Automatic Assignment Algorithms for Loading Double-Stack Railcars

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The development of two automatic suggestion algorithms (ASAs) for loading containers onto double-stack railcars is described. A container-oriented ASA (COASA) considers each arriving container and selects a loading position (LP) on the train. A location-oriented ASA (LOASA) considers each loading position and selects a container from the arrival pool (the containers at the terminal entrance queue). Both approaches use heuristics to improve train loading quality. A well-loaded train has a high load factor, low center of gravity, and uniform load distribution along the length of the train. Metrics were developed for each of these measures of performance. The loading strategies are tested using the Monte Carlo method based on historical container arrival data and typical train configurations. The performance of the LOASA improves when the pool size is increased, with the greatest improvement occurring when the pool size increases from one to two. For pool sizes greater than two, the COASA and the LOASA have similar performance. A simplified algorithm also was tested and evaluated. That algorithm produced load factors similar to the LOASA and the COASA, but did not perform as well according to the other metrics.

Intermodal container shipment is an important part of the global freight transportation industry. Containers have standard dimensions, are theft- and damage-resistant, and allow for efficient transfer between ships, railcars, and trucks. Use of double-stack railcars minimizes tare weight and decreases overall train length. The most commonly used containers are 6.1 and 12.2 m (20 and 40 ft) long, 2.6 m (8.5 ft) high, and 2.4 m (8.0 ft) wide. Less common, but growing in number, are container lengths of 7.3, 13.7, 14.6, and 16.6 m (24, 45, 48, and 53 ft). High cube (2.9 m or 9.5 ft) and wide (2.6 m or 8.5 ft) are also available. The weight is 20,500 kg (45,000 lb) for a 20-ft container and 25,000 kg (55,000 lb) for a 40-ft container. Dense commodities are often stowed in 20-ft containers.

Double-stack railcars have enhanced the efficiency of rail container transportation. These cars allow containers to be stacked two high. They may be single-, two-, three-, or five-platform units that are articulated above shared wheel sets known as trucks. A five-platform double-stack railcar is illustrated in Figure 1. Each platform has two loading positions (LPs). The dimensions of the LPs vary but, in general, the bottom LP can usually accommodate two 20s or one 40. [In the industry, containers are referenced in terms of nominal lengths in feet (e.g., 20s and 40s), and railcars are referenced in terms of their nominal capacities (e.g., 100 or 125 ton). That practice is used in this study.] Some of the more recently built cars will accommodate 45s and 48s in the bottom LP. The top LP can accommodate 40s or longer. Of the double-stack car types, five-platform are the most common. The railcars have nominal weight capacities of 113 tons [125 short tons (1 short ton equals 2,000 lb)] for high-capacity cars and 91 tons (100 short tons) for low-capacity cars. The actual weight limits depend on the distribution of the load on the railcar.

The following constraints, or rules, are observed in loading double-stack cars:

- Containers are grouped by destination and assigned to separate cars.
- Platforms and trucks should not be overloaded.
- The dimensions of containers must be compatible with the dimensions of the railcars.
- It is not possible to load a container in all LPs of any railcar. (20s must always be loaded into bottom LPs).
- On certain routes, clearance restrictions do not allow double stacking of high-cube containers.

The development of two automatic suggestion algorithms (ASAs) that recommend LPs for containers on double-stack railcars is described. Recommendations are made as the containers arrive at the rail terminal using a forecast of expected container arrivals. Although the exact arrival order of subsequent containers is not known, information on containers waiting at the gate queue is considered before a suggestion is made. The ASAs are based on a set of heuristics that produce load plans with a high load factor, a low center of gravity, and a uniform load distribution along the length of the train.

The ASAs are designed for use with Double Stack Planner (DSP), a decision-support system for loading double-stack trains (*1*). DSP has a graphical interface that provides a schematic side view of a double-stack railcar (Figure 2). The user can enter a container identification number to retrieve container information from a data base. The user may manually assign the container by highlighting an empty LP. The program checks to ensure that there are no loading rule violations. Alternatively, if the user clicks on the "Suggest" window, one of the ASAs described provides a suggestion. The prototype DSP and the ASAs were implemented in Level 5 Object® (L5O), an expert system development tool that supports object-oriented programming, data-base interaction, and graphical interface development.

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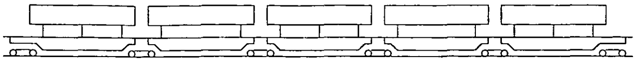


FIGURE 1 **Five-platform double-stack railcar.**

BACKGROUND

The optimal assignment of containers to trains, while possible, is difficult to achieve (*2*). Optimal assignment of trailers to train hitches by integer programming has been shown to be possible only if the exact number of trailers of each size that will arrive before the train's departure is known at the time of the first assignment (*3*). The same requirements apply to dynamic programming; the states and stages of the problem must be defined before the solution can be computed, but defining the stages requires complete knowledge of container arrivals (i.e., exactly which container will arrive when) (*3*). For many container terminals, the exact number of containers arriving and the arrival order are not known. Containers are assigned to railcars as each container arrives, before complete information is known about subsequent arrivals. Thus, absolute optimization of the assignment process is difficult.

