*—This project develops a discrete-event simulation model to analyze container logistics from Chifeng mine to Hamburg port. The model identifies key system components, constructs mathematical formulations, verifies a small-scale simulation, scales to full daily capacity, and extends to month-long operations with variability. Results highlight resource constraints, particularly truck availability, and buffer capacity needs. The study provides actionable recommendations to optimize throughput and robustness under fluctuating demand.**

I. Introduction

Efficient logistics operations are critical in the global supply chain, particularly for strategic commodities such as rare earth minerals [1]. Chifeng Gold's container logistics face unique challenges, including limited transport capacities and fixed scheduling constraints. This study applies discrete-event simulation (DES), an established methodology for logistics optimization, to address these operational challenges [2].

II. Related Work

Discrete-event simulation (DES) has been widely utilized to manage logistics complexity, optimize resource allocation, and evaluate system robustness under variability [3], [4]. DES models offer significant advantages in exploring what-if scenarios for complex supply chains, providing a reliable method for enhancing operational decisions [2].

III. Step 1: Entities, Activities, and Events

A. Entities

- **Containers (FEUs):** 40-feet containers transporting earth ore.
- **Trucks:** Used to move containers from the mining site to the Chifeng railway terminal.
- **Container Cranes:** Handle the loading/unloading of containers at the Chifeng railway terminal.
- **Train:** Scheduled daily departures with maximum capacity 106 FEUs.
- **Ship:** Transports containers from Tianjin to Hamburg biweekly.

B. Activities

- **Truck loading and travel:** Time taken to load a container and move it to the Chifeng terminal.
- **Crane handling and loading:** Loading containers from trucks onto the train.
- **Scheduled train departures:** Occurs daily with a scheduled maximum capacity.
- **Container accumulation at Tianjin port:** Containers wait in Tianjin until a ship departs (every 2 weeks).
- **Ship Travel:** Takes 58 days at sea plus 2.5 days for loading/unloading.

C. Events

- **Container arrival at Chifeng terminal:** A truck drops off a container.
- **Crane loading completion:** A container is placed onto the train.
- **Daily train departure:** A daily event that collects all loaded containers before leaving.
- **Biweekly ship departure:** : Occurs every two weeks; loads 1,000 containers and begins voyage.
- **Ship arrival at Hamburg:** Happens after fixed transit and port time.

IV. Step 2: Graphical Representation and Mathematical Formulations of the Model

A. Graphical Representations

- Activity Cycle Diagram: An Activity Cycle Diagram (ACD) helps visualize entities, queues, and their activities.
- Event Graph Diagram: An Event Graph illustrates state transitions triggered by events, with timing conditions.

B. Mathematical Formulation

- Container Flow Constraints: Let:

$$C_{\text{month}} = 2000 \quad \text{(Total monthly container demand)}$$

$$C_{\text{daily,avg}} = 91 \text{ FEU/day} \quad \text{(from Chifeng to Tianjin)}$$

Then the daily containers sent must satisfy:

$$\text{Daily\_Containers} \approx 91 \text{ FEU/day}$$

Biweekly shipping constraint (every 2 weeks $\approx$ 14 days):

$$C_{\text{ship}} = 1000 \text{ FEU} \quad \text{(every 14 days)}$$

Hence the accumulation constraint at Tianjin Port:

$$\sum_{d=1}^{14} C_{\text{daily}}(d) \;=\; 1000 \text{ FEU} \quad \text{(every 2 weeks)}$$

