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Transportation Research Record 1511

Contents

Foreword

The papers in this volume address diverse topics related to freight transportation. Topics range from technical tools for planning and constructing freight infrastructure projects to a review of intelligent transportation approaches from the motor carrier's perspective.

In the Naresh and Jahren paper, the tool of process simulation is proposed as a more efficient approach to planning and construction of guide walls using mobile cofferdams. For landside freight facilities, the paper by Jahren et al. reviews the use of the assignment of automatic algorithms for optimized loading of double-stack railcars. The McCord and Lee paper explores the possibilities for fuel savings and increased vessel speeds if near real-time estimation of ocean currents are available to vessel operators.

Two papers examine planning aids to improve investment analysis in intermodal infrastructure projects. Jayawardana and Webre discuss the Port Priority Program in Louisiana, which gives the state the ability to objectively analyze investments in port facilities. The Kavalaris and Sinha paper discusses a statewide survey in Indiana that queried commerical vehicle operators about their willingness to participate in various intelligent highway schemes, including weigh station preclearances and automated tolling procedures.

The paper by Mingo and Wolff examines the problematic issues confronting the Federal Highway Administration when the department collects data on truck vehicle miles traveled. Several recommendations regarding statistical collection efforts are presented.

Process Simulation for Guide Wall Construction Using Mobile Cofferdams

ARCOT L. NARESH AND CHARLES T. JAHREN

Proper planning for marine construction projects that involve new concepts is necessary for efficiency and economy. However, planning is difficult because there are no previous experiences to draw from. In such situations, simulation programs are an effective aid. Plans may be improved by iteratively simulating various construction sequences and resource allocations. Resources can include cranes, barges, and temporary structures. Simulation models assign probabilistic durations to work tasks, allowing more realistic analysis. After each simulation, results may be reviewed and improvements may be made. In this paper, simulation modeling is used to improve the resource allocation and construction schedule for a guide wall using a mobile cofferdam. A guide wall assists vessels as they enter and exit locks, and a mobile cofferdam provides a dewatered area for constructing a segment of the structure. The first model served as a point of comparison for modified versions. Modifications were made to the number of cranes, their work assignments, and the number of mobile cofferdams. The model logic was improved to enhance work flow. In all, six versions of the model were developed. The final version required 47 percent less time than the first version to complete 40 guide wall segments.

The construction of locks and guide walls represents a major portion of the cost involved in the construction of inland navigational facilities. Conventional methods of construction are costly. The U.S. Army Corps of Engineers (USACE) is trying to develop strategies for building more economical navigation projects that fit within the constraints of the Inland Waterway Trust Fund and the current federal budget. The resulting cost reductions would enable USACE to start planned projects earlier and to construct additional projects.

This study focuses on the use of a mobile cofferdam, a reusable cofferdam that allows construction of a lock guide wall or dam segment in the dry. Although this method has not been used to construct a lock, elements of the process have been accomplished in previous construction efforts such as floating dry docks, tremie concrete placements for bridge piers, and offshore oil drilling. This type of construction here is repetitive in nature, which is simulated in this paper. A wicket box (similar to a mobile cofferdam) is being constructed for use on the Olmsted dam, and the concept will be tested at the Smithland Dam (*1,2*).

OBJECTIVE

The objective of this study was to develop methods for mobile cofferdam construction that save time and money, with the aid of a simulation program. Methods for resource allocation and sharing were also investigated. Conclusions were drawn by comparing simulations that had different resource allocations. The results of this research complement the current efforts of the USACE.

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MicroCYCLONE

MicroCYCLONE is the simulation program that was used for this study (*3–5*). Flowcharts of MicroCYCLONE models use four basic components (Figure 1):

1. Circles represent queues or waiting positions for resources (the idle state). Examples of resources are equipment, materials, workers, and workspace.
2. Square nodes represent work tasks (the active state). The constrained work task (i.e., a work task that requires more than one resource) is modeled as a square node with a slash called a COMBI node.
3. Arcs represent the path of a resource as it moves between idle and active states.
4. Special function nodes can be used for generating and consolidating resources, or for counting cumulative production. These components are arranged to represent the logical flow of resources in the construction projects. Examples of resources are equipment, material, workers, and work space.

MicroCYCLONE supports probabilistic duration inputs (uniform, triangular, beta, normal, and exponential).

CONSTRUCTION OF GUIDE WALLS USING MOBILE COFFERDAMS

Guide Walls

Locks provide navigational routes through dam complexes; they are steps in an "aquatic staircase" by which vessels are lifted or lowered from one pool to the next, while the pools themselves remain level (*6*). Guide walls are built to assist vessels as they enter and exit the locks. Guide walls also allow temporary berthing for vessels waiting to enter the lock. They vary in length from 30 m to 450 m (100 ft to 1,500 ft) depending on the site conditions (*1*).

Description of the Process

A reusable mobile cofferdam (MC) (Figure 2) is a large steel box with walls that are 4.5 to 6 m (15 to 20 ft) thick. It provides a dewatered area for construction. The steel box is formed with a space truss, covered by steel plate inside and out. The rear wall has an opening shaped to accommodate the in-place guide wall. The volume within the MC walls can be filled with water or emptied to facilitate moving.

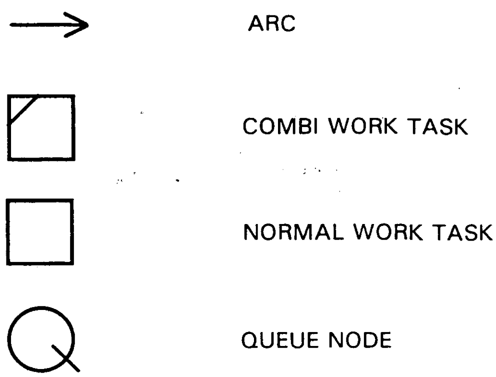


Figure 1 Basic modeling elements.

The operations involved in the construction of a guide wall using an MC follow a linear sequence of activities. The following steps are required for each section of the guide wall.

1. Excavation. The segment location is initially excavated in the wet to obtain the desired elevation of the base of the structure. Excavation is carried out with a barge-mounted clam bucket or dragline. Hydraulic dredging is also possible. The side slope for soft soils should be no steeper than 1 vertical on 2.5 horizontal. Better foundation conditions may allow steeper slopes.
2. Pile Driving. Driven piles are the most common foundation treatment for marine works. The piles can be driven with an underwater hammer in telescopic leads or driven from above the water and cut off to grade. For this simulation, the piles are assumed to be driven using pile drivers above water. A floating driver is assembled by placing a crane and pile hammer on a barge. Supplying the pile driver with piles requires a supply barge and a tug.
3. Float MC to location and position. Next, the MC is moved to the location where the segment is to be cast. The MC is lowered at the desired location in the construction and aligned, leveled, and maintained in position by spud piles at its four corners.
4. Tremie concreting. The tremie concrete seal, placed at the bottom of the MC, resists hydraulic uplift pressure. In addition, modern designs often use the seal as part of the permanent structure, as a distribution or footing block that transfers the load to the piles. The tremie method is often used for placing structural underwater concrete. Tremie pipes are used to limit the contact of fresh concrete with water. Rates of pour in standard practice cause the concrete to rise at a rate of 0.45 to 1.8 m/hr (1.5 to 6 ft/hr). For this simulation model, the rate of pour is 0.9 m/hr (3 ft/hr) (*7*).
5. Dewatering. After the tremie concrete has attained the required strength, the work area is dewatered with pumps.
6. Forming and Pouring. After the cofferdam is pumped dry, reinforcing steel is placed and the segment is formed. The reinforcing is placed in prefabricated units. The walls of the cofferdam act as side forms. Additional formwork is required only for the upper half of the cofferdam, where the wall segment thickness is less than the inner width of the cofferdam. Instead of using manual forming, an automated forming system can be incorporated into the MC. This system consists of forms mounted on tracks attached to the MC. These forms can be retracted, raised, and reset mechanically. The concrete is poured after the forms are all set in position. It should be possible to concrete a segment in a single pour.

DESCRIPTION OF SIMULATION MODELS

Several versions of the simulation model for the mobile cofferdam were developed. Version 1 provided a point of comparison for subsequent versions. For all the versions, construction of 40 segments was simulated. In later models, in which two MCs were used, construction of 20 segments was simulated for each of two guide walls. After the 40 segments were completed, the simulation stopped and the required construction time was recorded. The following resources were considered in the models.

1. Cranes: assisted in excavation, tremie concreting, forming segment, pouring concrete and pile driving.
2. Mobile Cofferdam: required for tremie concreting.
3. Location: also a resource. A location is an area where a guidewall segment will be built.

Activity Durations

It would be desirable to select the duration input by analyzing historical data from many similar construction activities. For MC construction, however, such an analysis would be difficult for several reasons. Although many of the activities have been performed on past construction projects, they have not been applied to MC construction. It is necessary to modify estimates in response to project-specific circumstances. Historical data may be presented in an inconvenient format and stored in scattered locations. In some cases the data are proprietary, owned by a particular construction contractor. In other cases there may not be enough data to perform a complete statistical analysis.

An alternative method for obtaining duration input is to ask marine construction experts to give estimates for activity duration and the range of expected productivity values. Program evaluation and review technique methods may be used to define an equivalent normal distribution (*8*). The expected duration is as follows:

$$t_e = \frac{a + 4b + c}{6}$$

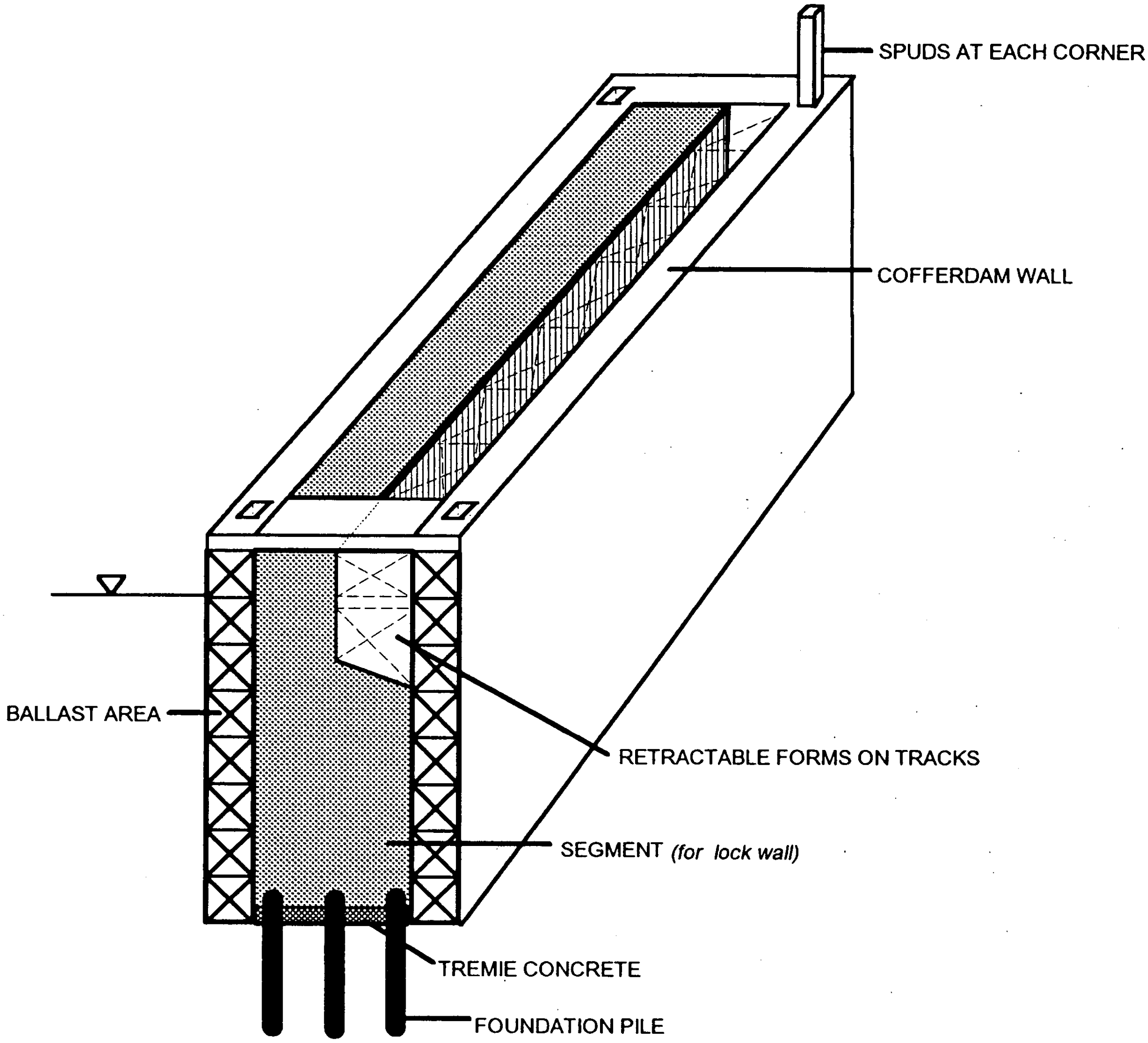
The standard deviation is as follows:

$$\sigma = \frac{c - a}{6}$$

where

t_e = expected duration,
a = optimistic duration,
b = most likely duration,
c = pessimistic duration, and
σ = standard deviation.

Three experts were consulted to find the most likely duration: two from marine construction contractors (M. Schnoeblen, Massman Construction Company; T. Pirtle, Traylor Bros., Inc.) and one (B. McClellan) from the USACE Louisville District. The first author personally reviewed the project requirements with the experts and requested duration or productivity estimates for each operation. The experts only gave estimates for operations about which they were knowledgeable. The estimates for the most likely



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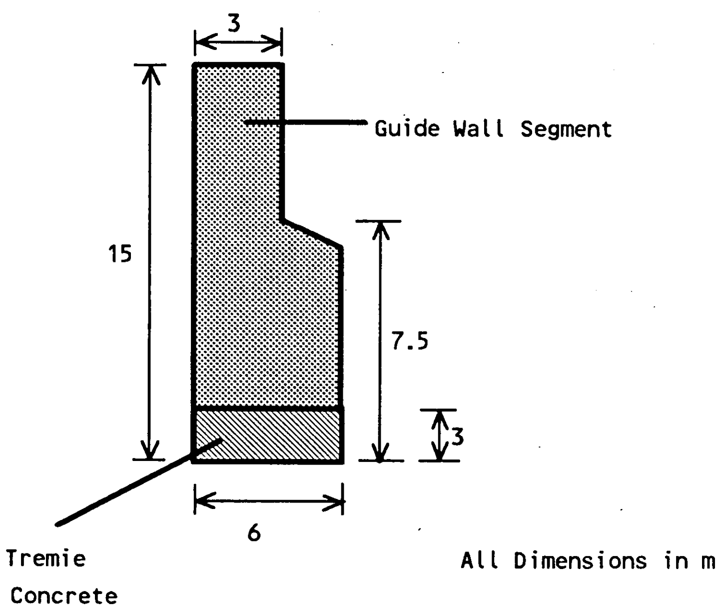


FIGURE 2 Mobile cofferdam and guide wall: (*a*) oblique pictorial view; (*b*) cross section of guide wall.

duration represent a consensus. In cases for which experts provided productivity information, the expected duration was found by the following equation:

$$t_e = \frac{Q}{fp}$$

where

Q = quantity of work,
P = productivity, and
f = efficiency factor, 0.83 (50 min/hr).

An efficiency factor of 0.83 is commonly used by construction estimators.

Some operations have little schedule variance. Concrete placement must be accomplished in a single day to avoid cold joints. Contractors will extend work hours to complete such activities in a single day. Deterministic duration is satisfactory for such activities. Other actives such as dredging, pile driving, positioning the mobile cofferdam, dewatering, and forming have a stochastic duration. Six marine construction experts were consulted in telephone interviews by the second author to find the typical range of duration as a percentage of the expected duration. The results are provided in Table 1. The duration range percentages were averaged and rounded to the nearest percentage. They were used to calculate the optimistic and pessimistic durations (a and c) and the standard deviation (σ). The activity durations are summarized in Table 1. Additional details regarding duration calculations are as follows:

1. The mobile cofferdam is 18 m (60 ft) long, 15 m (50 ft) wide (exterior) and 15 m (50 ft) high. The dimensions were from the drawings in reference (*1*). The internal work space is 6 × 18 m (20 × 60 ft).
2. The river bed soil is sand and a trench 3.6 m (12 ft) deep is assumed. Digging using a clamshell is relatively easy up to this depth. Thus, a 3-m^3 (4-yd^3) clam bucket can be used. Excavation duration is based on dredging productivity of 245 m^3/hr (320 yd^3/hr). The side slope of the excavation is assumed to be vertical on 2 horizontal.
3. Steel H-piles are driven to a depth of 6 m (20 ft) below the base of the cofferdam [total length of each pile is 9 m (30 ft)]. Hard soil exists at a depth of 4.5 m (15 ft) below base. The row spacing is assumed to be 3 m (10 ft). Six H-piles are assumed in each row. There are 5 rows of piles and a total of 30 piles, giving a total length of 270 m (885 ft). The duration estimate is based on a piling rate of 6 m/hr (20 ft/hr).
4. The bottom 2.7 m (9 ft.) of the cofferdam is tremie concreted and the rest of it is poured using a bucket. The production rate for tremie concreting is 55 m^3/hr (70 yd^3/hr). For dewatering calculations, the depth of water is assumed to be an average of 10.6 m (35 ft). Duration estimate is based on a dewatering rate of 5500 L/min (1200 gal/min).
5. A 2-m^3 (2.5-yd^3) bucket is used for concreting; the production rate is 75 m^3/hr (100 yd^3/hr). Although 15 hours are necessary, placement would be completed without a break, using two work crews, so that construction joints could be avoided. Thus, only one calendar day is required.