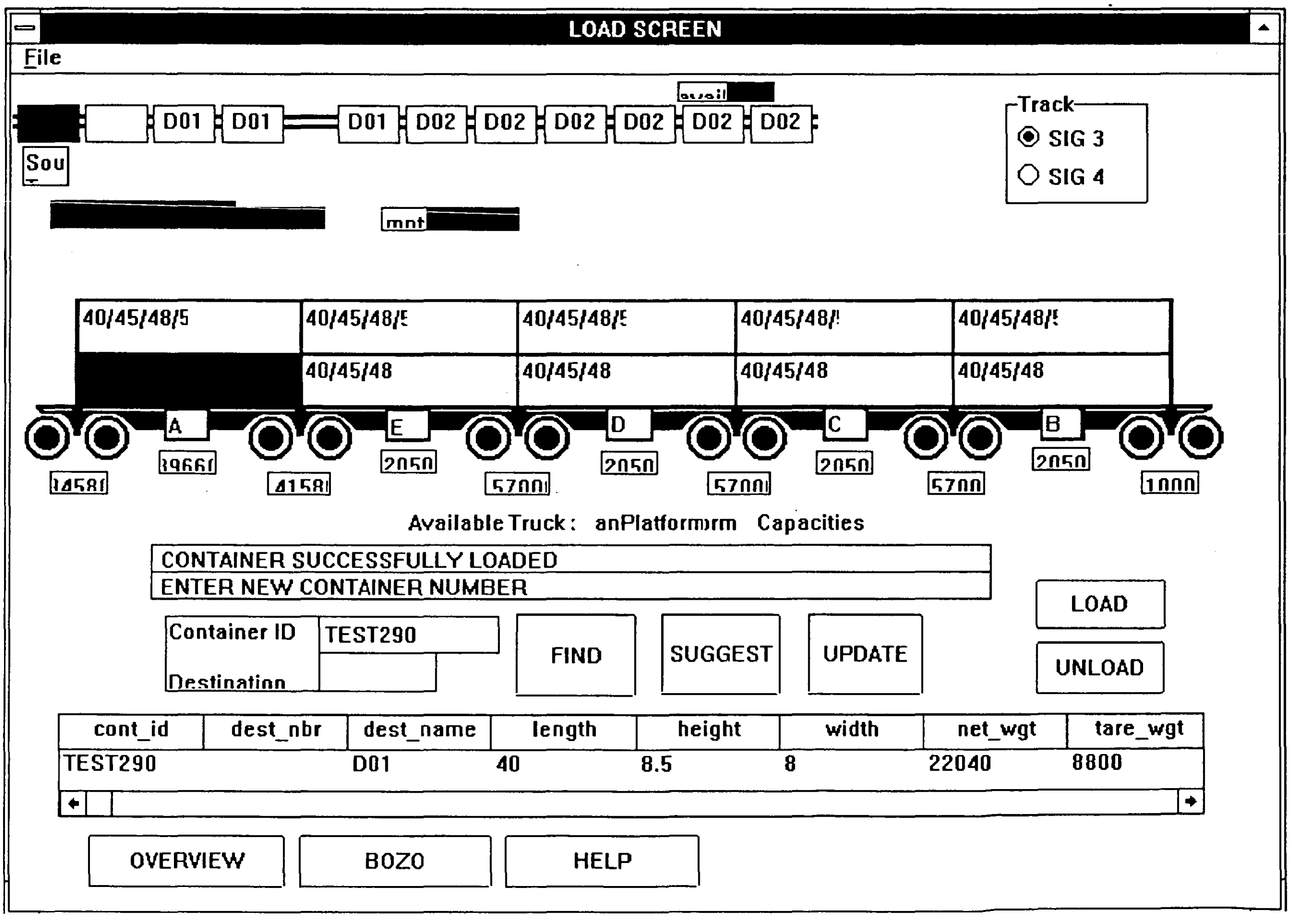
For this project, heuristic loading strategies were developed to meet load quality goals. The heuristics were based on current operating methods, but they incorporate improvements that increase the quality of the assignments. Such heuristics are expected to be more widely accepted among terminal personnel because they are based on current methods. Whenever possible, workers prefer to start loading at one end of the train and continue loading sequentially until they reach the other end. Some railcars have hand-placed connectors that join the top container to the bottom container. For these cars, workers prefer to load all bottom positions first and then all top positions. This allows time for manual placement of interbox connectors between top and bottom containers. Separate loaders are often used for 20-ft and 40-ft containers. Although the loaders can be adjusted to accommodate both sizes, the adjustment process is time-consuming; therefore, separate loaders are used. Twenty- and 40-ft containers are loaded in different areas of the train so the loaders are not crowded and do not interfere with each other.

ASSIGNMENT STRATEGY

Goals must be defined before an assignment strategy is developed. Maximum load factor, minimum height of center of gravity, and uniform load distribution are of primary concern (*1*). Metrics were developed for each goal so that comparisons could be made among trains loaded with different ASAs. Methods for attaining the goals were also considered.