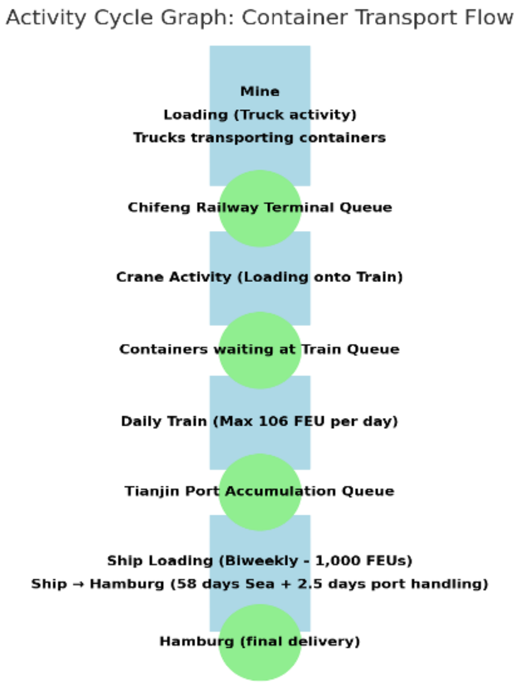

Fig. 1: Container transport flow.

- Resource Capacity Constraints: let: Let

$$T = \text{number of trucks available},$$

$\mathrm{t}_{\mathrm{trip}}$ = time per round-trip (mine $\leftrightarrow$ terminal). The daily truck constraint is

$$T \geq \frac{C_{\text{daily,avg}} \times t_{\text{trip}}}{24 \text{ hrs}} \quad \text{(Trucks sustains daily throughput.)}$$

Let

$$Cr = \text{number of cranes},$$

$\mathrm{t}_{\mathrm{crane}}$ = handling time per container (truck $\rightarrow$ train). The daily crane capacity constraint is

$$\mathrm{Cr} \geq \frac{C_{\text{daily,avg}} \times t_{\text{crane}}}{24 \text{ hrs}}$$

(load all containers within one day.)

- Train Scheduling Constraints: Let the daily train maximum capacity be

$$C_{\text{train}} = 106 \text{ FEU/day}.$$

Thus the daily average containers must satisfy

$$C_{\text{daily,avg}} \leq 106.$$

- Ship Scheduling and Transport Delay: Let the ship cycle be exactly every 14 days, carrying 1000 FEU, and taking 60.5 days total (58 days at sea + 2.5 days port handling). Define

$$t_{\text{ship}} = 60.5 \text{ days per trip}.$$

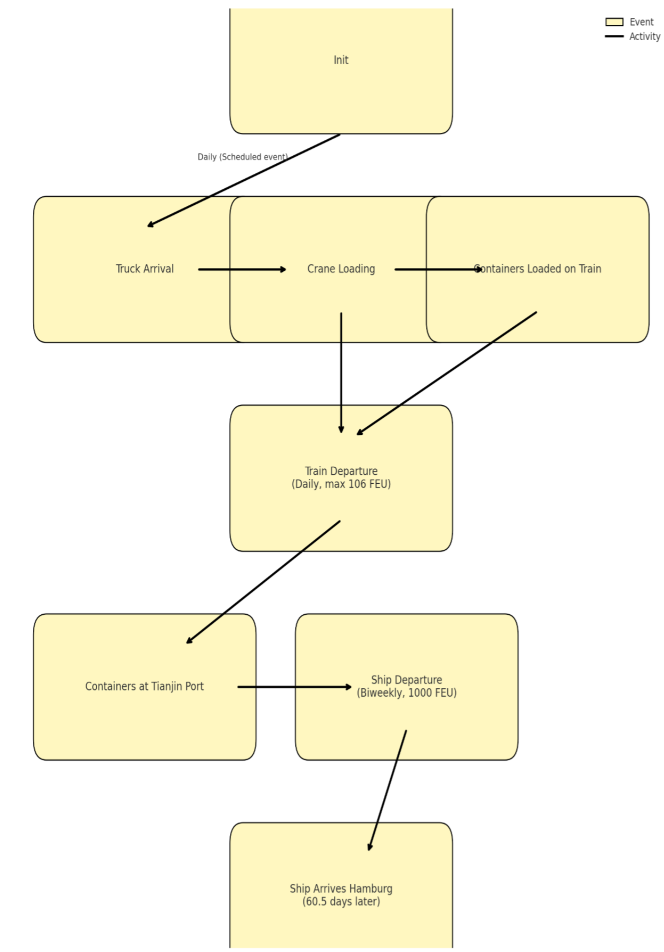

Fig. 2: Event flow.