Resource Costs

The costs of labor and equipment directly involved in mobile cofferdam construction were considered in the analysis. These costs are known as direct costs. Material costs such as concrete and reinforcing steel were not considered because they were not changed in the simulation. In MicroCYCLONE costs can be either fixed or variable. Variable costs are only incurred when the resource is operating. Fixed costs are incurred whether or not the unit operates. For cranes, the crew costs were considered fixed costs, as the cranes were seldom idle for long periods during which crews would be reassigned to other tasks. The equipment costs were split into variable and fixed costs. The variable costs included the cost of fuel, oil, and repairs. The fixed costs were based on the rental charges. The variable costs were one-third of the fixed costs for all equipment. The resource costs are listed in Table 2.

It is assumed that the mobile cofferdam will be used on three similar projects. The total fabrication and material costs including labor are estimated at $1,500,000 (*1*). A fixed cost of $500,000 was assigned to this project. The crew costs were considered to be variable because the MC remains idle for long periods, especially during the initial stages of the project. It is expected that the MC crew will be assigned other work.

In some cases, the project duration can be reduced by increasing the direct project cost. When should this be done? When a project duration is reduced, both the contractor and the government save project management expenses, known as time-related overhead. Waterway users also save, due to reduced delays. By considering

TABLE 1 Activity Durations

Activity	Calculated Durations	Distribution	Percent Variation	Standard Deviation
Excavation	6.2 hrs	**Normal**	15	0.3
Pile driving	35 hrs	**Normal**	15	1.75
MC Positioning	8 hrs	**Normal**	15	0.4
Dewatering	7.3 hrs	**Normal**	10	0.23
Tremie Concreting	5.7 hrs	**Deterministic**	0	0
Forming	16 hrs	**Normal**	20	1.07
Placing Concrete	15 hrs	**Deterministic**	0	0
Stripping MC	4 hrs	Normal	20	0.27

TABLE 2 Resource Costs

CRANE FOR CONCRETE PLACEMENT AND EXCAVATION

Item	Quantity	Unit cost	Daily Cost—Variable	Daily Cost—Fixed
Crane Operator	2	35/hr	-	560
Deckhand	1	25/hr	-	200
Tugboat Operator	1	30/hr	-	240
Supply Barge	1	200/dy	50	150
Welder	1	50/dy	12.5	37.5
Tug Boat	1	800/dy	200	600
Crane (165T)	1	1750/dy	435	1315
TOTAL			**697.5**	**3102.5**

CRANE FOR PILE DRIVING

Item	Quantity	Unit cost	Daily Cost—Variable	Daily Cost—Fixed
Crane Operator	2	30/hr	-	480
Foreman	1	35/hr	-	280
Deckhand	1	25/hr	-	200
Tugboat Operator	1	30/hr	-	240
Journey men	4	30/hr	-	960
Barges	2	200/dy	100	300
Welder	3	50/dy	37.5	112.5
Pile driving Hammer	1	1000/dy	250	750
Tug Boat	1	800/dy	200	600
Crane (165T)	1	1750/dy	435	1315
TOTAL			**1022.5**	**5237.5**

MOBILE COFFERDAM

Item	Quantity	Unit cost	Daily Cost—Variable	Total Cost—Fixed
Foreman	1	35	280	
Workers	5	30	1200	
Mobile Cofferdam Fabrication and Material	-	LS	-	500,000
TOTAL			**1480**	**500,000**

these savings, the value of the time and cost trade-off may be estimated and used as a decision aid.

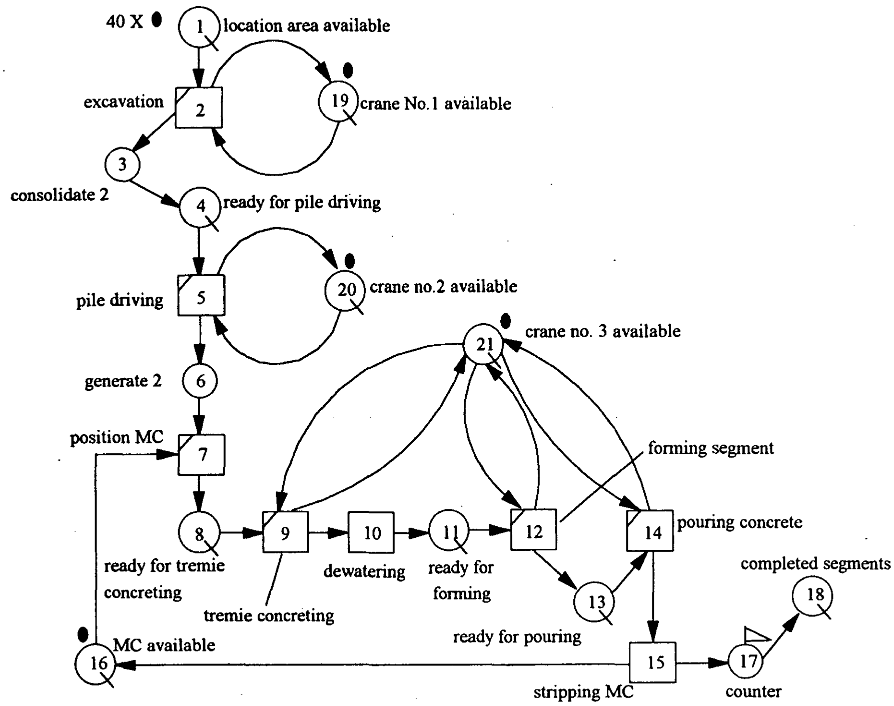
Most lock and dam construction contracts contain liquidated damage clauses that specify an amount that will be deducted from the payments due to the contractor for each day the project is delayed beyond the target completion date. The amount is usually based on government's time-related overhead expense. Liquidated damage amounts on the order of $10,000 per day are common for lock construction projects. To illustrate the process of making time and cost trade-off decisions, the amount of $10,000 per day is used in this analysis. This amount serves as a lower bound for the likely value of the time and cost trade-off.

Version 1

Version 1 (V1) used three cranes. The first was used for excavation, the second for pile driving, and the third for concreting and other cofferdam-related activities. To provide working space, it is desirable to maintain separation between activities such as excavation, pile driving, and positioning of the mobile cofferdam. This was accomplished by consolidating two segment locations before entering the pile driving node. The consolidation node released one resource entity for every two incoming entities. Thus two segments were completed before the next activity could start. Subsequently a generation function was used to free the consolidated resources.

This paragraph tracks the flow of resources through V1 (Figure 3*a*). The simulation begins with a queue node (Node 1—location area available) with 40 segment locations. The first activity is excavation (Node 2), for which the crane in Node 19 is a required resource. The segment location is released from Node 2 and enters the function node (Node 3), which only half of input resources will leave. Pile driving occurs at Node 5, where a crane with pile driving attachments is an input resource. The duration is adjusted to allow for driving for two segments. The segment is then released to the generation node (Node 6), where resources are restored to their original number. Node 7 simulates the positioning of the MC; an MC must be available before this activity can start. The segment then flows to Node 8, tremie concreting, where the third crane is an input resource, and Node 10, for dewatering. Then the segment goes through queue Node 11 to Node 12 (forming) and Node 14 (pouring concrete) where Crane No. 3 is an input. The MC flows through Node 15 (stripping and moving the MC to the next segment) before returning to the queue node (Node 16). The segment goes to the counter Node 17 where the production of one segment is recorded; then the segment goes to queue Node 18 where completed segments are collected. The simulation runs until all 40 segments are constructed and pass the counter Node 17.

Construction of 40 segments requires 267 days (6.67 working days per segment). The cost is $2,846,000 (Table 3) to complete the project, which gives a unit cost of $71,000 per segment. The production curve (Figure 3*b*) shows system cumulative productivity.



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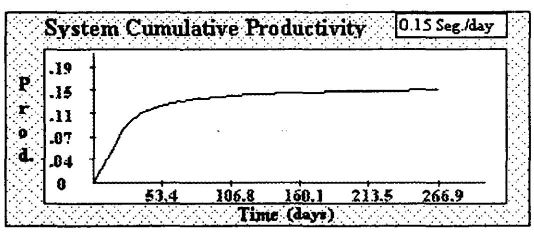


(b)

FIGURE 3 Model Version 1: (*a*) flowchart; (*b*) production curve.

TABLE 3 Time-Cost Trade-Offs

Comparing Version Nos.	Duration (days)	Direct Labor and Equipment Cost (K$)	Change in Cost (ΔC) (K$)	Change in Duration (ΔD) (days)	|ΔC/ΔD| (K$/day)	Better Alternative
1 and -	267	2,846	-	-	-	-
2 and 1	287	2,837	-9	+20	.45	1
3 and 1	246	3,231	+385	-21	18.3	1
4 and 1	198	3,153	+307	-69	4.5	4
5 and 4	191	3,630	+477	-7	68.1	4
6 and 4	141	3,412	+259	-57	4.5	6

Note:

- *If both ΔC and ΔD are positive, reject the new alternative.*
- *If both ΔC and ΔD are negative, accept the new alternative.*
- *If ΔC is positive and ΔD is negative, accept the new alternative if /ΔC/ΔD /< $10,000*
- *If ΔC is negative and ΔD is positive, accept the new alternative if /ΔC/ΔD /> $10,000*

Assumption: The time-related costs equal $10,000/day.

TABLE 4 Simulation Results

	% IDLE & DAYS USED						DAYS TO COMPLETE 40 SEGMENTS
MODEL VERSION	CRANE 1	CRANE 2	CRANE 3	CRANE 4	MC 1	MC 2	
1	0%, 32 X	1%, 177 P	4%, 267 T,F,R	-	4%, 267	-	267
2	1%, 177 P	33%, 287 X,T,F,R	-	-	4%, 287	-	287
3	1%, 178 P	22%, 246 X,T,F,R	-	-	7%, 149	40%, 246	246
4	1%, 179 P	3%, 198 X,T,F,R	-	-	25%, 193	6%, 198	198
5	1%, 178 P	49%, 190 X,T,F,R	39%, 190 X,T,F,R	-	32%, 191	26%, 183	191
6	2%, 90 P	2%, 90 P	31%, 140 X,T,F,R	31%, 140 X,T,F,R	7%, 141	8%, 140	141

Note: X- Excavation; P- Pile Driving; T- Tremie Concreting; F- Forming; R- Pouring.

The shape of this curve is typical for construction operations; it starts at zero, climbs quickly, and flattens out to a steady state. This indicates low productivity in the start-up phase and steady productivity after operations are established. The graph (Figure 3*b*) smoothly flattens out toward the end of the project, indicating that the system has reached its maximum possible efficiency with the given resources. Idle time was low for two of the cranes (excavation, 0 percent; pile driving, 1 percent) and high for the third (concreting, 40 percent) (Table 4). The concreting crane could also excavate or pile drive, thus eliminating a crane.

This model addresses the key issues of activity sequence and duration and serves as a base on which to improve. Other versions were developed to increase the productivity and maximize the utilization of the resources.

Version 2

In Version 2 (V2), two cranes were used: one for excavating, tremie concreting, forming, and placing concrete and the other for pile driving. This reduced the crane idle time. Compared to V1, there is a savings in cost of $9,000, however, 20 more days are required for construction. Thus $450 is saved for each day the project is extended (Table 3). Because time-related costs are $10,000/day, such a time extension cannot be justified.

Crane 1 (Node 2) is idle 33 percent of the time, while Crane 2 (Node 30) is idle 1 percent of the time (Table 4). The sequence of activities is similar to that of V1. The MC can be identified as the critical resource because it is idle only 4 percent of the time (Table 4). The production curve (Figure 4) shows that the system is not balanced, as the slope of the curve increases suddenly after day 40, indicating a bottleneck of some sort that restricts production. The simulation results show that during the initial stages, Crane 2 finishes excavation of 40 segments before tremie concreting segments. This should not happen, because it creates a bottleneck as segments queue up for tremie concreting. Moreover, excavated segments should be cofferdammed and tremie concreted as soon as possible to prevent silting. This issue is dealt with in Version 4, in which the node priorities were changed to improve the production rate and prevent this bottleneck. In the next model, the objective was to increase the utilization of Crane 1.

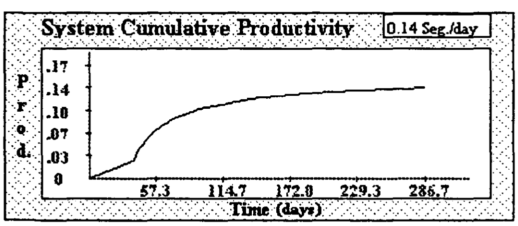


FIGURE 4 Production curve for Model Version 4.

Version 3

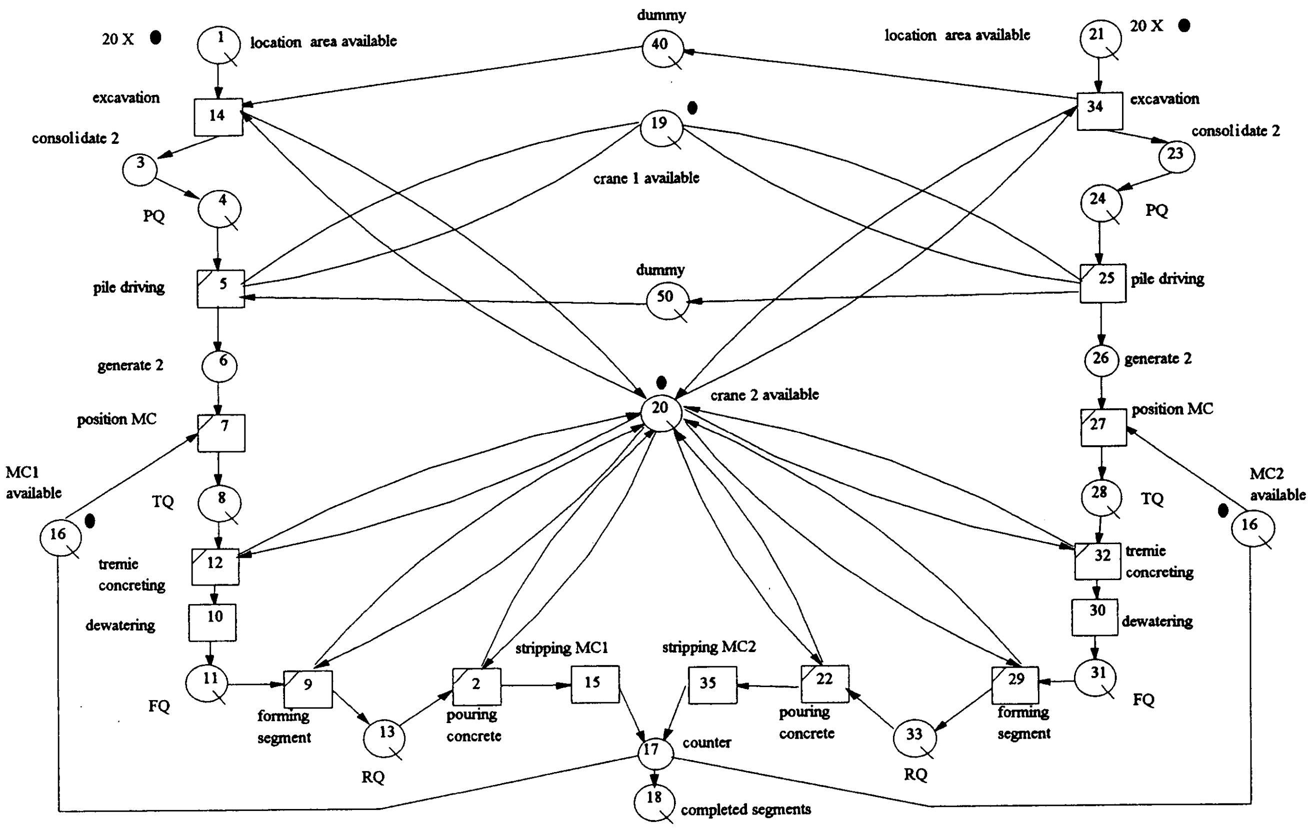
Version 3 (V3) used two mobile cofferdams to construct two parallel guide walls simultaneously. It was presumed that greater efficiency would result if the cranes were shared. One crane was used for excavation and concreting while the other was used for pile driving.

