Proceedings of the 1988 Winter Simulation Conference
M. Abrams, P. Haigh, and J. Comfort (eds.)

Steel product transportation and storage simulation: A combined simulation/optimization approach

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ABSTRACT

Product transportation and storage in steel works are modeled in order to evaluate both facility specification and transportation rules. Discrete-event simulation together with mathematical optimization technique are carried out based on probability distribution which is determined by analysis of actual operating data. The model utilizes a combined network and discrete-event approach written under the SLAM II simulation language. Simulation results show that the proper configuration of facilities and suitable transportation rules contribute to the carriage efficiency and lead to the great reduction of transportation cost in steel works.

1. INTRODUCTION

In the past days, steel products (wire rods and bars in coil) were carried by so-called lift cars (Refer to Fig.1) from mills to warehouses in steel works. A lift car can carry at most two coils at one time. It has been a big problem to develop a new efficient transportation system instead of lift cars which prevent effective carriage. At our steel works, we decided to transport steel products by the new transportation system which employs trailers and pallets (T&P), in order to increase carriage efficiency.

The purpose of simulation is to find the bottleneck of this new transportation system and to decide the proper facility configurations and transportation rules. The analysis reveals that the most crucial facility specification is a determination of the space capacity for pallets placed at millends. Two main transportation rules considered are the methods of product transportation and of storage in warehouse.

Prior to simulation, actual operating data at steel works in the last few months have been analyzed in order to determine the probability distribution used to generate simulation entities, which correspond to products at millends. The model is written under the SLAM II language(Pritsker 1986). Discrete-event simulations have been carried out together with mathematical optimization technique called linear search method(Meketon 1987). The simulation results show that it is possible to transport more efficiently than we expected at the beginning and to lead to great (about 20 %) reduction of transportation cost.

2. SYSTEM DESCRIPTION

The steel works which the new transportation system has been introduced into is one of integrated iron and steel works at Sumitomo Metal Industries Ltd., and mainly produces wire rods and bars. The total product quantity of the steel works amounts to approximately 100 thousand metric tons per month.

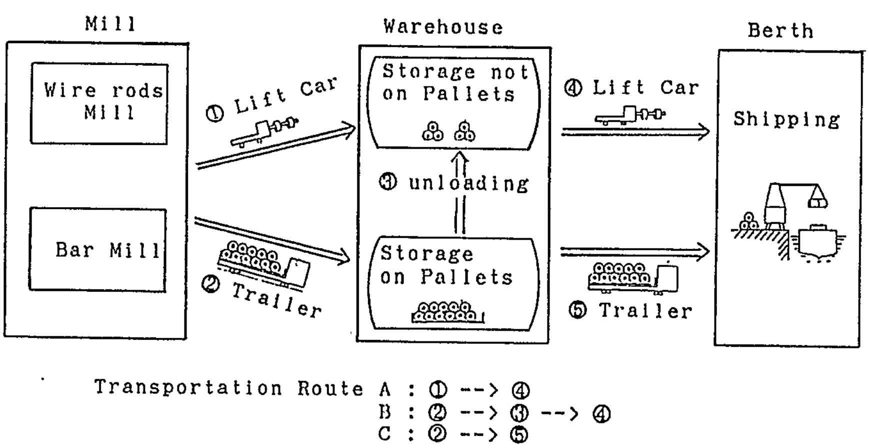


Figure 1: The New Transportation System

The operating processes in steel works are mainly divided into two stages. One is production stage and the other is transportation and storage stage. At the former stage, firstly pig iron is made from iron ores at blast furnaces and then is made into steel and formed into billet by casting machine. Next, billet is rolled to become wire rods or bars at one of mills. If necessary, heat treatment or testing is conducted after rolling. At the latter stage, on the other hand, steel products are transported from mills to warehouse in order to stock them temporarily. When ships arrive, steel products are carried from warehouse to berth in order to be loaded into the ships.