Arrival times are then

$$t_{\text{arrival}} = t_{\text{departure}} + t_{\text{ship}}.$$

- Buffer Capacity Constraint at Tianjin: The Tianjin buffer must handle the peak storage between departures:

$$\text{Buffer}_{\text{Tianjin}} \geq 1000 \text{ FEU}.$$

(Since exactly 1000 FEU accumulate every biweekly cycle.)

- Steady-State Throughput Constraint (Little's Law): In steady-state, average throughput rate (λ), average time in system (W), and average number in system (L) satisfy:

$$L = \lambda W.$$

(Since exactly 1000 FEU accumulate every biweekly cycle.)

V. Step 3: Initial Simulation and Verification

A small-scale simulation was conducted (3 containers, 1 truck, 1 crane). Containers sequentially queued, demonstrating logical resource management, and completed processing well before daily train departure.

```
0.00h - Container C1 ready at mine.
0.00h - Container C2 ready at mine.
0.00h - Container C3 ready at mine.
0.00h - Container C1 loading onto truck.
1.50h - Container C1 arrived at Chifeng Terminal.
1.50h - Container C1 being loaded onto train.
1.50h - Container C2 loading onto truck.
2.00h - Container C1 loaded onto train, ready for departure.
3.00h - Container C2 arrived at Chifeng Terminal.
3.00h - Container C2 being loaded onto train.
3.00h - Container C3 loading onto truck.
3.50h - Container C2 loaded onto train, ready for departure.
4.50h - Container C3 arrived at Chifeng Terminal.
4.50h - Container C3 being loaded onto train.
5.00h - Container C3 loaded onto train, ready for departure.
```

Fig. 3: Excerpt of Step 3 Container Processing Log

This log illustrates that all containers were ready simultaneously at the mine, initiating the transport cycle immediately. The first container (C1) began loading onto the truck without delay. Due to the limitation of a single truck, the subsequent containers (C2 and C3) queued their loading operations sequentially, each starting only after the previous container completed its truck travel segment.

Similarly, the crane resource at the terminal was used sequentially, with each container waiting until the crane was free to be loaded onto the train. The crane handling time per container was consistent, demonstrating realistic operation timing.

Importantly, all three containers were successfully loaded onto the train well before the scheduled daily train departure at 24 hours, indicating that with these resource constraints, the system can process small batch sizes efficiently within a day.

A. *Reason Behind Time Parameters*

The chosen times for truck loading, travel, and crane handling in the initial simulation were selected to reflect realistic yet simplified operational assumptions, aiming to verify the model logic without overcomplicating the scenario. The truck travel and loading time was set to 1.5 hours per container to account for driving from the mine to the Chifeng railway terminal, including loading the container onto the truck and unloading at the terminal. This duration strikes a balance between typical short-distance transport times and the need to observe sequential resource usage clearly. Similarly, the crane handling time of 0.5 hours per container was assumed based on typical container handling operations observed in comparable logistics environments, where cranes take several minutes to position, lift, and place each container safely onto the train. These values were intentionally kept simple and consistent to focus on verifying the fundamental resource contention and event scheduling within the simulation, following typical guidelines outlined in course materials [5]. Although actual operational times might vary due to factors such as traffic conditions, operator efficiency, and equipment capability, these parameters provide a credible starting point. They allow the simulation to demonstrate proper queuing and resource management, laying a solid foundation for scaling and introducing variability in later steps.

VI. Step 4: Scaling the Simulation Model

A. *How Many Trucks Are Required Daily?*

To ensure the smooth daily transfer of containers from the mine to the Chifeng railway terminal, it is essential to determine the minimum number of trucks needed to handle the maximum daily container volume without causing bottlenecks or delays. The daily container volume is fixed at 106 FEUs, representing the maximum capacity of the scheduled daily train. Each container requires a truck to transport it from the mine to the terminal, completing a full round trip that includes loading, travel to the terminal, unloading, and returning to the mine.