The results show that the productivity does increase. The construction of 40 segments took only 246 days, a savings of 21 days over V1; the costs increase by $385,000 to $3,231,000. The cost increased by $18,300 for each day saved (Table 3). Since this exceeds the $10,000/day of time-related costs, V1 is preferred over V3.

The cranes are used more efficiently in this version. Crane 1 is idle 22 percent of the time, and Crane 2 is idle 1 percent of the time (Table 4). MC 1 is used efficiently (7 percent idle), but MC 2 is idle for 40 percent of the time (Table 4). As the MCs are a valuable resource, it is essential to increase their utilization. At this point, balancing the system is more important than increasing resources, as idle time for both Crane 1 and MC 2 is high. This was done in the next version.

Version 4

If two activities call for using a resource simultaneously, MicroCYCLONE assigns the resource to the activity with the lower node number. The node numbering in Version 4 (V4) was changed, so that later activities have lower numbers and a higher priority. This



Note: PQ, TQ, FQ, and RQ denote the pile driving, tremie concreting, forming, and pouring queues, respectively, for segments

FIGURE 5 Process chart for Model Version 4.

prevents the segments from queuing in the middle of the construction process. Also, two dummy nodes were included, which cause the cranes to alternate between the two guide walls, spending equal time on each guide wall (resulting in a more balanced system). In the previous model, one guide wall had priority over the other. Figure 5 shows the process chart for this version.

The project was completed in 198 days, a savings of 69 days over Version 1. The cost was $307,000 more than V1, saving $4,500/day (Table 3). For most lock and dam construction projects, this would be an attractive alternative. Idle time decreases for both the cranes (3 percent for Crane 1, 1 percent for Crane 2) and the mobile cofferdams (25 percent for MC 1 and 6 percent for MC 2) (Table 4).

Version 5

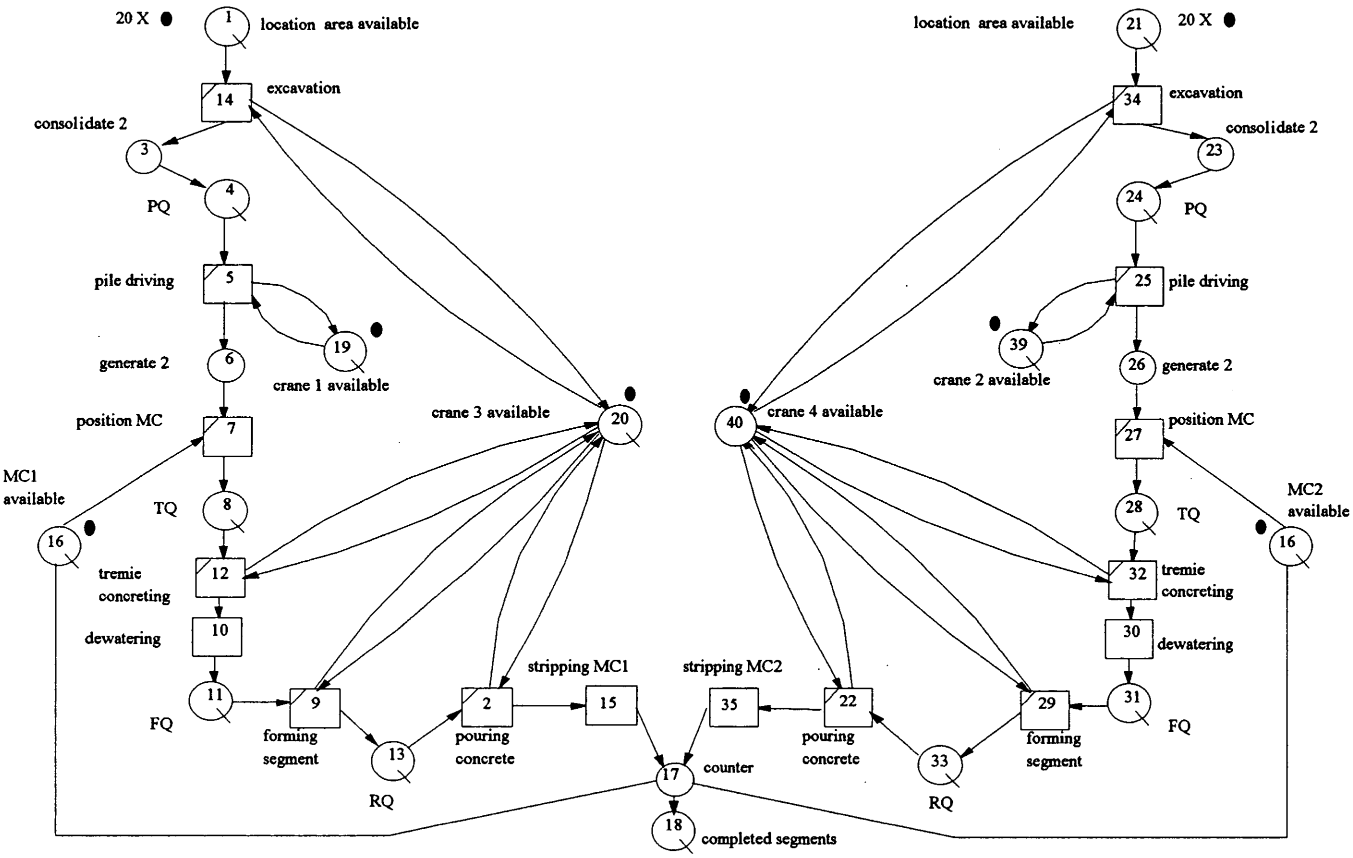
In Version 5 (V5), two cranes were used for excavation, tremie concreting, forming, and concrete placement. The duration was 191 days, a savings of 7 days over V4. Compared to V4, an additional $477,000 was required, or $68,100/day (Table 3). V5 is not preferred over V4 because $68,100/day exceeds the time-related costs of $10,000/day. The cranes used for excavation and concreting activities were idle 44 percent of the time (the average of Crane 1 and Crane 3). Crane 2 was used almost continuously (idle 1 percent of the time; see Table 4). It is the bottleneck in this model. The MCs were idle 29 percent of the time (average for MC 1 and MC 2, Table 4).

Version 6

In the final version, Version 6 (V6) (Figure 6), two cranes were used for pile driving. This was done because the previous model showed that the pile driving was the bottleneck. Compared to V4, the schedule was reduced by 57 days (141-day duration) and the cost increased by $259,000 ($3,412,000 total cost). An additional cost of $4,500 was required for each day the schedule was shortened (Table 3). V6 is preferred over V4 because $4,500 is less than the $10,000 of time-related costs. The MC was idle 7.5 percent of the time, the pile-driving cranes were idle 2 percent and the cranes tending the mobile cofferdam were idle 31 percent. As expected, looking at the high utilization of resources, the production curve for this version does not indicate any bottlenecks (Figure 7). The sawtooth pattern exists because two completed segments from each guide wall are being counted simultaneously. V6 is the recommended construction method.

SUMMARY AND CONCLUSIONS

A simulation model that includes all of the basic resources and work tasks has been developed. The model has been modified to



Note: PQ, TQ, FQ, and RQ denote the pile driving, tremie concreting, forming, and pouring queues, respectively, for segments

FIGURE 6 Process chart for Model Version 6.

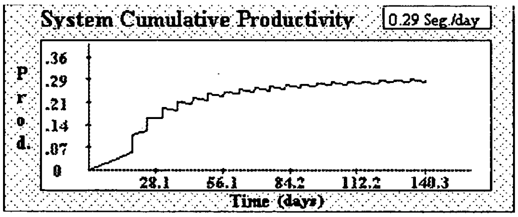


FIGURE 7 Production curve for Model Version 6.

experiment with changes in method that will increase construction efficiency.

In the transition from V1 to V2, one crane was eliminated and the productivity decreased only slightly. Incremental productivity improvements came with each subsequent modification. There was a 47 percent decrease in duration between V1 and V6. The resources were more completely utilized and better allocated so that bottlenecks were reduced. Although the direct equipment and labor costs increased, those costs were offset by time-related cost savings. The analysis shows that V6 is the preferred alternative.

The simulation process described here could be applied to other navigation structures. It provides planners with an effective method of testing the feasibility of new concepts and of refining construction plans. The ultimate result will be a reduction in construction costs for navigation structures.

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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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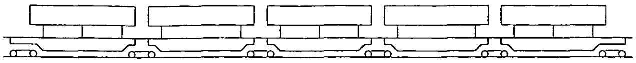

FIGURE 1 Five-platform double-stack railcar.

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-

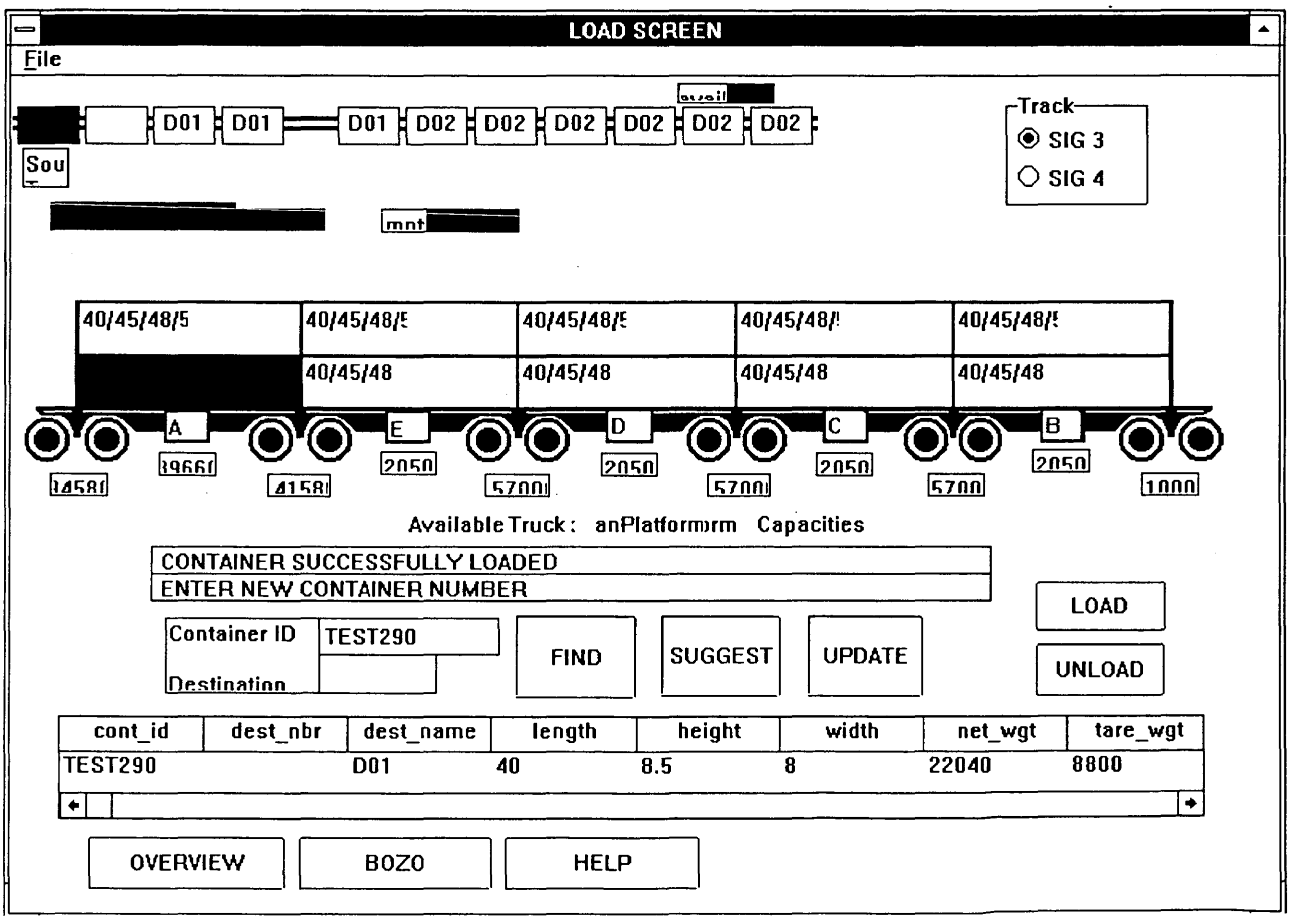

FIGURE 2 Typical Double Stack Planner load screen.

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.

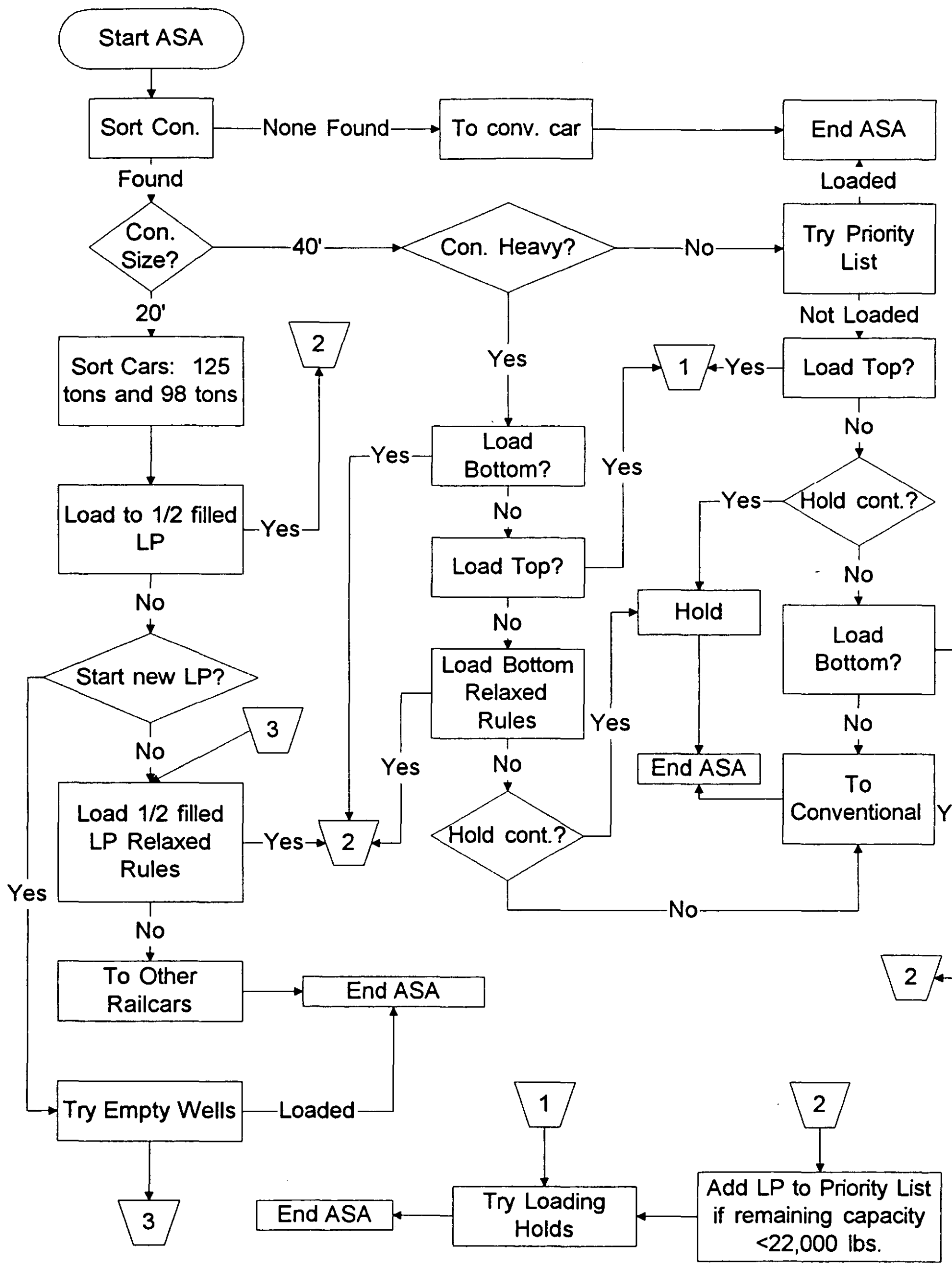

FIGURE 3 Flowchart of COASA.