Load Factor

Discussions with railroad representatives indicate that the primary measure of load quality is load factor (the percentage of LPs that are filled). Research (*4*) indicates that each unloaded position on a five-



Track
● SIG 3
○ SIG 4

CONTAINER SUCCESSFULLY LOADED
ENTER NEW CONTAINER NUMBER

Container ID TEST290
Destination

cont_id	dest_nbr	dest_name	length	height	width	net_wgt	tare_wgt
TEST290		D01	40	8.5	8	22040	8800

FIGURE 2 **Typical Double Stack Planner load screen.**

platform, double-stack railcar traveling between the West Coast and the Midwest of the United States costs approximately $100.

When possible, containers should be loaded to partially filled railcars instead of empty ones, and ASAs should avoid situations that cause low load factors, such as

- Insufficient weight capacity for upper LPs. This results when the load to the bottom LP limits the capacity of the upper LP. It is usually caused by two heavy 20s in the bottom LP, but can also be caused by unusually heavy 40s.
- Empty LPs when railcars are switched from the rail yard. Ideally, railcars should be removed from the terminal as soon as the last LP is filled. Because switch engines often cannot wait and coordination is difficult, the railcars may be removed before they are full.
- Unmatched 20s. If a 20 is placed in an LP and another 20 does not arrive to fill the bottom LP, loss of 1.5 LPs will result because no container may be loaded above a single 20.

Height of Center of Gravity

Height of center of gravity (*CG*) is calculated by:

$$CG = \frac{(h_c w_c) + (h_b w_b) + (h_t w_t)}{w_c + w_b + w_t}$$

where

w_c = weight of the railcar,
w_b = weight of the bottom container,
w_t = weight of the top container,
h_c = height of the center of gravity of the railcar,
h_b = height of the center of gravity of the bottom container, and
h_t = height of the center of gravity of the top container.

Because these calculations were for comparison purposes and not train safety, w_c and h_c were ignored, and the bottom of the bottom container was taken as the zero height reference.

One approach to lowering center of gravity is to load heavy 40s to the bottom and light ones to the top (all 20s are loaded in bottom LPs). In the logic of the loading strategy, the median container weight was defined as the dividing line between heavy and light. Container weight data obtained from a Seattle marine terminal indicate that median container weight for 40s is about 17,700 kg (39,000 lb). Very few containers weigh more than 29,500 kg (65,000 lb), and the lightest containers may weigh as little as 6,800 kg (15,000 lb). Because these were import containers, none was empty.

A strategy that makes assignments to top and bottom LPs based solely on expected median weight can have adverse effects on load factor if the actual weight distribution for a set of arriving containers is different than the expected weight. If the actual median arrival weight is lower than expected, the ASA will load too many containers across the bottom, using spaces needed for 20s. Additional rules to reserve loading positions for 20s and fill partially loaded railcars can mitigate these effects.

Platform Load Uniformity

The standard deviation of platform loads is calculated by comparing each platform load with the mean load of all platforms on the train.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (w_i - \mu)^2}{n}}$$

where

w_i = the load on each platform,
μ = the mean platform load, and
n = number of platforms.

One way to ensure uniform platform loads is to compare potential LPs with neighboring LPs and load a container only if a reasonably uniform platform load would result. However, this strategy may not result in the sequential, orderly loading that workers prefer. Also, load factor could be sacrificed in efforts to ensure uniformity.

Summary of Selected Rules for Incorporation into ASA

The rules in the ASAs were chosen because (*a*) they were previously successfully applied (Pacanovsky et al.), (*b*) they intuitively show promise, or (*c*) they reflect operational procedures at Burlington Northern Railroad's Seattle International Gateway (SIG) Terminal in Seattle, Washington, the case study site for this project. SIG Terminal handles international traffic, which consists primarily of 20s and 40s. Thus, rules were developed for these two container sizes. These rules are common to the ASAs developed in this study:

- Load heavy containers to bottom LPs, light containers to top LPs.
- Hold 20-ft compatible LPs for 20s.
- Start loading 20s in higher-capacity (125-ton) cars. The capacity of LPs in the 125-ton cars provides a better match to the weights of the 20-ft containers.

TWO AUTOMATIC SUGGESTION ALGORITHMS

Two approaches to ASA design were considered: the container-oriented ASA (COASA) (*5*) and the location-oriented ASA (LOASA) (*6*). After a container is entered into the system, the COASA suggests an LP according to the rule base. The assignment process at SIG Terminal may be described as a container-oriented approach because load clerks identify inbound containers upon arrival and then assign LPs based on the containers' characteristics. In its simplest form, this approach considers a single container and then assigns an LP.

An alternative approach (LOASA) is to select an LP and search through available containers for the "best fit." This process requires the ability to collect information from the queue of containers entering the terminal. To improve load quality, versions of both ASAs consider more than one container at a time for assignment. The arrival pool is the group of containers under consideration. In an actual intermodal terminal, this arrival pool would be selected from the containers waiting in line (queuing) for processing at the entrance gate.