In the transportation and storage stage, products used to be carried by lift cars. The problem of this transportation method is low efficiency. In order to improve the carriage efficiency, a new transportation method using trailers and pallets are introduced. In this method, prior to carriage on pallets, products at millends are assorted according to their destinations. Namely, products with the same destination are loaded on the same pallet. Then a trailer carries the pallet which is filled with products to warehouse. About 20 or 30 steel coils (wire rods or bars in coil) can be loaded on one pallet and a trailer can carry one pallet at one time. In the new transportation system, there are three alternative ways to carry and store products (Fig.1). In the first alternative, products on pallet are carried by a trailer and are temporarily stored on pallet in warehouse (Route C). In the second alternative, products on pallet are carried by a trailer and are stored not on pallet but individually in warehouse (Route B). Finally, in the third alternative, products are carried by lift car and stored in warehouse individually (Route A). Route A incidentally is the only possible mode of operation in our current system.

3. MODEL DESCRIPTION

The purpose of this simulation is to establish the transportation method so as to minimize total transportation cost. In other words, we want to:

- evaluate space capacity for product assortment at millend,
- predict the amount of products carried on pallets,
- study effects of different transportation rules and possibly look for an optimal rule,
- facilitate analysis on transportation quantity and bottleneck resolution.

Approximately 30 operational parameters are required for simulation which include:

- space capacity for product assortment at millends,
- unloading time from pallets to stock in warehouses,
- trailer's transportation time from millend to warehouse,
- transfer time of an empty pallet from berth to millend,
- products unloading time from a pallet at berth.

Most of the model is written as a SLAM network model except that several transportation rules are coded in Fortran which is linked with SLAM II.

SLAM II is found to be powerful for this simulation mainly because of the following two reasons. First, it allows to change parameters or rules with ease. Second, the language provides modeling capabilities which fit our T&P transportation problem. The essence of the model can be described as a SLAM network model without much difficulties. For example, BATCH node in SLAM II is convenient for the description of assorting and loading products on pallets according to their destinations. As an another example, SELECT node with ASM option is found to be suitable for the description of a trailer which carries products on a pallet. There were some aspects of modeling which initially created difficulties and required some thoughts. The main difficulty was due to the huge number of entities which exist in a model concurrently. The number of products could be as many as 25,000, and if we regard each product as an entity, the model blows up. In order to settle this problem, we code user subroutines with Fortran to store both the number of used pallets and weights according to destinations, and delete entities when the product arrives at warehouses.

4. SIMULATION

In this simulation study, there are three important aspects: identification of the input probability distribution, setting up of transportation rules, and optimization using simulation. In this section, these aspects are described in detail.

4.1 Identification of the Input Probability Distribution

For the purpose of our simulation, it was found enough to classify arriving products by the following three types of attributes: production mills, destinations, and weights. Generally speaking, not necessarily all product classes are produced on a particular day. If a particular product class is in production on a specific day, the products tend to arrive to a millend in several groups of batches. This is because it is more beneficial to manufacture steel coils with the same attributes consecutively as long as possible. But due date considerations as well as certain technological constraints (e.g., the quantity that the same product can be rolled continuously is limited in order to avoid unbalanced abrasion of the roll) prohibit production of the entire quantity in a single batch. Within each batch, products arrive the millend with an approximately constant interval (say, a 1-2 minute interval).

Based on the situation just described, product arrivals are simulated in two stages. First, product classes which are produced on a particular day are decided based on the past history. Second, if a particular product class is in production on a particular day, actual arrivals of individual products will be generated based on the probability distribution estimated from actual operation data. We now describe steps to determine this probability distribution (Fig.2):

Step 1 (Collection of historical data)- Production history during the last few months have been collected and classified according to three kinds of product attributes: production mills, destinations, and weights.

Step 2 (Identification of a frequency distribution)- For each product class collected in step 1, the following three types of data are compiled each day for the duration of a month;
1) the total number of product arrivals,
2) inter-arrival times of the product class,
3) the initial arrival time of product.