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.

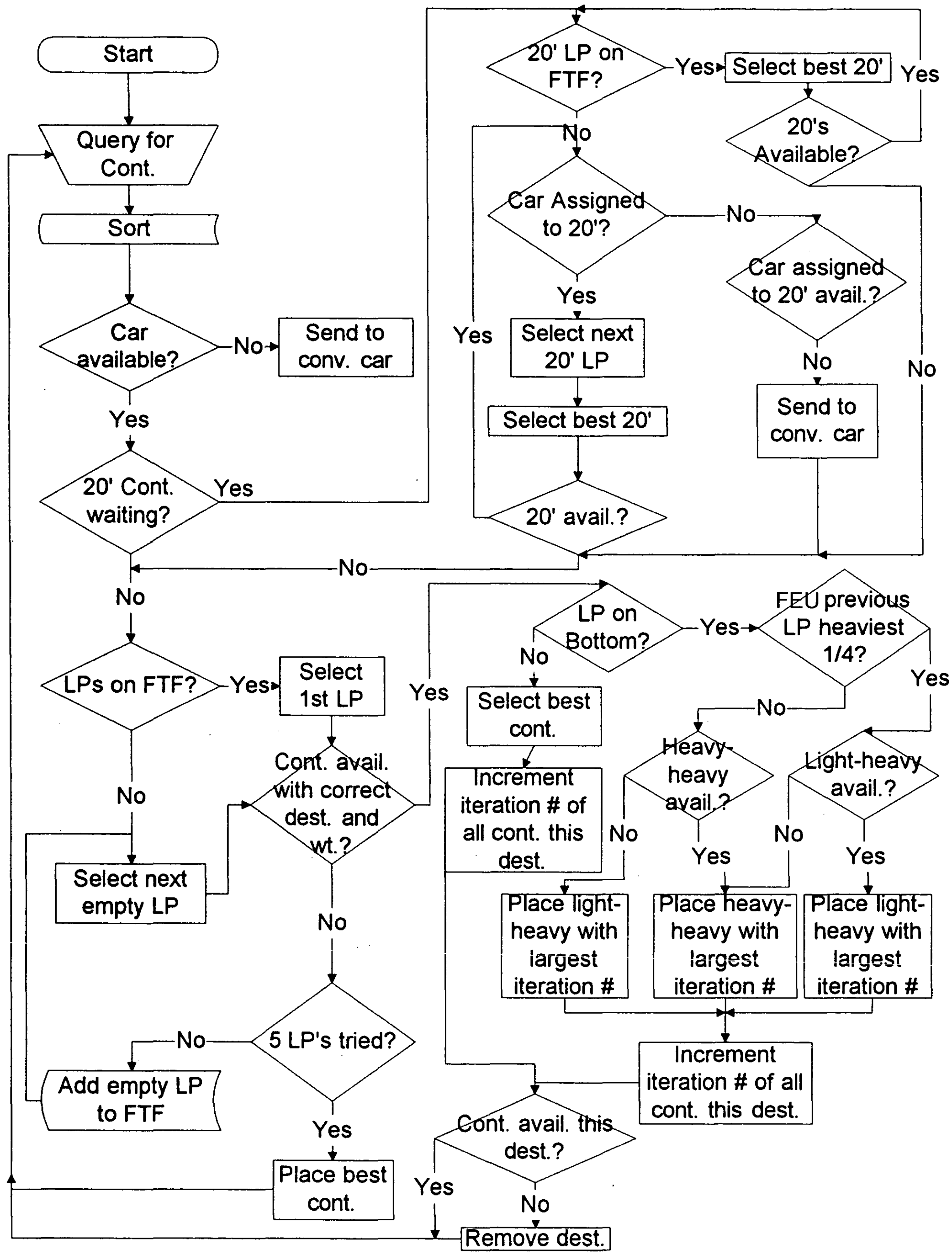

FIGURE 4 **Flowchart of LOASA.**

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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Beneficial Voyage Characteristics for Routing Through Dynamic Currents

MARK R. MCCORD AND YOUNG-KYUN LEE

Anticipating that near real-time estimates of ocean currents could feasibly be used to determine ship routes that would result in reduced fuel consumption, 360 voyages were simulated in the North Atlantic Gulf Stream region to investigate voyage characteristics leading to particularly high or low fuel savings. In the simulations, currents are the primary factor in determining the ship's course. Minimum fuel routes were determined for the currents, and the relative fuel savings of these routes were computed and compared to great circle routes. Ships that modified course slightly to take advantage of the positive effects of the currents had much larger savings than those that avoided the negative effects of contrary currents or went substantially out of the way to catch favorable flows. Determining where and how to cross the core flow was found to be more beneficial than trying to take advantage of the favorable or avoiding the unfavorable effects of rings that are shed from the core. The magnitude of the fuel savings, which often exceeded 10 percent in the study area, depended on the specific realizations of the dynamic current patterns when the voyages were conducted. Therefore, general rules balancing current-induced fuel consumption effects with weather- and wave-induced effects are probably not feasible, and explicit mathematical-based route analyses might be required to reap the benefits of ocean current routing.

Advances in remote sensing technology (*1*), developments in ocean current modeling and forecasting (*2–6*), and the present and planned satellite missions devoted to investigating oceanographic features (*7–9*) make near real-time estimates and forecasts of ocean currents possible (*7,8,10,11*). Using such information to alter strategic ship routes could help decrease voyage time and fuel consumption. In one simulation study, even the very aggregate (in time and space) ocean current data provided in the U.S. Defense Mapping Agency's pilot charts produced an estimated fuel savings of more than 1 percent on transoceanic U.S.-based routes (*12,13*). In other simulation studies, the finer spatial resolution available with advanced technologies produced fuel savings of 5 to more than 10 percent through parts of the Gulf Stream region (*14–16*).

The benefits of routing with ocean currents to minimize fuel consumption or travel time, which shall be referred to simply as "current routing," could complement the benefits of routing through the more traditional means of considering the effects of weather and waves (*17*). The combined environmental effects could conceivably be handled in a computer-based optimization algorithm (*18,19*). The authors' interaction with the commercial routing industry (*7,8*), however, indicates that the individual route analyst's experience is also influential in suggesting a route to the ship master. Analysts may need to update the routes of hundreds of ships dispersed throughout the world at the same time. Therefore, determining when a vessel would benefit by changing course to take advantage of favorable currents or avoid contrary ones would be of value. The current patterns used to determine suggested routes, whether the suggestion is based on a mathematical formulation or an expert router's opinion, are only estimates and subject to a variety of errors (*1,10,20,21*). Observing which vessels benefit most from changing course to take advantage of the currents could help determine whether the potential benefits outweigh the risks of chasing a current that might not be as strong or oriented in as favorable a direction as believed. Finally, knowing route characteristics that would result in large or small benefits could aid the design of simulation studies. These simulations could be used to determine routing benefits and the impacts of errors or sensing limitations of present estimation techniques (*10,20*). For example, the studies could be designed to sample routes more efficiently in various categories of interest instead of needlessly duplicating samples from the same category.

A simulation study was conducted to investigate voyage characteristics that would benefit from strategic current routing through strong dynamic current patterns. The effect on routing performance of the position of the origin and destination of the vessel relative to a portion of the North Atlantic Gulf Stream was examined. The Gulf Stream is typical of rapid Western boundary currents (*22,23*), such as the Kuroshio, the Agulhas, the Brazil, and the East Australian, where velocities can reach 4 knots. In addition to the currents core flow, these dynamic current systems can shed rings with elevated velocities moving in circular patterns. In the area of the Gulf Stream studied (Figure 1), the core flow of the current exhibits a serpentine pattern and sheds cold rings spinning counterclockwise to the warmer water to the south and warm rings spinning clockwise to the colder water to the north. The current routing problem (*14*), then, is deciding which path to follow so that the vessel rides with favorable currents and avoids contrary currents in the core flow or in the rings, thereby conserving fuel and decreasing travel time.

The results indicate that the advantages are greater when ships try to ride favorable currents than avoid contrary ones. They also show that the greatest benefits come from fine-tuning routes along the core flow. Ships that had to cut across the core flow show fewer benefits from current routing, but greater benefits than ships that primarily try to catch rings in the right location. The dynamics of the current pattern were also found to be significant in that some dates are better than others. The results pertaining to the locations appear general; that is, there appears to be enough causal relationship in them that they should give a good indication of the degree to which voyages would benefit from current routing relative to each other.

The results show that the magnitude of current savings cannot be predicted as a function of route characteristics. The results also show that the greatest benefits appear to come from fine-tuning routes or precisely determining when and where to cut across the current structure. Together, these results suggest that a mathematical analy-

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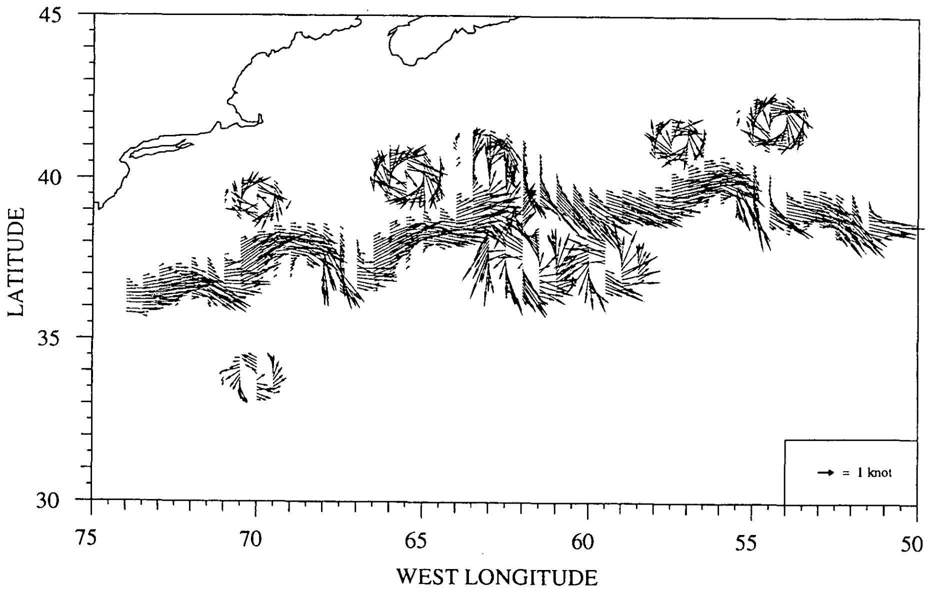

FIGURE 1 Pattern of currents in study region on 5/21/88 based on output of Harvard Gulf Stream model.

sis is needed to estimate the magnitude of fuel savings which would result from routing a vessel through a specific current pattern.

METHODOLOGY

The simulation study consisted of (*a*) choosing the location of the origin and destination of a ship's voyage near a current pattern; (*b*) categorizing this voyage according to the location of its origin and destination with respect to the current pattern; (*c*) determining the path from the origin to the destination that would minimize fuel consumption; (*d*) evaluating the performance of the voyage along this minimum fuel consumption route and using this performance measure as a realization of the performance of voyages in the category; and (*e*) repeating for different origin-destination locations, and different current patterns. (The following section covers these steps in more detail.)

The data consisted of a set of daily estimates of speeds and directions of surface currents in the North Atlantic Gulf Stream region in an area bounded by (north) latitude and (west) longitude coordinates (39°, 74°), (32°, 72°), (38°, 50°), and (46°, 55°) (Figure 1). The current patterns were produced from a forecasting model developed by Harvard University and the U.S. Navy (*2–4,10*) and gridded into 15-km by 15-km cells (one current vector per grid cell). The data was later aggregated into a 0.1°-latitude by 0.5°-longitude grid. Daily estimates from this model were obtained for each day in two 5-week periods, one in 1987 and one in 1988. Voyages beginning on 4 days (2 days in 1987 and two days in 1988) were considered. Voyages selected for the study began on 11/13/87, 11/28/87, 5/06/88, and 5/21/88. Approximately 2-week intervals were chosen between voyage "starting dates" in the same year to increase the independence of the current patterns used (*24*). The fine resolution of the data, the continuity produced by the daily estimates, and the advanced modeling and data acquisition techniques used to produce the estimates make this among the best ocean current data in existence for the types of simulations conducted in this study.

The locations of the origins and destinations were selected by considering five locations near the western boundary and nine locations near the eastern boundary. The five-integer degree latitudes between 34°N and 38°N along 73°W longitude were used as the western locations and the nine-integer degree latitudes between 36°N and 44°N along 53°W longitude were used as the eastern locations (Figure 2). The authors then considered as origin-destination (O-D) pairs the 90 combinations formed by using each of the nine eastern locations as destinations for origins consisting of the five western locations and each of the five western locations as destinations for origins consisting of the nine eastern locations. To study the 90 potential combinations on each of the four voyage starting dates, 360 voyages were simulated.

A western origin and eastern destination pair implies a route traveling primarily eastbound; this is called an eastbound (EB) route. Similarly, a route with an eastern origin and western destination is called a westbound (WB) route. Although these routes are denoted by a geographical direction, the important factor is that the EB routes can be thought of as progressing in the same direction as the primary current flow, and the WB routes can be thought of as progressing in the direction opposite the current flow. Therefore, EB routes primarily try to ride favorable currents and WB routes primarily try to avoid contrary currents. The circular flows of the rings make their effects less straightforward.

For a given starting date of a voyage, each of the 90 O-D pairs was categorized according to whether its origin was "Above," "In," or "Below" the Gulf Stream core flow on the starting date, and whether its destination was "Above," "In," or "Below" the core flow on the starting date. In this way, each of the 90 O-D pairs was placed into one of 18 categories, AA_{EB}, AI_{EB}, AB_{EB}, IA_{EB}, . . . , BA_{WB}, BI_{WB}, BB_{WB}. The first letter denotes the origin location on the starting date, the second letter denotes the destination location on the starting date, and the subscript denotes whether the route was EB or WB. For example, IB_{WB} denotes that the route was a westbound route with origin In and destination Below the core flow of the Gulf Stream on the date the voyage started. The number of voy-

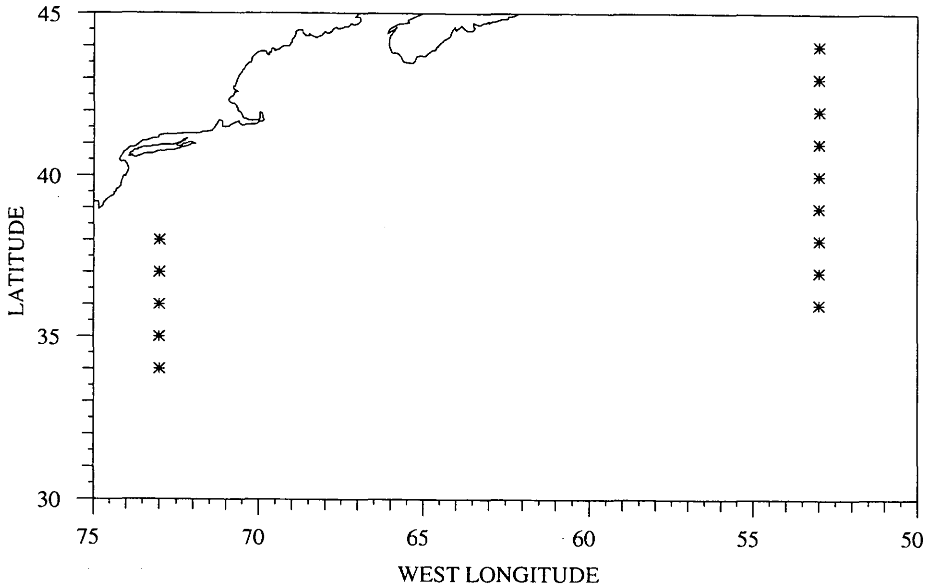

FIGURE 2 Locations of points serving as origins and destinations for simulation study.

ages in each of the 18 categories on each of the starting dates is shown in Table 1. In the In-Below cell, the numbers mean that there were 8, 8, 6, and 6 (4, 4, 4, and 4) EB (WB) voyages with origin In and destination Below the Gulf Stream on 11/13/87, 11/28/87, 5/06/88, and 5/21/88, respectively. The number of voyages can change with the starting date because the core flow is dynamic and changes location in time.

To determine the minimum fuel consumption path between the O-D pair on a particular starting date, a dynamic programming algorithm was used (*10,14,15*). The algorithm determines the minimum time route between the origin and destination through the currents that would be present when a ship traveling at constant velocity (pool velocity V_p) arrived at that location. For example, on the second day of the voyage, the current patterns considered in the optimization algorithm would be different from those on the first day of the voyage. Although the minimum time path is not guaranteed to be the minimum fuel consumption path, the two are practically identical for the types of routes considered in this study (*14,15*).