Container-Oriented ASA (COASA)

Primarily, the COASA uses a container-oriented approach; however, special rules were added that allow the COASA to consider other factors. A "hold option" allows a container that cannot be loaded to be temporarily "passed by" while more appropriate containers waiting in the arrival pool are assigned. The flowchart for the COASA is shown in Figure 3. As an aid in making assignments, the COASA uses daily forecast information on the estimated number of arrivals by size and destination.

Beginning of Loading Process

When a container arrives and the COASA is activated, a find-and-sort routine locates all double-stack cars with the same destination as that container and establishes a search order. The search for an LP begins with the railcar with the highest load factor and ends with the lowest. Groups of railcars with equal load factors are further sorted by their sequence number on the track, starting from one end of the terminal and working to the other. Separate strategies are used for 20s and 40s.

Assignment of 20s

For 20s, only bottom LPs may be used, and 125-ton cars are searched before 100-ton cars. The COASA first looks for a half-filled LP (one that is already loaded with one 20-ft container). Containers are not loaded to a bottom LP if the top LP would have less than 10,900 kg (24,000 lb) remaining capacity. This ensures that sufficient capacity will remain so that top LPs may be filled. Few loaded containers weigh less than this amount. If an intermodal terminal handles only loaded containers, filling such an LP will be difficult. If a suitable LP is not found, a test is conducted to decide whether the 20 should be loaded to a completely empty LP. This test decreases the chance that a 20 is loaded to an empty LP when another 20 will not arrive to fill the LP. If one of the following three conditions is true, the container is loaded.

1. Is there a 20 in the arrival pool with the same destination as the current container?
2. Are there fewer 40s for this container's destination forecast to arrive than total spaces available for this destination?
3. Is the remaining requirement for 20-ft LPs for this destination greater than 1?

If none of these tests is satisfied, the search routine begins again. The container may be loaded to any partially filled LP even if the remaining capacity for the top LP will be less than 10,900 kg (24,000 lb). If no suitable LP is found, the container is designated for loading on other equipment.

Assignment of 40s

The strategy is different for loading 40s. Rules are included to reduce the *CG* and increase load uniformity as well as maximize load factor. The container is designated as either heavy or light according to the previously mentioned 17,700-kg (39,000-lb) limit.

The search order of railcars for 40-ft LPs is similar to that for 20-ft LPs, except that cars are not sorted into groups of 125- and 100-ton cars. If an empty bottom LP is found that will accept only 40s, the container is loaded if it is heavy. If the LP can hold 20s, a series of tests is conducted to determine whether to load the LP with the current 40 or save it for a 20. If the LP can accept a 20, and any of the following rules are true, a 40 is not loaded to that LP.

1. Is this LP needed for a 20 in the arrival pool?
2. Is a significant number of 20s expected and are LPs for 20s constrained?
3. Is the railcar type 125 ton (not 100 ton)?
4. If the answer to Rule 3 is false, then is the number of 20s forecast for this destination greater than the number of 20-ft LPs in 125-ton cars?

If all the answers are false, the current container is placed in this LP. If a bottom LP cannot be found for a heavy container, then a top LP is considered. Although loading heavier containers to the top is not preferred, it is warranted if bottom loading is not possible, because sending heavy containers to other equipment would negatively affect load factor. This is especially true if a group of arriving containers has unusually heavy weight characteristics. If a top LP is not found for the heavy container, bottom loading is attempted without Rules 2 and 3. The space will be reserved for later 20s only if either Rule 1 or 4 tests true. If a suitable LP is not found, the container is held.

If the current arrival is a light 40, an assignment is first attempted to a top LP. The first step in attempting an assignment to a top LP is to check the container weight against the priority list, a data base of LPs with less than 16,000 kg (22,000 lb) of remaining capacity. These LPs are considered difficult to fill. If several spaces are compatible, then the container is matched with the LP with the lowest remaining capacity.

If no match is found, the COASA examines the arrival pool to determine whether the container should be held or loaded to a bottom LP. If the arrival pool contains a heavy 40 or any 20s, then the current light 40 will be held. Otherwise, a bottom LP is considered.

After a container is processed, held containers are checked to see whether they may now be loaded using the same suggestion process. To limit the size of the hold buildup, the maximum number of turns a container may be held is equal to the size of the arrival pool. If a bottom LP is completely loaded and the remaining platform capacity is less than 10,900 kg (24,000 lb), the top LP is added to the previously mentioned priority list. This list ensures that an arriving container that could fit in an LP with low-weight capacity is placed in such an LP.

Location-Oriented ASA (LOASA)

The LOASA, unlike the COASA, requires a pool of containers at the gate queue so that the best container can be selected for each LP. The LOASA increases load factors by selecting partially filled cars and identifying containers from a pool of available containers to fill in empty LPs. If containers are not available to fill an LP because of size or weight constraints, the LP is added to the first-to-fill (FTF) list so they will be the first positions evaluated when new containers arrive. The FTF list is a first-in first-out inventory. Figure 4 shows the strategy in flowchart form; a detailed explanation follows.