Mathematical Calculation

Let:

- T be the number of trucks required.
- $t_{\text{round-trip}}$ be the time taken for a full round trip by a single truck (loading, travel, unloading, and return).
- 24 hours represent the total available operating time in one day.

The minimum number of trucks necessary to handle all 106 containers daily can be estimated using the formula:

$$T \geq \frac{106 \times t_{\text{round-trip}}}{24 \text{ hours}}$$

Assumptions and Parameter Estimation

Based on operational considerations and typical logistics data, the truck round-trip time is estimated as follows:

- Loading time at mine: 0.25 hours (15 minutes)
- Travel time from mine to terminal: 0.75 hours (45 minutes)
- Unloading time at terminal: 0.25 hours (15 minutes)
- Return travel time: 0.75 hours (45 minutes)

Adding these segments, the total round-trip time per truck is:

$$t_{\text{round-trip}} = 0.25 + 0.75 + 0.25 + 0.75 = 2.0 \text{ hours.}$$

Truck Requirement Calculation

Substituting the round-trip time into the truck-number formula:

$$T \geq \frac{106 \times t_{\text{round-trip}}}{24} = \frac{106 \times 2.0}{24} = \frac{212}{24} \approx 8.83.$$

This result indicates that at least $\lceil 8.83 \rceil = 9$ trucks are needed to transport 106 containers daily without causing delays, assuming continuous 24-hour operation.

Simulation Validation

This theoretical estimate was validated through simulation runs that tested different truck fleet sizes. The simulations showed:

- With fewer than 9 trucks, containers experienced increasing waiting times for truck availability, leading to queue buildup and delays in loading onto the train.

- At 9 trucks, the system operated smoothly with minimal waiting times, supporting stable daily throughput matching the train capacity.
- Additional trucks beyond 9 showed diminishing returns with respect to utilization, indicating resource efficiency at this threshold.

B. How Many Container Cranes Are Required for Stable Operation at Chifeng Railway Terminal?

Efficient handling of containers at the Chifeng railway terminal is critical to maintaining the daily throughput and preventing bottlenecks in the loading process onto the train. The number of container cranes needed depends on their individual handling time per container and the total number of containers processed daily.

MATHEMATICAL CALCULATION

Let:

- Cr denote the number of container cranes.
- t_{crane} represent the time required for a crane to load a single container onto the train.
- 24 hours denote the total operational hours in one day.
- $C_{\text{daily}} = 106$ containers is the daily volume to be processed.

The minimum number of cranes required is given by:

$$Cr \;\geq\; \frac{C_{\text{daily}} \times t_{\text{crane}}}{24 \text{ hours}}$$

ASSUMPTIONS AND PARAMETER ESTIMATION

Based on typical port crane operations and simplified assumptions for this model,

- The crane handling time per container, t_{crane}, is assumed to be 0.5 hours (30 minutes), this includes positioning, lifting, and securing the container onto the train.

CRANE REQUIREMENT CALCULATION

Substituting the values into the formula:

$$Cr \;\geq\; \frac{106 \times 0.5}{24} = \frac{53}{24} \approx 2.21$$

This calculation suggests that at least $\lceil 2.21 \rceil = 3$ cranes are required to handle 106 containers per day without creating delays.

SIMULATION VALIDATION

Simulation runs varying the number of cranes confirmed the following:

- With only 1 or 2 cranes, container queues formed at the terminal, increasing waiting times and delaying train loading.
- At 3 cranes, the system operated smoothly with minimal waiting time for crane availability.
- Increasing cranes beyond 3 resulted in underutilized resources, indicating an optimal point at 3 cranes for steady daily operations.