The variable relative fuel savings (*RFS*) (*12–16*) was used to represent performance of the minimum fuel route. Specifically, (*a*) a voyage time T between the origin and the destination in the study area was determined by routing a vessel at a constant speed V_p along a base route between the study area origin and destination; (*b*) the reduced constant speed through the water V^*, $V^* < V_p$, that would result in a voyage time T along the minimum fuel route between the study area origin and destination was determined; and (*c*) the *RFS* of routing the vessel at V^* along the minimum fuel route through the study area (compared with routing the vessel at V_p along the base route in the study area) was determined. *RFS* is based on the assumption that the fuel consumed by a ship traveling at velocity v for a time t is approximately equal to $c*t*v^3$, where c is a ship constant (*25*). *RFS* is the fuel consumed along the base route minus the fuel consumed along the minimum fuel route, divided by the fuel consumed along the base route, multiplied by 100 percent (*12–16*). This can be shown as

$$RFS = [1-(V^*/V_p)^3]*100\% \quad (1)$$

V_p = 16 knots was used to represent the class of ships most susceptible to benefits from current routing (*12,13*). Routing at constant speed through the water is consistent with industry practice. It also has proven to be approximately optimal in simulations of current routing (*12,14,15*). The great circle route was used as the base route for comparisons. Basing the comparisons on the great circle route makes sense because the great circle is the shortest distance and therefore is the route that would be followed if currents (and other environmental factors) were ignored (*10,12–16*). Fixing the base and minimum fuel routes to have constant voyage time T

TABLE 1 Number of Voyages in O-D Categories by Starting Date (Starting Date Order: 11/13/87, 11/28/87, 5/06/88, 5/21/88)

Origin	Direction of Voyage	Destination: Above	In	Below	Category Total
Above	EB	3,3,4,4	2,2,2,2	4,4,3,3	9,9,9,9
	WB	3,3,4,4	6,6,8,8	6,6,8,8	15,15,20,20
In	EB	6,6,8,8	4,4,4,4	8,8,6,6	18,18,18,18
	WB	2,2,2,2	4,4,4,4	4,4,4,4	10,10,10,10
Below	EB	6,6,8,8	4,4,4,4	8,8,6,6	18,18,18,18
	WB	4,4,3,3	8,8,6,6	8,8,6.6	20,20,15,15
Category Total:	EB	15,15,20,20	10,10,10,10	20,20,15,15	
	WB	9,9,9,9	18,18,18,18	18,18,18,18	

ensures that at the end of the analysis both routes would be at the same point at the same time and simplifies the analysis because the voyage time is eliminated in the math leading to Equation 1.

RESULTS

Table 2 shows the mean *RFS* values for each of the 18 categories and each of the four starting dates. The means are arranged in the order of starting dates. The numbers in the Above-Above category indicate that the average *RFSs* of the voyages whose origins were above and whose destinations were above the core Gulf Stream flow were 7.8, 6.4, 9.7, and 11.0 (3.0, 3.7, 3.6, and 2.6) percent on 11/13/87, 11/28/87, 5/06/88, and 5/21/88, respectively, for EB (WB) routes. The means are determined by averaging the *RFSs* of all the O-D pairs in a category on the specific date. In the Above-Above category in Table 1, the means average 3, 3, 4, and 4 (3, 3, 4, and 4) *RFS* values on 11/13/87, 11/28/87, 5/06/88, and 5/21/88, respectively, for EB (WB) routes.

The way in which the locations of the origins and destinations were determined may lead to some of the Above or Below locations being particularly better or worse than some of the other Above or Below locations on a given starting date because a location may be much closer to or farther from the core flow, or because a location may be particularly well or poorly located with respect to the warm or cold rings. Such a phenomenon could increase the variability of the *RFSs* within the categories. Investigating the effect of specific locations was beyond the scope of this study, however. Moreover, because the number of observations is small in any category and the *RFSs* depend on the common current pattern of the starting date, the authors were hesitant to perform any statistical analysis based on the variances of the categories.

To lessen the possible effect of particularly well or poorly situated locations on the category mean, then, the median *RFS* for each category for each starting date also was computed. Instead of presenting these in a table, the authors chose to present them more graphically in Figure 3. There are some differences in magnitudes between the means of Table 2 and the medians of Figure 3, and even some changes in the position of a category in a ranking from highest to lowest *RFS* value, depending on whether the ranking was according to the mean or median. The differences are slight, however. Both the mean and median were considered in drawing the conclusions in the next section.

In Table 3 the relative ranking of each category on each particular starting date is indicated by dividing the rankings into thirds (i.e., groups of six out of the 18 categories) for each date. Specifically, the number of times the particular category has an *RFS* in one of the top six or bottom six categories on the date is presented. For example, the numbers 3/0 (2/0) in the Above-Below EB category indicate that AB_{EB} ranked in the top and bottom six categories, respectively [3 and 0 out of four times (one for each starting date) when considering the ranking according to the mean, and 2 and 0 out of four times when considering the ranking according to the median].

DISCUSSION

Tables 2 and 3 and Figure 3 show that the effects of current routing depend on the O-D category and the starting date. Given that the latitudes and longitudes of the O-D pairs were the same on different dates, the differences in the fuel savings statistics of the different starting dates must be due to different current patterns (directions, widths, and velocities of the core flow and rings). The implication is that some mathematical analysis, such as the dynamic programming-based algorithms that were used, is required to predict the magnitude of the fuel savings for a given voyage and a given current pattern.

Comparing fuel savings of the O-D categories on a particular date indicates some general characteristics, however. The mean *RFSs* in an O-D category (Table 2), the median *RFSs* in an O-D category (Figure 3), and the number of times that an O-D category ranks high or low (Table 3) all show that EB routes tend to have higher *RFSs* than WB routes. Given that EB routes travel primarily in the direction of the core current flow and that WB routes travel primarily opposite the core flow, the results indicate that the current routing is more useful when trying to catch favorable currents than when avoiding contrary currents. This result is consistent with other, more aggregate studies (14–16).

The results also indicate that the best routes were IA_{EB}, II_{EB}, and especially AI_{EB}. Except for II_{EB}, these routes were in the top third of the rankings on each of the four starting dates. II_{EB} was in the top third three times and in the middle third the fourth time. Figure 3

TABLE 2 Mean RFS of O-D Categories by Starting Date (Starting Date Order: 11/13/87, 11/28/87, 5/06/88, 5/21/88)

Origin	Direction of Voyage	Destination: Above	Destination: In	Destination: Below	Category Mean
Above	EB	7.8; 6.4; 9.7; 11.0	11.8; 8.9; 13.2; 18.2	8.6; 7.1; 11.3; 8.2	9.3; 7.5; 11.4; 12.5
	WB	3.0; 3.7; 3.6; 2.6	6.9; 7.0; 9.3; 6.6	5.1; 5.1; 8.3; 6.4	5.1; 5.3; 7.1; 5.2
In	EB	8.5; 8.6; 12.5; 10.8	6.8; 7.4; 12.8; 14.9	6.7; 5.7; 11.2; 8.6	7.3; 7.2; 12.2; 11.4
	WB	4.6; 6.9; 4.9; 5.8	11.5; 5.5; 9.8; 12.6	8.7; 3.1; 1.9; 4.6	8.2; 5.2; 5.5; 7.6
Below	EB	8.1; 6.1; 7.8; 7.3	6.5; 4.8; 9.8; 15.4	3.8; 4.3; 2.8; 3.9	6.2; 5.1; 6.8; 8.9
	WB	3.5; 1.4; 7.8; 8.1	5.1; 4.4; 6.9; 7.7	1.4; 2.3; 3.1; 4.3	3.3; 2.7; 5.9; 6.7
Category Mean:	EB	8.2; 7.0; 10.0; 9.7	8.4; 7.0; 12.0; 16.2	6.3; 5.7; 8.4; 6.9	7.6; 6.6; 10.2; 10.9
	WB	3.7; 4.0; 5.4; 5.5	7.8; 5.6; 8.7; 8.9	5.0; 3.5; 4.4; 5.1	5.5; 4.4; 6.2; 6.5

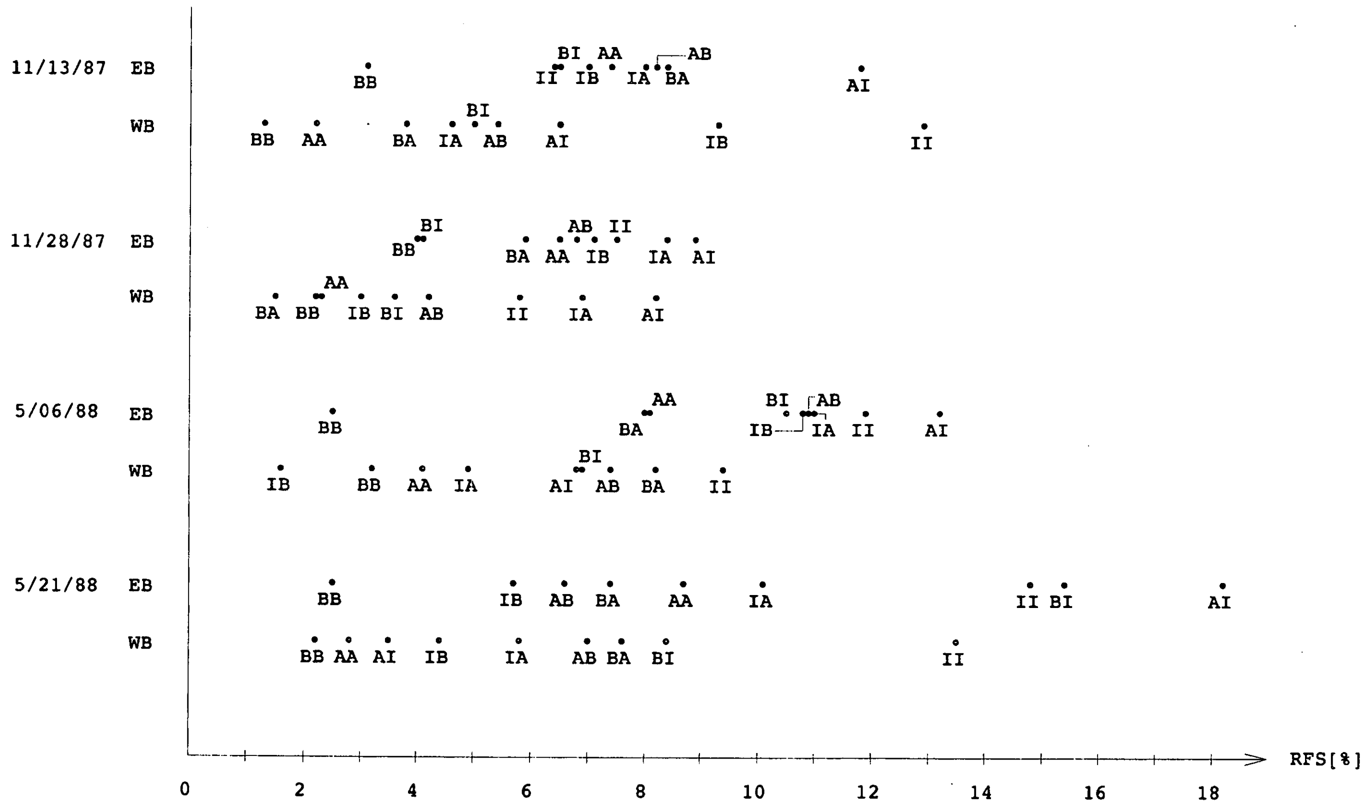

FIGURE 3 **Median *RFS* of O-D categories by starting date.**

TABLE 3 Number of Times (Based on Four Starting Dates per Category) O-D Category was in Top Third or Bottom Third of Ranking According to *RFS* [Based on Means (Medians)]

Origin	Direction of Voyage	Destination Above	In	Below	Category Total
Above	EB	1/0 (1/0)	4/0 (4/0)	3/0 (2/0)	8/0 (7/0)
	WB	0/4 (0/4)	1/0 (1/2)	0/1 (0/0)	1/5 (1/6)
In	EB	4/0 (4/0)	3/0 (3/0)	1/0 (2/1)	8/0 (9/1)
	WB	1/3 (1/2)	2/0 (2/0)	1/3 (1/3)	4/6 (4/5)
Below	EB	1/0 (1/0)	2/0 (2/0)	0/4 (0/4)	3/4 (3/4)
	WB	0/2 (0/2)	0/3 (0/2)	0/4 (0/4)	0/9 (0/8)
Category Total:	EB	6/0 (6/0)	9/0 (9/0)	4/4 (4/5)	
	WB	1/9 (1/8)	3/3 (3/4)	1/8 (1/7)	

shows that AI_{EB} had the highest median *RFS* on three of the four days, and Table 2 shows that it had the highest mean *RFS* on all four starting dates. To determine exactly what is making these routes so favorable, it would be necessary to superimpose the minimum fuel routes and the great circle routes on the current pattern. Doing so for all of the 360 voyages was beyond the scope of this study, but it appears that the voyages with the best potential for current routing are those that would normally (i.e., in the absence of the current routing) ride through or near the core flow and in its general direction. Having an origin or destination in the core flow would increase the likelihood of the base route going along the core flow for some portion of its time. Based on this reasoning, IB_{EB} and BI_{EB} might be expected to exhibit large fuel savings. Although these categories are not as good as the other EB routes with an origin or destination in the core flow, they are still fairly good categories. Table 3 shows that only IB_{EB} ever fell in the bottom third of the ranking, but that was for only one starting date and only when the ranking was according to the median. Except for this instance, the routes were either in the middle third or, almost as likely, in the top third of the ranking.

The categories with the worst performances were AA_{WB}, BB_{WB}, and BB_{EB}, ranking in the bottom third of the categories on all four starting dates, whether the ranking was according to the mean or median (see Table 3). Note that in these three categories the origin and destination are on the same side of the core flow. BB_{EB} could only benefit from current routing by going out of the way to catch the core flow or by trying to catch a ring at the right location. The core flow would not have much of an effect on the WB voyages, because the base (great circle) route would generally not pass through it and a vessel would never go out of the way to get in the contrary flow of the core. Therefore, it would appear that the benefit to these routes would be primarily from catching the rings at the right location. The tentative conclusion, then, is that taking advantage of the positive impacts or minimizing the negative impacts of the cold or warm rings that shed off of the core flow can lead to fuel savings, but that the magnitude of these savings would generally be less important than the savings associated with routing in or through the core flow. The only other category with both origin and destination on the same side of the core flow is AA_{EB}, which never ranked in the bottom third but generally ranked in the middle third of the categories. The authors speculate that it had greater fuel savings than AA_{WB}, BB_{WB}, and BB_{EB} because there is generally more ring activity above the core than below and because the meandering nature of the Gulf Stream could allow the base path to go nearer the core flow traveling in the same direction than the other three categories (see Figure 1).

Those categories with origins and destinations on opposite sides of the core flow (the categories that must cross the core flow) rank primarily in the middle. Table 3 shows that AB_{EB} did rank in the top third three (two) times according to the mean (median), but Table 2 and Figure 3 show that they were close to the middle third on these occasions. Also, BA_{WB} ranked in the bottom third two times and was ranked particularly low on 11/28/87 (Figure 3). In general, however, the categories that cross the core flow are better than those dealing primarily with rings and worse than those whose base routes would travel a fairly long distance in the core flow.

The routes benefiting most from explicitly considering dynamic current patterns were those whose base routes (routes that would be best if the currents were not considered) were in or close to the core flow and going in the direction of the flow. This result seems logical: if a ship only has to modify its shortest distance route slightly to take advantage of the positive currents, the net benefit will be greater than if it has to travel farther from the shortest distance route. The results also indicate that greater benefits are associated with routing correctly through the core flow than with changing course to avoid contrary currents, and that determining where and how to cross the core flow is more beneficial than trying to take advantage of the favorable or avoiding the unfavorable effects of rings that are shed from the core. Trying to take advantage of or avoid the rings resulted in the least fuel savings of all the characteristics analyzed. Because the orbiting satellites gathering the raw data to estimate the current patterns would have limited spatial coverage (*1,7,8,16*), the ring patterns might not be as well resolved as the core flow. The combined effects of relatively low potential benefits and poorer quality of input data significantly decrease the desirability of changing course to ride the favorable or avoid the contrary velocities in rings.

The results also indicated that the magnitudes of fuel savings depended substantially on the specific current patterns associated with the days of the voyage. It would therefore appear that dynamic programming, or some other form of explicit mathematical analysis, might be necessary to help routing analysts studying the combined fuel consumption effects of currents, winds, waves, and weather.