Beginning of Loading Process

Before the first container assignments, railcars are manually assigned to destinations based on arrival projections. The mean 25, 50, and 75 percent quartiles of the container weights are computed for each destination based on a forecast of container arrivals. These statistics are later used to decide whether a container should be assigned to a top or bottom LP.

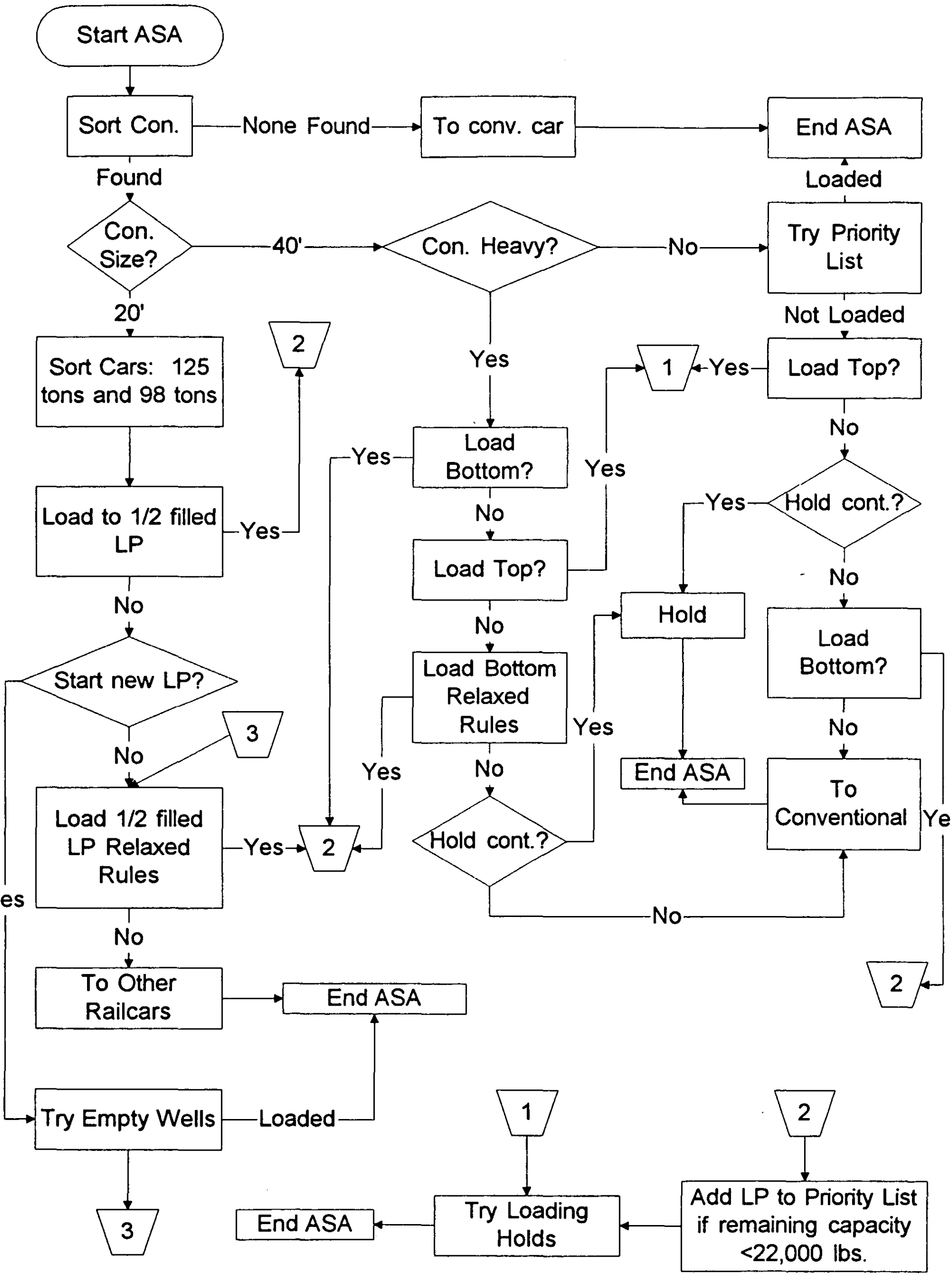


FIGURE 3 Flowchart of COASA.

During operation, the container identification numbers of arriving containers are entered into a pool from which assignments are made. When the clerks wish to assign waiting containers to available cars, they activate the assignment routine by clicking on the "Suggestion" window on the load screen. The LOASA selects the destination of the container in the pool that arrived first. Next, the pool is searched for 20s bound for the selected destination.

Assignment of 20s

Twenty-foot containers are given priority for two reasons. Some of the advantages of the COASA are preserved by assigning 20s first. Unlike the COASA, LPs are not reserved for containers before they arrive. As the container pool size increases, the results of the LOASA method approach those of a perfect reservation system, which would load every 20, but reserve no extra LPs. Attempts are also made to fill 125-ton railcars first. This is advantageous because two heavy 20-ft containers in the bottom LP and a heavy 40-ft container in the top LP may exceed the carrying capacity of a 100-ton car.