Step 3 (Transformation into a cumulative distribution) - Based on the data compiled in step 2, a cumulative probability distribution for inter-arrival times is determined for each product class.

Product arrivals are then generated in simulation using the initial arrival time of products to millend, a cumulative probability distribution for inter-arrival times, and the total number of product generation all of which are defined for each product class.

<Step 1> Date 12/1/88

Sequential No.	Product Class			Arrival Time
	Mill	Destination	Weight (tons)	
1	W	a	1	7:10
2	B	b	2	7:11
⋮	⋮	⋮	⋮	⋮
10	W	a	1	7:23
⋮	⋮	⋮	⋮	⋮

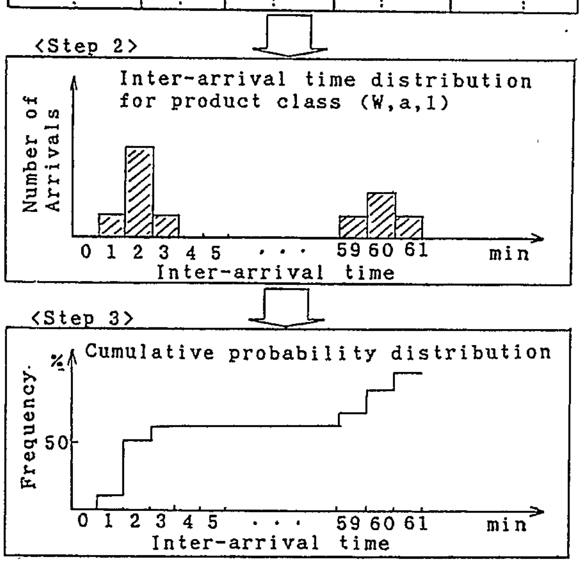
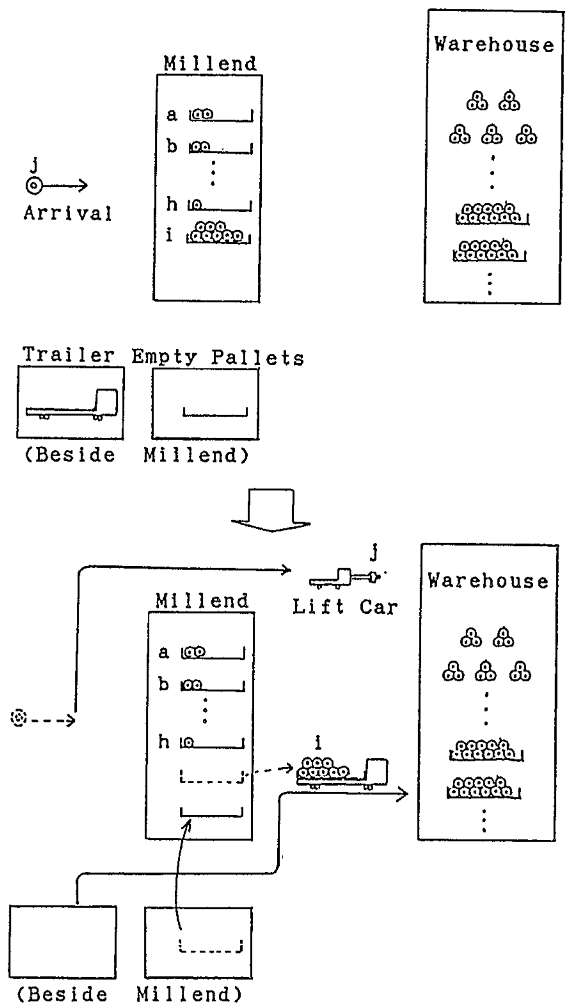


Figure 2: Identification of the Inter-arrival Distribution for Each Product Class from Historical Data