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Louisiana Port Priority Program: An Application of Benefit-Cost Analysis to Project Appraisal

JAY JAYAWARDANA AND D. J. WEBRE, JR.

In this study Louisiana's Port Construction and Development Priority Program and the methodology utilized therein to evaluate capital investments are described. The program is designed to allocate state funds, with incentives for participation by public ports and the private sector. To ensure maximum participation by stakeholders, several measures were adopted at the program formulation stage, and continuing outreach efforts were made to assist ports throughout implementation of the program. The experience gained from operating this program is thought to be unique for several reasons: first, the multifaceted role of public ports both as commercial enterprises and as agents of economic development differs from the role of other public transportation providers, requiring adjustments in project appraisal methodology; second, competitive and cooperative postures among private and public port terminals raise unique policy dilemmas for public intervention in the market; and third, working with small to medium-size, semiautonomous local port authorities for program implementation requires various adjustments in policy prescriptions. Also discussed are the program provisions specifically designed to address these structural characteristics in the maritime sector. The evaluation methodology that was developed takes into account social, economic, environmental, and other impacts from the state's point of view. Over the initial 5-year period, 75 public port projects valued at about $166 million have been evaluated and funded. The program has been successful, with broad acceptance from public ports and the state legislature.

In 1989, Louisiana's citizens approved a constitutional amendment establishing a Transportation Trust Fund (TTF) to ensure a stable and dedicated source of revenue for the construction and maintenance of transportation infrastructure. The major sources of revenue for the TTF are state taxes on gasoline and other fuels, and revenues from state motor vehicle license taxes. The TTF Act provides broad guidelines regarding allocation of revenues to different transportation modes and activities, including highways, statewide flood control, ports, airports, mass transit, and state police traffic control. The TTF provided a funding source for the Port Construction and Development Priority Program (PCDP), which was created by Act 452 of the same year. This act authorizes the Louisiana Department of Transportation and Development (DOTD) to contract with the Louisiana State University National Ports and Waterways Institute to assist in developing a methodology for evaluating and priority rating proposed port projects. The program operated under interim rules and regulations for the first 3 years until more comprehensive rules and regulations were adopted in 1992.

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The focus of this paper is to describe the PCDP formulation and implementation process. From the outset, enhancement of productivity and competitiveness of ports through rational investment of public funds was the primary goal of the program. With this objective in mind, procedures were developed to disburse state funds to projects with the highest prospects for success as determined by objective standards of technical and financial feasibility and other overall socioeconomic impacts to the state.

The experience gained from operating this program is thought to be unique for several reasons: first, the multifaceted role of public ports both as commercial enterprises in the transportation business and as agents for economic development differs from that of other public transportation providers, requiring appropriate response in the project appraisal methodology; second, competitive and cooperative postures among public and private port terminals raise unique policy dilemmas for public intervention in the market; and third, working with small to medium-size, semiautonomous, local port authorities for program implementation requires various adjustments in policy prescriptions.

This paper includes a description and an analysis of salient features of the PCDP and the procedures adopted in its formulation and implementation. More specifically, the paper evolves as follows: (*a*) description of critical characteristics of the maritime industry that influenced the program's framework; (*b*) explanation of program requirements and the user outreach program undertaken for its implementation; (*c*) review of program methodology developed to evaluate proposed projects; and (*d*) evaluation of program experience gained and review of areas for further improvements.

BASIC APPROACH

Several structural characteristics specific to the maritime industry largely determined the content and form of the PCDP. Three major characteristics in particular, namely, the diversity of port size and operations, the diversity of port missions and goals, and private sector participation in waterborne commerce, made development of standard project evaluation procedures extremely challenging. A program formulated within the current industry framework and evolving as an outgrowth of the existing system was foreseen as critical to broad public participation and program success.

Louisiana Maritime Sector

Louisiana is endowed with an extensive system of ports and waterways. With access to the Mississippi River System, the Intracoastal

Waterway, and international shipping through the Gulf of Mexico, Louisiana in recent years has handled more than 400 million tons of waterborne cargo annually. Of the 24 active public ports located in different parts of the state, 18 are categorized as shallow-draft and 6 as deep-draft ports (Figure 1). Generally, the shallow-draft ports are inland ports accommodating vessels having less than 25-ft draft and engaged primarily in domestic trade. Four of the state's ports, South Louisiana, New Orleans, Baton Rouge, and Lake Charles, are among the nation's largest ports. In addition to public ports, a large number of private marine terminals also contribute to the port output in the state. The maritime sector provides substantial economic benefits to the state and the nation in terms of resource development, employment, personal income, business revenue, and taxes.

Organizational Setup of Public Ports

In many localities ports serve not only as links in the freight transportation chain, but also as nodes for industry location with easy access to land and other infrastructure facilities. Furthermore, local port authorities act as grass-roots leadership organizations for community development and economic planning. The organizational setup of most of the ports reflects a desire to maintain local autonomy in business and planning decisions, and it seems to be generally averse to centralized state control. This sentiment is partly reflected in the procedures followed for appointment of port commissioners. In the case of shallow-draft ports, 79 percent of the port commissioners are appointed by local authorities and 21 percent by the governor. For the deep-draft ports, 78 percent of the appointments are made by the governor and 22 percent are either appointed by local authorities or are elected. Essentially, all port commissioners are from the local community. Therefore, one guiding principle in formulating the program procedures has been to maintain local responsibility for the port planning process and decision making.

State Funding for Public Ports

State funding is a major source of capital investment for public ports in Louisiana. It is estimated that, from 1977 to 1984, Louisiana expended more funds for ports than any other state in the nation. For this period Louisiana spent $26 million on shallow-draft ports and $173 million on deep-draft ports for a total of $199 million (*1*). Before the PCDP, the state funded port projects through the Capital Outlay Program without requiring feasibility studies. The basis for priority rating and funding depended on political sponsorship of projects at the state legislature, which was dictated mainly by regional sociopolitical interests.

Size of Public Ports

Public ports eligible for funding under the program varied substantially from well-established deep-draft ports with many berths catering to ocean shipping, to new shallow-draft ports with very limited or no physical infrastructure. The availability of professional staff and the levels of financial and technical capabilities also varied widely with the scale of operations and the duration in port business. These variations had to be reconciled and addressed in program formulation. For example, the project appraisal methodology and the application procedure had to be logical and technically acceptable, but simple enough to be understood by all port participants.

Stakeholder Participatory Process

Outreach efforts to obtain input from program participants and stakeholders were conducted in two stages: initially, in formulating the rules, regulations, and procedures for the program; and on a continuing basis during implementation. In 1990 a Transportation Infrastructure Evaluation Committee was appointed by the governor to provide a general overview of the capital improvements required to the state's transportation network. This committee was composed of legislators and public and private sector officials representing state agencies and the various modes of transport. The PCDP benefited, specifically, from the input provided by an advisory committee representing deep- and shallow-draft public ports. The comprehensive rules and regulations were adopted by the DOTD in 1992 with approval and support by the state legislature and the port industry. In addition, several provisions in the program provided for public ports to participate on a continuing basis in the program as it is implemented. These aspects will be discussed next.

Missions, Goals, and Philosophy of Public Ports

In the past, public ports in Louisiana have not operated strictly as profit-driven commercial enterprises. Predominant in their missions and goals is the diversification of the local economy and community development, mainly through fuller utilization of local resources. In fact, the *ad valorem* property tax assessments passed by many communities indicate that such a role for ports is desired. Implicit in these voter actions appears to be that communities are willing to subsidize port enterprises in order to revitalize local economies, especially to generate local employment. Therefore, creation of jobs is considered a major project benefit under the program.

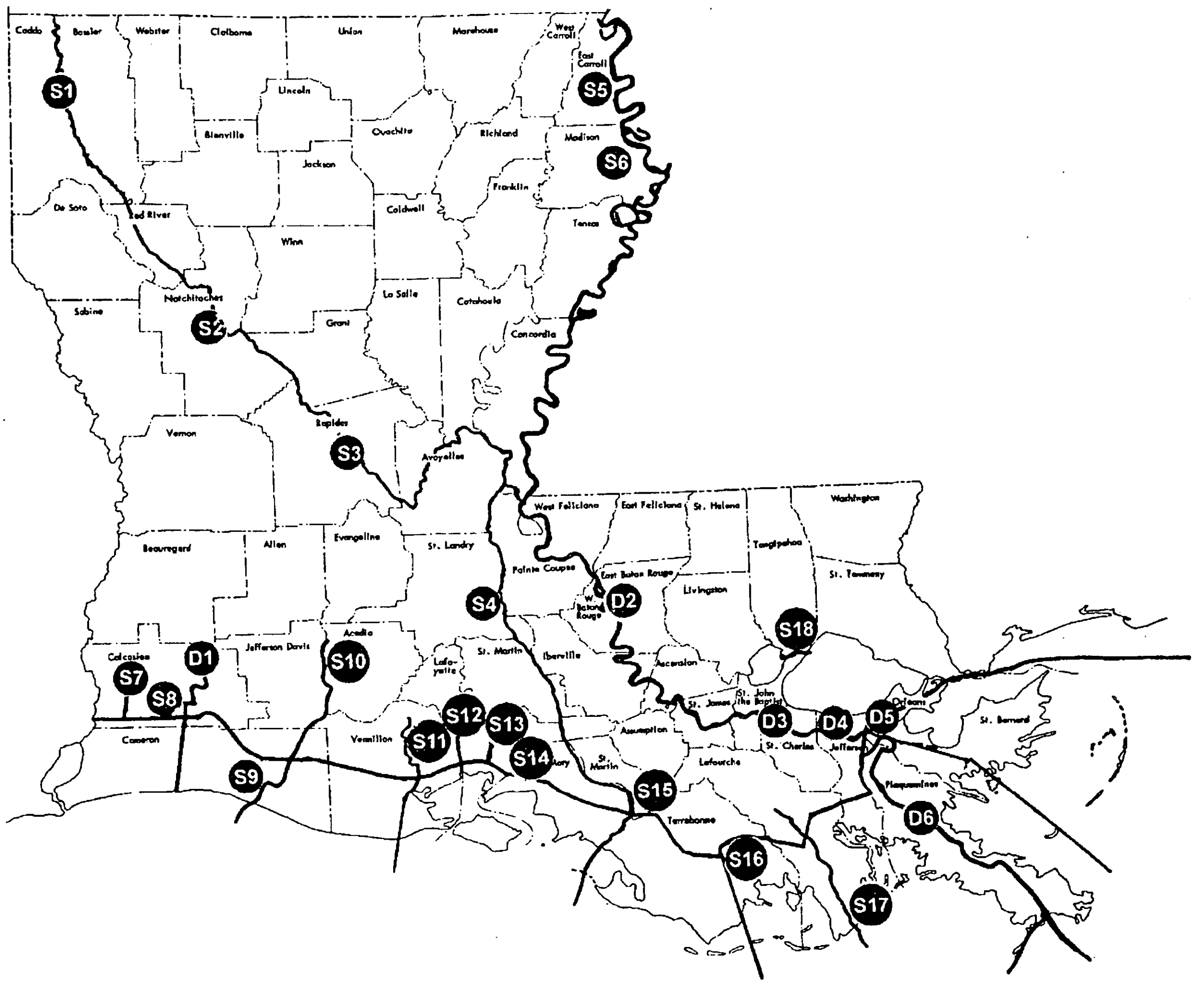
The objectives of ports lead them to support various economic development enterprises other than traditional cargo handling and transfer activities. For example, some industries located in the port industrial park may have only a very peripheral relationship with water transport, but the port may choose to support them by, for example, providing storage services, rail links, or other infrastructure facilities. The economic activities previously undertaken by the ports have indicated that the program methodology must be robust in accommodating and evaluating various economic development projects even if they are not directly involved in maritime commerce.

Public Ports Versus Private Terminal

Public ports interact with private sector operators in two main ways: competing with the private sector by owning and operating terminals; and, more frequently, acting as "landlord ports"—leasing public terminal facilities to private sector operators. Although in most cases this competition tends to be indirect (types of cargo handled are different), the program had to be extremely cautious so that infusion of subsidized capital to public ports would not adversely affect the inflow of private capital and entrepreneurship. In order to ensure that reasonable port tariffs are charged for the use of facilities funded under the program, sponsoring ports are required to structure tariffs (port revenues) to satisfy a minimum rate of return on program funds. This aspect is discussed further in the following section.

PROGRAM FRAMEWORK

In this section several requirements incorporated into the program will be analyzed in order to explain the general objectives and the



Deep Draft Ports

- D1 - Port of Lake Charles
- D2 - Port of Baton Rouge
- D3 - Port of South Louisiana
- D4 - Port of New Orleans
- D5 - St. Bernard Parish Port
- D6 - Plaquemines Parish Port

Shallow Draft Ports

- S1 - Caddo-Bossier Port Commission
- S2 - Natchitoches Parish Port Commission
- S3 - Alexandria Port Authority
- S4 - Greater Krotz Springs Port Commission
- S5 - Lake Providence Port Commission
- S6 - Madison Parish Port Commission
- S7 - Vinton Harbor & Terminal District
- S8 - West Calcasieu Port, Harbor & Terminal District
- S9 - East Cameron Port Commission
- S10 - Mermentau River, Port, Harbor & Terminal District
- S11 - Abbeville Harbor & Terminal District
- S12 - Twin Parish Port Commission
- S13 - Port of Iberia
- S14 - West St. Mary Parish Port, Harbor & Terminal District
- S15 - Morgan City Harbor & Terminal District
- S16 - Terrebonne Port Commission
- S17 - Greater LaFourche Port Commission
- S18- South Tangipahoa Parish Port Commission

Figure 1 Shallow- and deep-draft public ports in Louisiana.

underlying reasons for their inclusion. Two documents incorporating rules and regulations and program procedures were developed for use by the port participants (*2,3*). In essence, all program requirements are directed to ensure maximum economic impacts to the state with limited program funds. However, they target three specific policy areas: first, that the program funds be invested in specific types of maritime projects to ensure maximum sectoral impact; second, that cost sharing be encouraged to ensure maximum leverage of program funds; and third, that high standards of credible project data be provided by port sponsors, both for project evaluation purposes and to ensure the quality of decision making by port sponsors themselves.

Type of Projects

A wide variety of projects are funded under the program, ranging from construction, to improvement, to capital facility rehabilitation, and to expansion of publicly owned port facilities. This includes intermodal facilities, maritime-related industrial parks, and port infrastructure such as wharves, storage facilities, cargo handling capital equipment, utilities, railroads, and primary access roads. Excluded from program participation are state sponsorship of new construction and/or maintenance of federally authorized navigable waterways, and land acquisition by ports for speculative reasons. Land acquisition is eligible for funding only when it is an integral component of a project and necessary for the project benefits to be derived. These requirements are intended to avoid large outlays in areas marginal to the maritime sector and to concentrate funds specifically for the development of infrastructure that serves port objectives.

Cost-Sharing Procedures

The PCDP identified four main sources of project financing: program funds, port funds, federal funds, and private sector funds. The legislative act provided that the sponsoring port provide a minimum of 25 percent of the project cost (construction and engineering, etc.). This requirement was subsequently changed to 10 percent of project construction costs, excluding engineering fees. The change was made to allow construction of port infrastructure sooner, inasmuch as DOTD was no longer required to review engineering selection, contracts, and fee schedules.

To encourage higher funding participation levels from ports and the private sector, an additional benefit-cost ratio was calculated. All project benefits were divided by the program investment. This ratio is utilized in the final evaluation and ranking. By utilizing program investment in the calculation, projects with higher levels of port and private sector funding will rank higher and possibly be funded sooner.

Project Information Requirements

The most challenging task in formulating program rules and regulations was to specify project information requirements to be submitted by the sponsoring ports. The information submitted had to be logical and acceptable for evaluation. The wide diversity of port projects as well as the range of technical capabilities available to the various ports had to be reckoned with in framing the regulations. Furthermore, because project benefits are closely related to anticipated future market developments, certain guidelines had to be provided regarding market forecasts. Discussions with port authorities and the private sector port operators were helpful in drafting these requirements. The following section is a brief analysis of the major project definitions and concepts included, and the outreach program undertaken to explain the requirements.

The information requested from sponsoring ports on proposed projects can be divided into five major categories (Table 1). The section on project description is designed to focus on defining the physical and financial parameters of the project. According to the nature and goals of the project, sponsors are required to provide a narrative description of the project in sufficient detail to clearly convey the purpose, design, and major components of the project. The discussion of alternatives is aimed at ensuring that the proposed project is selected as a result of an objective analysis. The adequacy of components requirement directs port planners to evaluate port operations as a total integrated system, to identify possible bottlenecks resulting from implementing the new project, and to plan corrective action.