After a 20 is selected, the FTF list is searched for a 20-ft LP assigned to the appropriate destination. If a container is available for an LP on the FTF list, the container is assigned to that LP. Otherwise, the program seeks the car for this destination to which a 20 was most recently assigned. If no 20s have been assigned, or if no empty 20-ft LPs are left on the most recently assigned car, then the 125-ton car nearest to the front of the train is selected. If no 125-ton cars are available, a 100-ton car is selected.

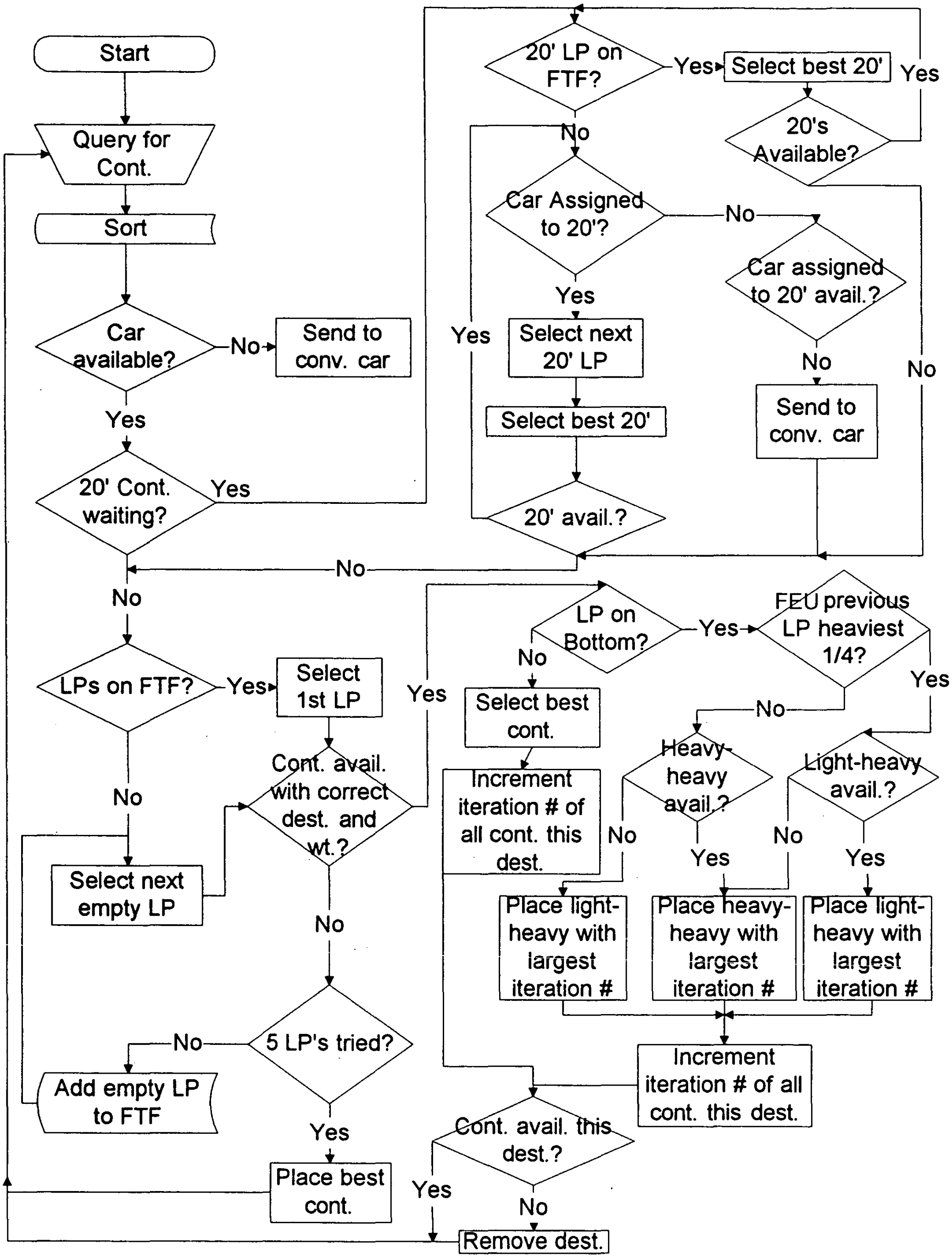


FIGURE 4 **Flowchart of LOASA.**

After the car is selected, the empty 20-ft LP closest to the front of the car is selected. If a 20 has been previously assigned to this LP, then a 20 is selected from the pool that minimizes the difference between the mean weight of the two containers on the platform and the mean weight of all the 20s bound for the same destination. This reduces the standard deviation of the platform loads, one of the secondary loading objectives. If no assignment can be made, the LP is added to the FTF list and the next LP is selected. If no assignment can be made within 10 attempts, then a 40 is selected for the same destination. If this also is unsuccessful, another destination is selected and the process is repeated.