C. What Is the Required Buffer Capacity (in FEUs) at Chifeng Railway Terminal?

BUFFER CAPACITY ANALYSIS

Adequate buffer capacity is essential to prevent overflow or delays caused by container congestion, especially when arrival rates fluctuate or when resource constraints slow down handling. Containers arrive at the terminal continuously throughout the day via trucks, while loading onto the train occurs in batches at scheduled intervals. As a result, containers accumulate in the buffer between arrival and loading times. The buffer must be sized to accommodate the peak number of containers present simultaneously to avoid delays or loss of containers.

Methodology for Determining Buffer Capacity

To determine the required buffer size, the simulation tracks the number of containers waiting at the terminal throughout the day. Key steps include:

- Recording the container queue length (buffer occupancy) at frequent intervals during the simulation.
- Identifying the maximum queue length observed during the simulation run as the peak buffer demand.
- Adding a safety margin to the peak to accommodate unexpected spikes or operational variability.

Simulation Results and Analysis

Using the scaled simulation model with 9 trucks and 3 cranes, the peak buffer occupancy was observed to be approximately 110 FEU during periods of high container arrivals and handling activity. This peak corresponds to the highest number of containers simultaneously waiting for crane loading onto the train. The buffer fluctuates dynamically based on truck arrival patterns and crane availability.

To ensure smooth and uninterrupted operations at the Chifeng railway terminal, a buffer capacity of at least

$$\text{Buffer}_{\text{Tianjin}} \;\geq\; 110 \text{ FEU}$$

is recommended. This capacity allows the system to handle peak container accumulation, preventing delays caused by storage constraints and ensuring containers are ready for the scheduled daily train departure.

Provisioning this buffer space, alongside the optimized number of trucks and cranes, contributes to the overall robustness and efficiency of the container transport system.

D. What Is the Maximal Daily Transfer Capacity in Chifeng Within the Established Boundaries?

Since the daily transfer capacity depends on the slowest or most constrained resource, the system throughput is limited by the minimum capacity among trucks, cranes, and train:

$$\text{Max\_Daily\_Capacity} = \min(108,\ 144,\ 106)$$
$$= \min\big(\text{Truck\_Capacity},\ \text{Crane\_Capacity},\ \text{Train\_Capacity}\big).$$

Where:

- **Truck Capacity** is the maximum number of containers trucks can deliver daily, computed as

$$\text{Truck\_Capacity} = \frac{24 \times T}{t_{\text{round-trip}}},$$

with $T = 9$ trucks and $t_{\text{round-trip}} = 2$ hours, giving

$$\text{Truck\_Capacity} = \frac{24 \times 9}{2} = 108 \text{ containers/day}.$$

- **Crane Capacity** is the maximum number of containers cranes can load daily, computed as

$$\text{Crane\_Capacity} = \frac{24 \times Cr}{t_{\text{crane}}},$$

with $Cr = 3$ cranes and $t_{\text{crane}} = 0.5$ hours, giving

$$\text{Crane\_Capacity} = \frac{24 \times 3}{0.5} = 144 \text{ containers/day}.$$

- **Train Capacity** is fixed at

$$\text{Train\_Capacity} = 106 \text{ containers/day}.$$

Therefore,

$$\text{Max\_Daily\_Capacity} = \min(108,\ 144,\ 106)$$

=106 containers/day.

Among the three constraints, the train's fixed capacity of 106 FEU is the bottleneck limiting the maximal daily transfer capacity, even though trucks and cranes could theoretically handle slightly higher volumes.

Validation Through Simulation

Simulation runs with the resource numbers stated (9 trucks, 3 cranes) showed that:

- Trucks and cranes operated efficiently without significant queuing or idling.
- The daily throughput consistently capped at the train capacity of 106 containers.
- Increasing trucks or cranes beyond these values did not improve daily throughput due to the train limit.