The demonstration of immediate need for the project is extremely important, and if the need is not adequately justified, the project is rejected at the early stages of evaluation. Most of the information required in this section is to support market forecasts and estimates, and port authorities are encouraged to justify market projections through detailed market analyses and commitments by port users to utilize the expanded project facilities. Furthermore, ports are required to establish the level of utilization of existing facilities by providing data on cargo throughput for the last 5 years. If congestion was experienced, it was necessary to identify facility bottlenecks and how they were overcome. With regard to cargo forecasts, ports are advised to extrapolate past trends and/or to follow national projections of waterborne commerce as estimated by the U.S. Army Corps of Engineers (*4,5*). Any deviations from these growth rates are expected to be justified either as diverted cargo from other facilities or as cargo generated by new agricultural and industrial developments. In such cases, the sources of cargo, origins and destinations, and shares for different transportation modes need to be analyzed and justified.

Preliminary plans and cost estimates are included to further describe the proposed port projects. The level of detail is conceptual in nature, but enough detail must be provided to indicate that adequate thought and planning has been accomplished to provide for the needed infrastructure to satisfy a real and definable market need. It is not the purpose of the program to build infrastructure on speculation (". . . and they will come").

Benefits from the proposed projects are evaluated from the state's point of view, which includes the taxpayer's point of view and the port's point of view. Accordingly, if benefits are to be counted for any cargo diverted from another Louisiana port, the project must demonstrate an improvement in the overall efficiency of the state's port system through transportation cost savings. Overall, benefit estimates are required to be logical, verifiable, and based on sound judgment and acceptable industry norms. If the claimed benefits are not adequately justified or do not conform to industry norms, they are adjusted before evaluation. At the same time, benefits that may have been overlooked by port applicants are brought to their attention at the preliminary review of applications.

The creation of new permanent jobs or retention of existing jobs in local communities is considered a major project benefit. For evaluation purposes, several guidelines are provided to estimate the

TABLE 1 Program Requirements and Guidelines for Port Participants

Information Requirements	Guidelines Provided
1. Project Description	**Focus on physical and financial parameters of the project.**
Project Definition	An activity derives benefits after program investments.
Nature and Goals	To convey the purpose, design, and components of the project.
Project Financing	Indicate total funds needed and funding sources.
Alternatives	Indicate which alternatives were considered and explain why the project was selected over alternatives.
Adequacy of Components	Establish that all the components necessary to derive the benefits are available.
2. Demonstration of Immediate Need	**Focus on marketing potential of the project.**
Cargo History	Establish the level of utilization of existing facilities.
Market Analyses	Forecast the cargo that will use the project for ten years.
Industrial Development	Indicate what new industrial development with project.
Letters of Commitment	Submit letters of commitment from industrial tenants.
3. Preliminary Plans and Costs	**Focus on engineering aspects of the project.**
Design Criteria	List criteria needed for design, e.g., 300 LF of bulkhead.
Design Calculations	Provide conceptual design calculations.
Preliminary Construction Plans	Sufficient detail to conceptually convey project components and requirements.
Cost Estimates	Detailed cost estimates of project components and recurring maintenance costs.
Progress Schedule	Provide an anticipated implementation schedule.
4. Determination of Benefits	**Focus on economic returns of the project.**
Definition of Benefits	Indicate net benefits "with the project" condition.
Revenues and Expenses	Estimate net port revenues "with the project" condition.
Number of Jobs	Indicate the # of jobs created/saved.
5. Environmental Impacts	**Focus on positive and negative externalities of the project.**
Impacts on Resources	Water quality; habitat modification; fish and wildlife; cultural, historical, and archeological features.

number of jobs created and the payroll. First, the jobs created have to be identified either as directly related to port activities or as related to other industries. Second, the number of jobs is estimated from industry norms such as capital investment per worker, volume of cargo handled per worker, and the number of employees per firm. A classification of commercial firms in port related industries in the state by employee size is provided for reference purposes (*6*). In order to measure employment impacts in an equitable manner across projects, a standard payroll for managerial, skilled, and unskilled workers was made available for use by all project applicants. On the assumption that true net benefits from employment diminish over time, the payroll benefits resulting from the project are allowed to decay in a linear manner annually, reaching zero at the end of 10 years. Furthermore, spinoff benefits of payroll are calculated as equal to payroll benefits, creating an earnings multiplier of two for all projects throughout the state. The spinoff benefits also decay in a linear fashion annually, reaching zero at the end of 10 years. Since project benefits are from the state's point of view, if jobs are displaced elsewhere in the state due to the project, only the net benefits are taken into account.

Port revenues and expenses are also estimated for both the "with" and "without" project conditions in the determination of benefits. Revenue estimates are based on present and future port tariff rates or must conform to industry norms. In the calculation of expenses, project maintenance costs are included along with operational expenses. Only the projects that realize a minimum rate of return of 3.7 percent as net port revenue for the state's investment are funded by the program. This minimum rate of return requirement was incorporated into the program principally for two reasons. First, because the general objective of all public ports is to develop viable commercial operations, it was necessary to ensure that new investments do not adversely affect the financial position of ports. Second, the public port tariff rates need to reflect the cost of providing the facilities (including return on investment) to protect private sector terminals from unfair competition by subsidized public ports.

BENEFIT-COST METHODOLOGY

Project Definition

For purposes of benefit-cost evaluation, investments are divided into two categories: "total project" and "project." The total project includes all improvements that are necessary by both the public and private sectors in order to derive the benefits identified in the application. Project refers to that part of the total project for which the port is seeking program funds from the department. The project includes all components to be built/acquired by the public port within the program's limit of two consecutive years for implementation.

Project Life and the Planning Horizon

Project life for civil construction work is estimated to be 30 years, and for mechanical equipment such as cranes and other cargo handling equipment, it is variable, ranging from 10 to 20 years. The number of years over which the benefits and costs of the project will be evaluated is limited to 10 years. If the project life exceeds the evaluation period, the salvage value is determined using the straight line method of depreciation and is tabulated as a benefit.

Discount Rate

The discount rate used in the evaluation process is 3.7 percent. This rate is derived from the average interest rate paid on 30-year General Obligation Bonds (GOB) during the period 1987 to 1990 (7.7 percent) by the state, less the average inflation rate (4.0 percent) as indicated by the Consumer Price Index. Because these bonds were the funding source for public ports before the new program started, it is assumed that this discount rate reflects "opportunity cost" of capital to the state. However, as long-term interest rates and the rate of inflation change, periodic adjustment of this discount rate will be necessary.

PROJECT PRIORITY CRITERIA

Minimum Threshold Requirements

If the proposed projects do not meet project information requirements and some minimum financial indices, they are not further considered for priority rating. These are identified as minimum threshold requirements (Table 2). Incomplete applications are rejected because evaluation and ranking of projects require sufficient information. Establishing the need for the project in terms of market developments or operational requirements of the port provides the basic foundation for project benefits. As discussed in an earlier section, the minimum rate of return on investment for net port revenues is introduced to ensure that public port tariffs cover reasonable costs, including a return on investment. Since public ports generally act as landlord ports leasing basic infrastructure to private operators, the final tariff rates at public terminals are expected to be competitive with private sector tariff rates. A benefit-to-total cost (B-C) ratio of 1 is considered a minimum threshold for the proposed project. In calculating this B-C ratio, the costs include the total investment, both private and public, needed to implement the total project and derive the benefits.

Scoring Criteria and Ranking of Projects

In the final analysis, the program procedures require the department to prepare a recommended list of projects in priority order and sub-

TABLE 2 Project Criteria: Minimum Threshold Requirements

Minimum Requirement	Guidelines
Completeness	If application incomplete, advise applicant of missing data.
Project Need	The need has to be verifiable and real for the application to be considered.
Location	Ports should provide adequacy of highway, rail, and waterway access to support increased activity with the project.
Return on Investment	All acceptable projects must generate at least 3.7% rate of return in terms of net port revenues on Program investment.
Benefit-Cost Ratio	B-C ratio of total project must be 1 or >1. Costs include all public and private sector project costs.

mit the list for funding consideration to the state legislature. The scoring criteria followed for ranking of projects are shown in Table 3. For a project to qualify under technical feasibility, it must score a minimum of 15 points. Some indications of technical feasibility are completeness of project design, appropriate consideration of alternatives, compatibility of the project with the port's master plan, level of detail of preliminary plans, and a cost estimate sufficiently detailed to allow verification. The project with the highest benefit-cost ratio receives the maximum 100 points. Scoring for the other projects is prorated. The cost used in economic feasibility and economic impacts is the amount of program funds required for the project. This requirement encourages ports to contribute a higher amount of matching funds, and maximum leverage of program funds.

PROGRAM REVIEW

Investment Levels

Since the inception of the program in 1989, about $82.5 million of program funds has been allocated to the PCDP, which has allowed funding of 75 port projects (Table 4). Some of these are multiyear projects and will require an additional $8.5 million of program funds to complete, totaling $91 million. With matching funds from the ports, private sector port tenants, and other agencies, the program has provided for $166 million worth of projects to the port sector in the state. At this writing, approximately $13 million in projects have been completed, $22.1 million are under construction, and construction plans specifications are being prepared for the balance. The major types of projects funded are: ship berths and bulkheads, warehouses at ports and industrial parks, access roads and rail spurs to ports, and rehabilitation of existing port infrastructure. Over the initial 5-year period, the legislature has approved the list of projects essentially as priority rated in the evaluation process.

Type of Projects Funded

Investment in facility expansion projects is $92 million, and upgrading and maintenance of existing facilities total $74 million. The deep-draft port facilities received 65 percent ($108 million) of the investments, and about 60 percent of this is spent on maintenance projects. The shallow-draft ports allocated 84 percent of their investments to expansion of existing facilities or construction of new terminals.

Public-Private Partnerships

In terms of cost sharing, the program share in total investments is 55 percent, compared to 45 percent from the ports and other sources. This indicates that the program is successful in leveraging other funding sources over and above the minimum program requirement of 25 percent. The participating ports in many instances were able to join with the private sector port tenants and operators in packaging innovative project financing methods.

An important dimension of the PCDP investments is the broader impact on local resource development and the leverage of private capital and entrepreneurship for the development of maritime facilities. A significant percent of port projects undertaken are private and public sector partnerships providing incentives to local resource based industries which generate cargo for the public port. Construction of warehouses for new industries on port premises (such as fabrication of off-shore oil-rig equipment and metal fabrication); direct rail and waterway access to port tenants which may lead to transportation cost savings and business expansion; and upgrading of cargo handling equipment for private operators managing a public terminal are some examples of public/private partnerships.

Areas for Further Improvement

Two of the most difficult challenges that emerged during several years of evaluating project applications are as follows. Because of

TABLE 3 Project Ranking: Scoring Criteria

Feasibility Measure	Feasibility Indicator	Maximum Points	Scoring Method
Technical Feasibility	Capable of being built	45	To qualify must score a minimum of 15 points.
Economic Feasibility	Benefit-cost ratio	100	Project with the highest B-C score 100; others are prorated.
Economic Impacts	# of jobs created or saved	20	Project with highest job potential score 20; others prorated.
Environmental Impacts	No adverse impacts or enhance environment	15	Project with no adverse impacts score 10; if it enhances the environment, 15.
Management of Port	Return on Investment	20	Port with highest ROI for the last five years scores 20; others prorated.
Total Points Possible		200	

TABLE 4 Types of Projects Funded and Cost-Sharing Levels by Various Entities

Cost Sharing Entity	Expansion of Facilities					Upgrading of Facilities			
	Shallow - draft								
	Existing Ports	New Ports	Total Sh. draft	Total Deep dr.	Total (sh./ deep)	Shallow Draft	Deep Draft	Total (sh./ deep)	Grand Total
					(in $ millions)				
Program Share *	15.8	12.9	28.7	19.3	48.0	6.3	37.0	43.3	91.3
Port/Others Share *	10.3	10.3	20.6	23.7	44.3	3.2	27.4	30.6	74.9
Total Cost	26.1	23.2	49.3	43.0	92.3	9.5	64.4	73.9	166.2
Total Cost Shares (percent):									
Program Share	10	8	17	12	29	4	22	26	55
Port/Others Share	6	6	12	14	27	2	16	18	45
Total Cost	16	14	30	26	56	6	39	44	100

* Includes commitments through financial year 1995/1996

the wide variety of project types, credible demand projections had to be made not just for diverse cargo flows, but also for industrial uses of port facilities (such as demand for off-shore oil rigs and demand for equipment fabrication and maintenance). Secondly, a very difficult judgment must be made regarding the role of subsidized public capital in public-private partnerships. Infusions of subsidized capital may be necessary to attract certain industries, but in the long run these enterprises have to be strong and viable to compete under open market conditions.

Since an understanding of program rules, regulations, and procedures by the participating ports is key to the successful implementation of the program, various outreach efforts were undertaken to provide instructions and guidelines to port officials in the state. Port officials nominated by the Ports Association of Louisiana were included on the committee which developed the program rules, regulations, and procedures. These were then submitted to the general membership for comment. Several workshops were conducted to explain the theoretical aspects of project evaluation and cost benefit analysis, and engineering information required with project proposals. In addition, technical assistance was provided to participating ports on an individual basis in a presubmittal review of project applications. This preliminary review proved to be very effective in assisting port officials to streamline their applications and to present information effectively, in conformance with program rules and regulations. Further, it helped to ensure that infrastructure is built for a given and real market need and increased the probability of a successful operation.

For 3 years after the completion of a project funded under the PCDP, the port authority is required to submit a report comparing the actual benefits derived with the estimated benefits in the project proposal. This report requires that significant deviations be identified and corrective actions be enumerated. At present, a review of these project monitoring procedures and the development of a standard reporting format are under way. The development and maintenance of a statewide inventory of maritime facilities and a database on Louisiana's marine terminal operations is considered an additional product of the program.

CONCLUSIONS

The creation of PCDP has resulted in several structural adjustments in the Louisiana maritime industry. First, it provided a dedicated and stable source of funding for construction and maintenance of port infrastructure. Second, it established an objective methodology for project evaluation and ranking for funding purposes. In developing this methodology, input and cooperation from the participating ports was obtained, and technical assistance is provided to ports on a continuing basis to improve project proposals. Third, and perhaps most importantly, the program provisions in many ways encourage public and private sector alliances in building maritime transportation infrastructure for accelerated economic development.

ACKNOWLEDGMENTS

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Intelligent Vehicle Highway System Commercial Vehicle Operations: Perceptions, Needs, and Concerns of Indiana-Based Interstate Motor Carriers

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This paper highlights results of a comprehensive statewide survey examining Intelligent Vehicle Highway System (IVHS) perceptions, needs, and concerns from the perspective of Indiana-based interstate motor carriers. It was conducted as part of a study to examine institutional issues related to the application of IVHS technologies to commercial vehicle operations (CVO) in Indiana. Specific survey issues included how motor carriers perceive IVHS-CVO concepts would affect their current operations; what data items motor carriers are willing to have electronically stored within automatic vehicle identification (AVI) transponders; what type of weigh station preclearance information storage motor carriers prefer (i.e., centralized data base or data stored within a transponder); how willing motor carriers are to participate in a "Gold Card" precertification process for weigh station preclearance; what type of automatic toll collection system motor carriers prefer (i.e., debit system or credit system); how willing motor carriers are to pay additional tolls to help cover costs of building bypass lanes next to existing toll plazas for AVI-equipped vehicles to automatically pay tolls while operating at mainline speeds; and the degree to which motor carriers believe IVHS-CVO implementation will lead to a level playing field between motor carriers.

Trucking is a key component of Indiana's diverse economy. Whether hauling $4.93 billion worth of commodities from the state's 65,000 family farms, or transporting 155 million tons of freight into and out of the state each year, truck-dependent industries encompass almost 68,000 Indiana businesses, employ approximately 1.37 million people (65 percent of Indiana's workers), and utilize over 25 280 km (15,700 mi) of state and federal roads that connect the state's economic centers (*1*).

In addition to these home-based operations, Indiana's location makes it a key component of the United States' trucking economy. Containing 1 835 km (1,140 mi) of both rural and urban Interstates, Indiana is a major through-travel state for operations along the north-south I-65 and I-69 corridors, and the east-west I-64, I-70, I-74, I-80, I-90, and I-94 corridors, including the 253-km (157-mi) Indiana Toll Road (I-80/90) that is often called the "Main Street of the Midwest" due to its connections with the Ohio Turnpike for points east and both the Chicago Skyway and Borman Expressway for points west (*2*).