Assignment of 40s

If 20s cannot be loaded and 40s are available for the selected destination, the algorithm initiates a method to assign them. First the FTF list is considered. If no FTF LPs can be filled, another appropriate LP must be selected while considering two additional objectives.

1. The loading equipment for the 20s should be separated from the equipment for the 40s.
2. The bottom LPs should be loaded first, to allow for manual placement of interbox connectors.

The first objective is achieved when the next railcar is selected for loading. The procedure selects the first car assigned to the correct destination that has empty 40-ft LPs, and, provided that multiple cars are available, is not the car currently designated for 20-ft containers. The second objective is realized by selecting the next LP on a railcar by moving along the bottom of the car before selecting LPs on the top.

After the next LP is selected, an appropriate container is sought for the LP. For bottom LPs, containers of the heaviest and second from heaviest quartiles are placed alternately to ensure balanced loading. By placing only the heaviest containers on the bottom (whenever possible) the *CG* is minimized. In the case of top LPs, containers are selected to minimize the difference between the platforms load and the mean platform load. This assignment decision improves load factor by preferentially placing the lightest containers on the heaviest bottom containers. Otherwise, LPs witih limited weight capacities might remain empty. If, after attempting to place containers in five LPs, no assignment can be made, the computer will search all cars assigned to the correct destination for an empty top LP. If none is available, it will assign the heaviest of the light containers to a bottom LP. In the rare event that none of the containers in the pool can be assigned, the clerk is requested to enter additional containers, or make manual assigments.

BASIC ASA FOR COMPARISON

The ASAs were tested against simplified loading routing called Basic Automated Suggestion Algorithm (BASA), which assigns containers consecutively, bottom and top, to the greatest extent possible. This algorithm does not use any forecast or queue information, but represents an ordered, sequential loading of the railcars. Containers are not held and loading positions are not reserved for 20-ft containers. Like the COASA and the LOASA, the BASA begins loading 20-ft containers in 125-ton cars, and 40-foot containers in 100-ton cars. The BASA is similar to the methods currently used at SIG Terminal. Therefore, it serves as a baseline from which to evaluate methods at SIG Terminal.

PERFORMANCE TESTING OF ASAs

Evaluating the performance of any operating scheme is important and often difficult. The testing environment should represent actual conditions as closely as possible. Performance testing for the ASAs was designed to replicate actual operations of a container-loading terminal. The first source of data used in the performance testing process was a list, in arrival order, of containers that were loaded at SIG Terminal over a 1-week period. Information included identification number, destination, and size. The container weights were not provided with the arrival data; instead, container weights were obtained from vessel stowage records. Container tare and net weights for 800 containers were obtained and sorted by length. Container weights for the test data were randomly selected, with replacement, from the appropriate length group of this set.

Eight data sets were used in testing, each containing either 110 or 110.5 40-ft equivalent units (FEUs). An FEU is a theoretical container consisting of either two 20s, or one 40. An 11-car train is exactly filled by 110 FEUs. The data sets had containers bound for three or four destinations. The percentage of 20s range from five to 24 percent, with a mean of 17 percent. Containers tended to arrive in groups of similar length and destination.

The ASAs were modified to operate without human interaction by reading container arrivals from a file, assigning containers to LPs, and writing results to another file. For each pool size and each ASA, eight test data sets were used to load a hypothetical 11-car train.

Two major operating decisions could affect the performance of the ASAs. The first is the container pool size. As the pool size increases, it is expected that the load characteristics will improve. Four pool sizes of 1, 2, 4, and 12 were tested for each data set to examine a feasible range of container pool sizes.

The second operating decision involves the composition of the trains. railcars vary in weight capacity and their ability to accommodate 20-ft containers. Table 1 summarizes the characteristics of the railcars used in this test.

Simulations were not performed for unbalanced situations in which the number of containers did not fit the train capacity. At SIG Terminal, when a group of cars is not filled to capacity, the empty cars remain at the terminal for future loading. Partially filled, five-platform double stacks are loaded so every platform has one container. If necessary, the containers will be rearranged to meet this requirement after initial loading. Placing one container on each platform prevents stringline derailments on curves when the train is climbing a steep grade. Cars in the front of the train are particularly vulnerable to such derailments. If the ASAs were implemented in their present form, container placement for the last car would have to be manually reviewed if the car was partially filled.

If the number of containers exceeds the capacity of a group of railcars, the containers will be loaded onto other railcars at the terminal. Empty railcars may be switched into the terminal, or containers may be loaded onto railcars other than five-platform double stacks. Other railcars may include single-platform double stacks or single-level (conventional) cars. SIG Terminal has a policy of placing every container that arrives before the gate closes on a departing train.