4.2 Setting up of Transportation Rules

There are three areas in this model which require determination of transportation rules. The first one is a transportation rule from mills to warehouse, which is described by Fortran. When there is no pallet which has the same destination as that of the newly arrived product at the mill, that product is carried to a warehouse by lift car and not by trailer & pallet (1) in Route A). In addition, if a trailer is available for transportation and there is an empty pallet near the millend (Empty pallets, if any, are stored at the storage area located beside the millend.) at that time, the pallet which is most fully loaded with products is transferred from millend to warehouse by trailer. Then, a new empty pallet is placed at the millend (Fig.3). If a trailer is not available or there is not an empty pallet near millend, no pallet is transferred to ware-



◎ : steel product
a,b,⋯h,i,j : products' destinations

Figure 3: Transportation Rule from Mill to Warehouse

house. The reason why a trailer is requested to move the most fully-loaded pallet whenever a lift car is used to move an individual product for which a pallet with the same destination cannot be found, is that, because of the current mode of production described at the beginning of this section, the same product class tends to arrive more in the future, and thus it appears beneficial to have a pallet for this product class (i.e., for this destination). We also note that a trailer is requested to move a pallet from millend to warehouse once the pallet becomes full.

The second is a product unloading rule from pallet at warehouse. If a pallet with products arrives at warehouse and the number of pallets at millend (including near millend) are less than N (for example, 4), the products are unloaded from the pallet at warehouse, which then is carried back to millends (3 in Route B). The purpose of this rule is to keep the number of pallets a fixed level all the time so as to avoid the increase of amounts in Route A caused by pallet shortage.

The third is a shipping rule described by Fortran. When a ship arrives to a berth, products on pallets which have the same destination with that of ship are carried out to the berth and loaded into the ship, then the empty pallets are returned to millends. Trailers and lift cars used for transportation on Route 4 and 5, respectively, are dedicated to the transportation between the warehouse and the berth, and they are not of concern in this simulation study.

Other rules are expressed using network constructs of SLAM II. Two main rules of them are a trailer returning rule and an empty pallet returning rule. The former is a rule to determine which millends the trailer returns to after transporting products to warehouse. In this model, trailer is assumed to return to the millend where the number of trailer is smaller. The latter is a rule to determine which millends the pallet is returned to after products unloading at warehouse or berth. In this model, a pallet is assumed to be returned to the millends where the number of empty pallets is smaller. Table 1 summarizes simulation specifications.

4.3 Optimization using Simulation

For the type of problem scenario described in this paper, there exist a number of parameters related to the physical configuration of the proposed transportation system for which optimization may be considered. Several such examples are listed below:
1) the number and the capacity of trailers (for transportation between mills and the warehouse),
2) the number and the capacity of pallets,
3) the capacity of the warehouse in terms of the maximum number of pallets that can be stored,
4) the pallet space capacity at millends.

In our case, 1) through 3) were already fixed due to various other considerations when this study was initiated, and thus we were interested in determining pallet space capacity at millends so as to minimize total transportation cost. Total transportation

Table 1: Simulation Specifications

Items	Specifications
Number of Trailers	about 5
Number of Pallets	about 150
Number of Lift Cars	about 100
Weight Capacity of a Pallet (for wire rods)	about 50 tons
Weight Capacity of a Pallet (for bar in coil)	about 70 tons
Number of Destinations	about 10
Number of Mills	2
Simulation Period	30 days
Number of Products Created	about 25000

Table 2: Simulation Results

Iteration	Transportation Route (Cost†) / N††	Transportation Amounts (%) A (10)	B (2.5)	C (1)	Total ---	Total Cost (%)	Average Utilization (%) Lift Cars	Trailers	Average Number of Pallets stored in Warehouse
1	#	25.5	0.0	74.5	100.0	100.0	41.9	42.8	59.7
2	4	7.0	9.0	81.0	100.0	55.0	14.1	55.5	60.7
3	8	2.9	18.3	78.8	100.0	46.6	6.9	52.3	59.1
4	12	1.0	20.7	78.3	100.0	42.5	3.7	49.1	57.0
5	10	1.1	20.5	78.4	100.0	42.6	4.0	49.2	58.2
6	11	1.0	20.2	78.8	100.0	42.3	3.7	49.1	57.2