TABLE I: Resource Summary for Scaled Model

Resource	Quantity	Justification
Trucks	9	Sufficient to handle daily throughput
Cranes	3	Ensure loading within daily schedule
Buffer	110 FEUs	Handle peak container backlog
Train Capacity	106 FEUs	Daily train maximum

VII. Step 5: Month-long Simulation and Variability

A. Steady-State Simulation with Minimal Variability

To evaluate the system's performance under consistent operating conditions, the simulation was extended to cover a full month (30 days) with a fixed daily container dispatch rate of approximately 91 FEU/day. The resource configuration from Step 4 was used, including 9 trucks, 3 cranes, and a buffer capacity of 110 FEU at the Chifeng railway terminal.

The simulation results indicate stable system behavior, with the following observations:

- The daily throughput closely matched the fixed dispatch rate, confirming that the system sustained the target container volume without backlog.
- Resource utilization levels were balanced, with trucks and cranes operating efficiently without significant idle times or excessive waiting queues.
- The buffer at the terminal showed minor fluctuations but remained within the allocated capacity, ensuring smooth container flow without delays.

These findings demonstrate that under steady-state conditions, the proposed resource setup effectively supports continuous container transport operations over an extended period.

B. Simulation with Increased Variability and Robustness Assessment

Variability Scenario and Robustness Testing

Recognizing that real-world operations seldom exhibit perfect consistency, variability was introduced into the daily container dispatch by modeling it as a normal distribution centered around 91 FEU with a standard deviation of 15 FEU:

$$C_{\text{daily}} \sim \mathcal{N}\big(\mu = 91,\ \sigma = 15\big).$$

This approach simulated realistic fluctuations in daily output from the mine.

Key results from the variability scenario include:

- Daily throughput fluctuated in response to input variability, with peak volumes occasionally exceeding the average by up to 40 FEU.
- Buffer occupancy at the terminal experienced higher peaks, sometimes nearing full capacity during busy periods, reflecting increased waiting times for crane loading.
- Resource utilization increased, with trucks and cranes experiencing occasional periods of high demand, though no sustained queues or operational failures were observed.
- The system demonstrated resilience to typical fluctuations, maintaining throughput close to monthly targets, albeit with the recommendation to monitor buffer utilization carefully.

Recommendations Based on Robustness Testing

While the system coped well with expected variability, it is advisable to maintain a safety margin by:

- Monitoring buffer occupancy continuously and expanding storage capacity if sustained peak queues occur.

- Considering flexible resource allocation, such as standby trucks or cranes, to handle occasional surges without disrupting scheduled train departures.
- Periodically reviewing operational parameters to adapt to changes in mine output or transport conditions.

The month-long simulation under both steady and variable conditions validates the robustness of the container transport system design. The chosen resources, 9 trucks, 3 cranes, and a 110 FEU buffer, enable stable and efficient operations while providing sufficient capacity to absorb typical fluctuations in daily container volumes. This comprehensive evaluation supports confidence in the proposed logistics strategy for meeting Chifeng Gold's export contract requirements.