RESULTS OF TESTING

The experimental results are summarized in Table 2. The entries represent the average values obtained for the eight data sets. The basic algorithm is listed under a pool size of 1 because it considers only one container at a time as it makes loading suggestions. Paired tests were performed on the results to determine the significance of differences in load quality measures for different assignment procedures:

$$T = \frac{\bar{d} - \Delta}{\frac{S_D}{\sqrt{n}}}$$

TABLE 1 Railcar Characteristics

Sequence Number	Platform Capacity	Number of 20 ft LPs
1	125 tons	10
2	125 tons	6
3	125 tons	4
4	125 tons	4
5	125 tons	0
6	125 tons	0
7	100 tons	6
8	100 tons	4
9	100 tons	4
10	100 tons	0
11	100 tons	0

TABLE 2 Experimental Results

Pool Size	Algorithm	Load Factor	CG		Std. Deviation of Platform Loads	
		%	m	in	kg	lb
1	LOASA	90.5	2.05	80.6	10,746	23,691
1	COASA	95.8	2.13	83.8	7519	16,577
1	BASA	95.6	2.27	89.5	10,198	22,483
2	LOASA	95.4	2.13	83.9	9236	20,362
2	COASA	96.0	2.14	84.1	7696	16,967
4	LOASA	96.1	2.13	84.0	8461	18,653
4	COASA	96.7	2.14	84.2	7585	16,721
12	LOASA	96.7	2.14	84.2	7685	16,943
12	COASA	96.3	2.10	82.5	7870	17,350

where

T = the test statistic with student's t-distribution and $(n - 1)$ degrees of freedom,
$\bar{d}$ = mean of the differences of the eight data sets,
Δ = hypothesized mean difference (zero for these tests),
S_D = sample standard deviation of differences of the eight data sets, and
n = number of data sets (i.e., eight).

The results were considered significantly different if the confidence level exceeded 90 percent.

All ASAs, including the basic ASA, provide a load factor of between 95 and 97 percent (except the LOASA, which is significantly different when the pool size is 1). Thus, the simple, sequential loading used in the basic algorithm is effective in maintaining a high load factor.

Compared with the BASA, the COASA and LOASA reduce the *CG* and provide a more uniform load distribution. The exception was the LOASA with a pool size of 1; it had a higher standard deviation of platform loads. For the LOASA, the largest improvements in load factor and standard deviation of platform loads occur when the pool size is increased from 1 to 2. The LOASA has significant differences in the standard deviation of platform loads between Pool Sizes 1 and 2 and Pool Sizes 4 and 12, but not between Pool Sizes 2 and 4.

The *CG* for the LOASA increases when the pool size increases from 1 to 2 (both differences are significant). The increase in load factor causes the *CG* to increase because more top LPs are filled as the load factor increases. Because the primary objective is to increase the load factor, the increase in *CG* is accepted in exchange for the higher load factor. For smaller pool sizes (1, 2, 4), the platform load distribution is significantly more uniform (as indicated by a lower standard deviation of platform loads) for the COASA than for the LOASA.

The COASA with a pool size of 1 was selected for field testing a SIG Terminal during actual operations; it was selected because it most closely matched the current procedure for loading railcars and would have the least potential to disrupt operations. The ASA produced assignments that were acceptable to the workers because they were orderly and sequential.

SUMMARY AND CONCLUSIONS

Two automatic suggestion algorithms for loading containers onto double-stack railcars were developed. One was a container-oriented suggestion algorithm that selected the first-arriving container and assigned an LP. The other was a location-oriented suggestion algorithm that selected LPs that may be difficult to fill and selected containers from the arrival pool (gate queue). The ASAs were tested using a Monte Carlo simulation and compared with a basic automatic suggestion algorithm that provided sequential loading but did not consider forecasts or LP weights. The BASA is similar to the methods currently used at SIG Terminal. The simulated containers were based on historical data, whereas the simulated railcars were typical of the railcars loaded at intermodal terminals. Comparisons were made for load factor, center of gravity, and standard deviation of platform load (a measure of load uniformity). The following was concluded:

- The COASA, LOASA, and BASA all provide similar load factors.
- The COASA and LOASA provide a significantly lower *CG* and more uniform load distribution.
- The performance of the LOASA improves significantly when the pool size is increased from 1 to 2. Further improvements when the pool size increases to 4 or 12 are less significant.

The results show that a simple assignment algorithm can achieve load factors that are similar to those of more complex algorithms. However, the complex algorithms are better able to achieve the secondary objectives of lowering the *CG* and providing more uniform platform loads. The cost benefits of these improvements are difficult to quantify. However, achieving the secondary objectives improves train handling, and that reduces the chance of derailments and lading damage, both of which are high-cost events.

ASAs are beneficial because they provide checks against human error (e.g., overloading railcars or placing containers on railcars bound for the wrong destination) and allow the assignment process to be integrated with other tasks associated with intermodal transportation. For example, one system could scan a data base of expected container arrivals provided by marine carriers and request railcars. Other systems locate the railcars and dispatch them to the rail terminal. After the container arrival order and railcar configurations are known, containers could be assigned by an ASA to specific LPs and work orders could be sent to employees to execute the plan. When the exact train configuration is known, locomotive assignments, detailed train schedules, and plans for handling the containers at the destination may then be made. Such system integration benefits may be the most compelling reason for implementing automatic assignment algorithms.

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