† Cost : cost per transportation weights
†† N : pallet space capacity at each millend
\# : products unloading at warehouse is prohibited

cost in this model is assumed to be unimodal function of the number N of pallets which are always kept at each millend. That is, N is the pallet space capacity at each millend. To find an optimal pallet space capacity, simulation is run repeatedly with the help of a mathematical optimization technique called linear search method. In other words, simulation runs are repeated while automatically changing the value of N based on the total transportation cost in the previous iterations.

5. RESULTS

Table 2 shows simulation results for each iteration. Iteration 1 shows that many products (25.5 %) are transported by lift cars because of shortage of empty pallets at millends when products unloading at warehouse is prohibited. Therefore all products which are carried by T&P from millends are stored on pallets at warehouses in iteration 1.

Iterations 2 to 6 are the results when the new transportation rule is applied. The rule means that when the number of pallets at millend is less than N (parameter), products which newly arrive at warehouse are unloaded from pallet, and the pallet is carried back to millend. According to the results shown in Table 2, the larger N is, the smaller the product amount carried by lift cars (Route A). This means that pallets will be short at millends unless pallets are compulsorily carried back to millends.

On the other hand, when N is greater than 11, the product amount carried by lift cars are not decreasing because of temporary shortage of trailers. This means that it is enough to place 11 pallets at each millend. In other words, it is necessary for pallet space capacity to be at least 11. Furthermore, iteration 6 has the minimum transportation cost.

The validity of these results has been thoroughly checked among three groups, namely, simulation engineers, key persons on products transportation in steel works, and decision makers. Through this simulation project, such validity check has proved to be the most important factor of simulation and decision making. The purpose of this simulation is to find the bottleneck of the new trailer and pallet transportation system and to decide the proper facility configurations and transportation rules. In actual steel works operation, there are three important items to be well considered; 1)cost, 2)efficiency and easiness of transportation work, and finally 3) safety of workers.

Cost is certainly the most important factor in steel works. Therefore simulations are repeated until the system configuration and its operating rule have been found which lead to minimum cost transportation. Efficiency and easiness of transportation work is also an important factor. Even if the minimum cost transportation method is found through simulation, it is meaningless in steel works operation if the new system makes workers' operation more difficult. The new transportation system must lead to easier and more effective operations. Furthermore, even if the new system is easier and more effective, it must not accompany hazardous work. Considering all these factors, discussions were repeated among simulation engineers, key persons on products transportation, and decision makers. A trial transportation system using trailers and pallets were set up based on simulation results. The trial system was actually implemented and its results were thoroughly checked. In case that a new problem was found, solutions for the problem were discussed and simulations with new conditions were performed. Repeating the process of simulation ,discussions, a test trial, checking, and re-simulation, project members have reached the most desirable form of the new transportation system.

6. CONCLUSIONS

With the help of simulation, we could find appropriate facility specifications and transportation rules before the actual T&P transportation system is implemented. Through taking advantage of simulation, the fact that this new system leads to great reduction of transportation cost is found.

In this simulation project, we successfully combined discrete-event simulation with an optimization technique, and found a plan which minimizes transportation cost. In the present study, we only considered a single objective function, namely transportation cost. As a future direction, we intend to study system optimization with simulation in a multi-criteria environment. Transportation cost certainly is not the only performance measure, and thus we hope to expand our work into a direction of multi-objective optimization coupled with simulation.

ACKNOWLEDGMENT

The authors would like to express their gratitude to our colleagues, Mr. S. Sotojima and Mr. J. Takeda, for their valuable suggestions. They would also like express their thanks to staffs in both transportation and system sections at Kokura Steel Works for their earnest discussions.

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