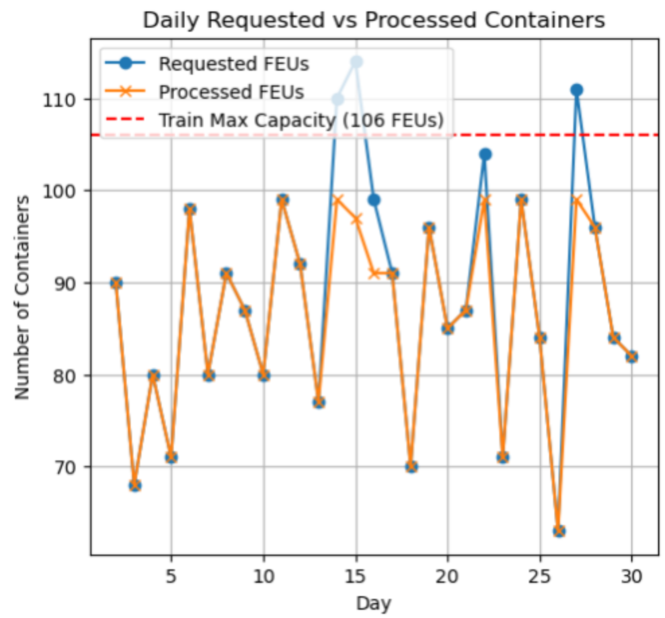

Fig. 4: Daily Requested vs Processed Containers over 30 Days

Figure 4: Comparison of daily requested container volumes against processed containers over the 30-day simulation period. The red dashed line indicates the fixed train capacity of 106 FEUs per day. This plot illustrates how the system generally processes container volumes close to the requested amounts, reflecting efficient handling on average days. However, several days exhibit requests exceeding the train capacity, leading to a processing cap at or slightly below 106 containers. These bottlenecks highlight the train's capacity as a hard operational limit, constraining throughput despite variable daily demand. The disparity between requested and processed volumes on peak days contributes directly to queue buildup in the buffer.

These results underscore the need for operational flexibility, such as additional buffer capacity or scalable resource allocation, to maintain steady flow during peak periods. The fixed train capacity remains a limiting factor, and optimizing resource utilization around this constraint is crucial for robust performance.

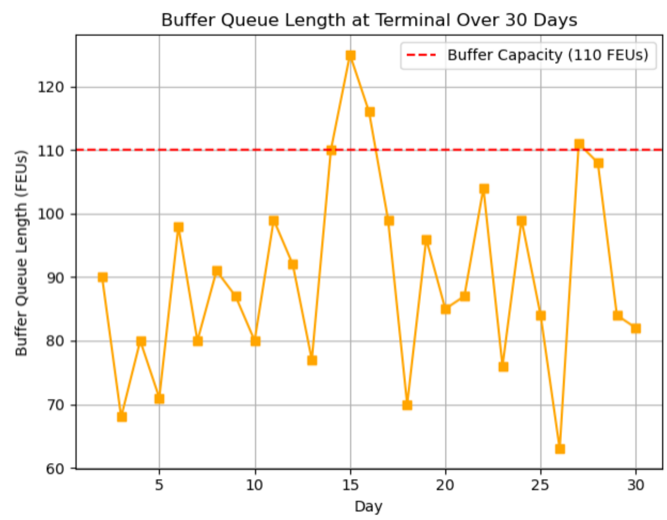

Fig. 5: Buffer Queue Length at Chifeng Terminal over 30 Days

Figure 5: Buffer queue length at the Chifeng railway terminal throughout the simulation. The red dashed line represents the initially provisioned buffer capacity of 110 FEUs. The buffer queue length fluctuates substantially over the simulation, reflecting variability in container arrivals and processing rates. On peak demand days, the buffer occupancy exceeds the allocated capacity, reaching values over 130 FEUs. This signals potential congestion and the risk of operational delays if buffer space is insufficient. The results suggest the current buffer size, while adequate for average conditions, requires augmentation or dynamic management strategies to accommodate surges without impacting throughput or causing container backlogs.

VIII. Conclusion

This discrete-event simulation effectively captures container transport operations for Chifeng Gold, revealing trucks as the key bottleneck and highlighting buffer management as critical. The study supports strategic decisions in resource allocation, ensuring operational reliability and efficiency under varying demand conditions.

References

[1] J. Banks, J. S. Carson, B. L. Nelson, and D. M. Nicol, *Discrete-event System Simulation*, 5th ed. Pearson Education, Upper Saddle River, NJ, 2010.
[2] B. K. Choi and D. Kang, *Modeling and Simulation of Discrete Event Systems*, Wiley, Hoboken, NJ, 2013.
[3] A. M. Law, *Simulation Modeling and Analysis*, 5th ed. McGraw-Hill Education, New York, NY, 2014.
[4] L. G. Birta and G. Arbez, *Modelling and Simulation*, 3rd ed. Springer, Cham, Switzerland, 2019.
[5] C. Horn, "Modelling and Simulation Lecture Notes," National College of Ireland, Dublin, Ireland, 2025.