With this operational magnitude, Indiana actions that benefit trucking efficiency, while still maintaining trucking safety, can potentially yield significant benefits to both the state and national economies—especially to those areas with companies operating on the "just-in-time" (JIT) philosophy that has effectively turned many roads into moving warehouses for industry. Seeing this potential, the Joint Highway Research Project at Purdue University initiated a contract with the FHWA to identify government-based and industry-based institutional barriers affecting the implementation of Intelligent Vehicle Highway System (IVHS) technologies to interstate commercial vehicle operations (CVO) in Indiana. Specifically, research was focused on the potential for

- Automatic payment of tolls (while driving at mainline speeds) through the use of automatic vehicle identification (AVI) transponders;
- Preclearance of vehicles and drivers past weigh stations through the use of AVI transponders, weigh-in-motion (WIM) devices, and prequalifying safety inspections;
- "One-stop shopping" for licenses, registrations, and permits through increased cooperation and data sharing between state agencies; and
- Transparent state borders through increased cooperation and data-sharing between states.

Actions were coordinated with a similar study for the state of Illinois (conducted by the University of Illinois at Urbana-Champaign) as part of an FHWA initiative to designate I-80 as a "test bed for the next generation of highway safety improvements" due to its natural "link between existing IVHS operational tests in the east (Advantage I-75) and in the west (HELP/Crescent)" (*3*). Particular emphasis was given to achieving uniformity of Indiana laws with those of surrounding states so that the concept of transparent state borders could be realized.

This paper highlights methods and results from one portion of that study—a comprehensive statewide survey to examine IVHS-CVO perceptions, needs, and concerns from the perspective of Indiana-based interstate motor carriers. A detailed report of the full study, *Institutional Issues Related to the Application of Intelligent Vehicle Highway System Technologies to Commercial Vehicle Operations in Indiana*, is available (*4*). The full report includes a review of existing laws and policies applying to commercial vehicles operating in Indiana; an inventory of the agencies responsible, their existing procedures, their physical facilities, and their human resources used to implement these regulations; an itemization of present impediments preventing IVHS-CVO implementation under current Indiana State Laws; and recommendations for future phased-in modifications to the present systems for effective IVHS-CVO implementation. In addition, the full report contains details

Purdue University/Indiana Department of Transportation Joint Highway Research Project, 3154 Civil Engineering Building, Purdue University, West Lafayette, Ind. 47907-1284.

about a day-long consensus-building workshop regarding future directions for Indiana/Illinois IVHS-CVO, which was held in Merrillville, Ind., on November 17, 1993. Organized by Purdue University in cooperation with the University of Illinois at Urbana-Champaign and the FHWA, it was attended by more than 100 representatives from a broad range of public and private sector interests. Participants included motor carriers, their industry associations, the above sponsors, and various state agencies from both Indiana and Illinois, including each state's Department of Transportation, Department of Revenue, Bureau of Motor Vehicles, and State Police.

BASIS FOR SURVEY

This study's Phase I efforts to determine trucking industry concerns and perceptions about IVHS-CVO development and implementation had been of a qualitative nature due to its basis on interviews and workshop-type meetings with motor carriers. However, quantitative data about these issues were still needed in order for unbiased inferences to be made about the entire population of Indiana-based interstate motor carriers. This was especially important because understanding these specific industry viewpoints is vital to the process of getting IVHS-CVO development and implementation to be acceptable to both government and industry—a critical element in fully realizing and utilizing the many potentials of IVHS-CVO technologies. As such, this study's Phase 2 included a comprehensive statewide survey to provide decision-makers with the quantitative data that they needed.

Intrastate carriers were not included in this survey due to its focus on interstate concerns such as transparent state borders and the reduction of multiple weigh station stops per trip. Currently, Indiana weigh stations are located such that it is highly unlikely that significant numbers of intrastate carriers would ever have to stop at more than one Indiana weigh station per trip. In addition, the "barrier" portion of the Indiana Toll Road, where electronic toll collection could be most beneficial due to the need to pay a toll every few miles, is primarily used by interstate carriers making trips to and from Illinois. Conversely, intrastate carrier trips on the Indiana Toll Road tend to be focused on the "gated" portion of the system where drivers obtain a ticket at their point of entry, and then pay an appropriate toll at their point of departure—a portion of the system thought to derive fewer benefits from implementing electronic toll collection.

SURVEY DEVELOPMENT

The questionnaire form used for this survey evolved from government and industry comments on two previous questionnaires developed for this survey, including critiques from pretesting a version to about 30 persons attending a government/industry IVHS-CVO seminar on June 17, 1993. This seminar was sponsored by the FHWA's Office of Motor Carriers in Indianapolis.

The survey mailing list was based on an International Registration Plan (IRP) registration list provided by the Indiana Bureau of Motor Vehicles. It was decided that this list would be used because of its comprehensive nature and because it provided necessary data for conducting a random, statistically significant, stratified sampling of the 7,136 Indiana-based interstate motor carriers who had vehicles registered with IRP on August 27, 1993. The list included each company's name, address, the number of power units registered in each of their fleets, and the name of their designated IRP contact person.

SAMPLING METHOD

To get responses from a cross section of motor carriers, both large and small, the IRP list was stratified into five groups based on the number of power units in a company's fleet—a surrogate measurement for company size and volume of their shipments. This was especially important for balanced opinions because trucking in Indiana tends to follow the motor carrier industry's general rule of thumb regarding large carrier dominance (i.e., approximately 80 percent of the companies have less than 20 trucks; however, the 20 percent of the companies that have more than 20 trucks transport approximately 80 percent of the goods). Thus, if responses were weighted only by the number of power units in a company's fleet (e.g., without stratification), instead of first grouping carrier responses by size, the many voices of smaller carriers whom Indiana's farmers are especially dependent on would be muffled by the relatively few number of larger carriers. However, it must be pointed out that, when the implementation policy is determined, the concerns of the smaller carriers will have to be balanced with those of the larger carriers that in fact control the majority of Indiana-based interstate vehicles. Indiana's version of this phenomenon along with a summary of the population of the Indiana-based interstate motor vehicles from which sampling was conducted appear in Table 1.

IMPLEMENTATION/RESPONSE RATES

First, an announcement postcard was sent to the 3,000 randomly selected companies who were in the survey sample. This was to let them know that they would be receiving a questionnaire and that they should expect it in 1 week. It was hoped that this would help to increase the response rate by familiarizing each recipient with the survey, by giving them time to plan/set aside a moment to complete and return it, and by helping to add legitimacy to the survey by distinguishing it from other unsolicited (and presumably unread) mail that companies get every day. One week later, on November 12, 1993, the actual questionnaire was mailed.

Responses, amounting to a 16.4 percent overall response rate, were received through January (Table 2). Response rates ranged from a low of 8.7 percent by carriers with only one truck, to a high of 32.6 percent by carriers with 20 or more trucks. It should be noted, however, that due to large carrier responses, the survey can describe IVHS concerns for a total of 19,657 trucks—32.4 percent coverage relative to the 60,730 Indiana-based IRP-registered power units.

STATISTICAL ANALYSIS METHODS

All survey data were entered into the SAS statistical software package for analysis (*5*). Preliminary examination of this data indicated that responses were not distributed normally. Also, many of the variables were discrete. Therefore, it was deemed appropriate to use nonparametric tests known for their robustness against departures from normality in order to determine the existence of statistically significant differences when data were stratified into various classes.

TABLE 1 Population of Indiana-Based Interstate Motor Vehicles from Which Sampling Was Conducted

Categories of Company Fleet Size	Based on all Indiana-based IRP registrants				Based only on surveys received			
	Companies in Category		Trucks in Category		Companies in Category		Trucks in Category	
	Number	Pct.	Number	Pct.	Number	Pct.	Number	Pct.
1 Unit	3379	47.4	3379	5.6	87	17.7	87	0.4
2-3 Units	1184	25.4	4230	7.0	95	19.3	226	1.1
4-7 Units	964	13.5	4880	8.0	88	17.9	475	2.4
5-19 Units	582	8.2	6746	11.1	90	18.3	1013	5.2
20+ Units	380	5.3	41495	68.3	124	25.2	17856	90.8
Other	17[a]	0.2	0	0.0	8[b]	1.6	0	0.0
Totals:	7136	100.0	60730	100.0	492	100.0	19657	100.0

[a]There were 17 companies that only had trailers registered with IRP (i.e. no power units).
[b]There were 8 surveys returned without any indication of company fleet size.

The χ^2 nonparametric test (*6*), able to discern differences in response frequencies between various classes of cross-tabulated data, was utilized to determine if stratifying companies into various classes produced any significant differences in the proportion of companies who indicated an awareness of IVHS before receiving this survey. The Kruskal-Wallis nonparametric test (*7*), able to discern differences in a variable's mean value when stratified into various classes, was utilized to determine if there were significant differences in each IVHS-CVO concept's mean rating when companies were stratified into various classes. Finally, when calculating confidence intervals around various sample means in order to bound the actual population proportion for that variable at a given level of significance (*6*), the large sample assumption was applied. Thus, the following was used as an estimator of the population variance: $\{[p \times (1 - p)]/(n - 1)\}$.

SURVEY RESULTS

Company Characteristics

Table 3 summarizes the types of trucking operations of the companies that responded to the survey. Private carriers were the most frequent type, representing 42 percent of the responses. For-hire less-than-truckload carriers were the least frequent type, representing only 5 percent of the responses. Table 3 also summarizes the driver payment methods used by responding companies. Both per-hour wage and percentage of load revenue were the most frequent methods, each representing 32 percent of the responses. Per-trip flat fee was the least frequent method, representing only 4 percent of the responses. Finally, Table 3 summarizes the percentage categories of time-sensitive fleet trips that must be made within a 2-hour or less time frame by companies who responded to the survey. The 1 to 50 percent JIT trips is the most frequent category, representing 26 percent of the responses. The 85 to 99 percent JIT trips is the least frequent category, representing 11 percent of the responses.

IVHS Awareness

Only 33.9 percent of the companies who responded to the survey were aware of IVHS before receiving this survey. This aggregate statistic is stratified in the following paragraphs so that a targeted IVHS education program can be developed that would enable government and industry representatives to communicate with a

TABLE 2 Survey Response Rates Grouped by Fleet Size

Company Size	Total Number of Surveys Sent	Total Number of Surveys Returned	Response Rate
1 Truck	1,000	87	8.7%
2 - 3 Trucks	600	95	15.8%
4 - 7 Trucks	460	88	19.1%
8 - 19 Trucks	560	90	16.1%
20+ Trucks	380	124	32.6%
Total:	3,000	492[a]	16.4%

[a]The total returned includes 8 surveys without any indication of company fleet size.

TABLE 3 Types of Trucking Operations of Responding Companies

Characteristic	Category / Method	Number of Companies in Group	Percent of the 492 Responses
Type of Carrier	For-Hire L.T.L.	27	5.5%
	Truckload	149	30.3%
	Contract	99	20.1%
	Private	205	41.7%
	Unknown	12	2.4%
Method of Driver Payment	Annual Salary	30	6.1%
	Per-Hour Wage	158	32.1%
	Per-Mile Wage	111	22.6%
	Per-Trip Flat Fee	22	4.5%
	Pct. of Load Revenue	156	31.7%
	Unknown	15	3.0%
Percent Just-In-Time Trips	0%	110	22.3%
	1% - 50%	128	26.0%
	51% - 84%	90	18.3%
	85% -99%	53	10.8%
	100%	84	17.1%
	Unknown	27	5.5%

common terminology—thus increasing the potential for effective cooperation during IVHS development and implementation. This is especially important since what has long been known as IVHS is now being identified with the acronym ITS—Intelligent Transportation Systems. It should be noted, however, that even though current awareness of the term IVHS is low (and most likely lower for ITS), based on company comments and the general pattern of survey responses, there appears to be an industry understanding of concepts/user-services such as automatic payment of tolls, preclearance of vehicles and drivers past weigh stations, transparent borders, and one-stop shopping—even if they did not know of them collectively as IVHS.

Figure 1 summarizes prior IVHS awareness as stratified by the average number of vehicles in each company's daily operating fleet. The largest mean awareness is 44.3 percent by companies with 20 or more trucks. The smallest mean awareness is 27.7 percent by companies with two to three trucks. Using the χ^2 test, prior IVHS awareness between these strata is statistically different at a 90 percent level of significance. Figure 2 summarizes prior IVHS awareness as stratified by type of trucking operation. The largest mean awareness is 50.0 percent by for-hire less-than-truckload carriers. The smallest mean awareness is 24.6 percent by private carriers. Using the χ^2 test, prior IVHS awareness between these strata is statistically different at a 95 percent level of significance. Figure 3 summarizes prior IVHS awareness as stratified by method of driver payment. The largest mean awareness is 48.2 percent by companies that pay their drivers a per-mile wage. The smallest mean awareness is 16.7 percent by companies that pay their drivers an annual salary. Using the χ^2 test, prior IVHS awareness between these strata is statistically different at a 95 percent level of significance. Figure 4 summarizes prior IVHS awareness as stratified by the percentage of trips categorized as JIT with delivery scheduled within time frames of 2 or fewer hours. The largest mean awareness is 39.6 percent by companies with 85 to 99 percent time-sensitive trips. The smallest mean awareness is 24.1 percent by companies with zero percent time-sensitive trips. Using the χ^2 test, prior IVHS awareness between these strata is statistically different at an 85 percent level of significance.

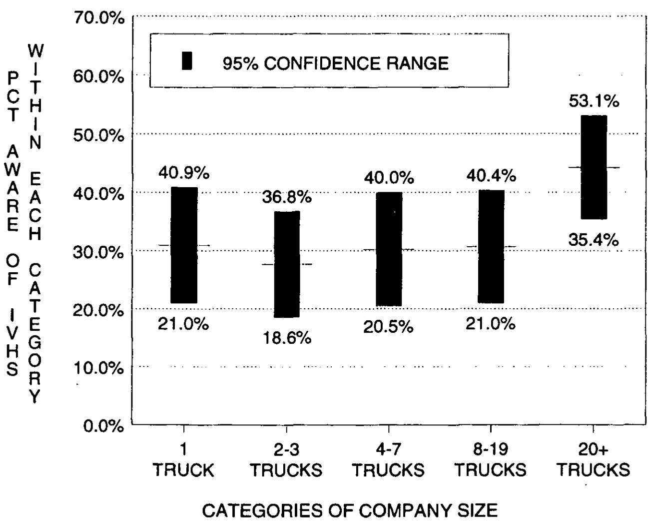

FIGURE 1 IVHS awareness of companies before receiving the survey, grouped by average number of vehicles in a company's daily operating fleet.

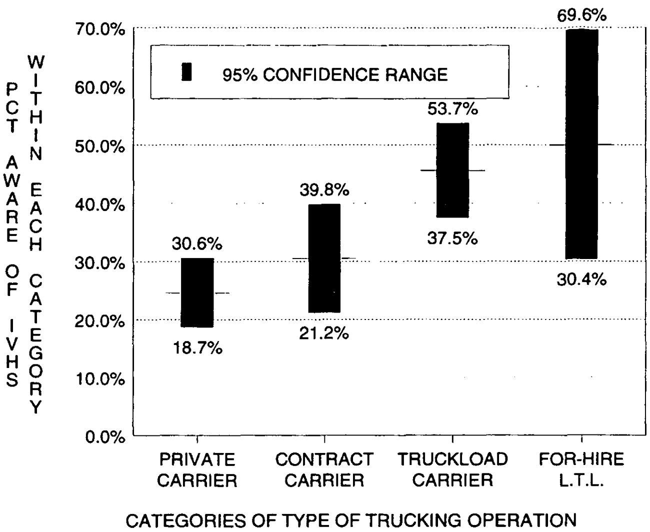

FIGURE 2 IVHS awareness of companies before receiving the survey, grouped by categories of trucking operations.

Overall Ratings of IVHS-CVO Concepts

Companies were presented with brief descriptions of the four main IVHS-CVO concept areas so that they could express expectations of how implementing each CVO innovation would possibly affect their current operations. Ratings were given on a scale of 1 (very harmful) to 7 (very beneficial).

Of these four concepts, "one-stop shopping" received the highest mean rating at 5.9, with 54.6 percent rating it very beneficial, and 3.5 percent rating it in one of the "harmful" categories (Table 4). "Preclearance of vehicles and drivers past weigh stations" received the second highest mean rating at 5.7, with 48.7 percent rating it very beneficial, and 6.7 percent rating it in one of the harmful categories (Table 4). "Transparent state borders" received the third highest mean rating at 5.5, with 40.1 percent rating it very beneficial, and 5.6 percent rating it in one of the harmful categories (Table 4). "Automatic payment of tolls while driving at mainline speeds" received the fourth highest mean rating at 5.0, with 27.3 percent rating it very beneficial, and 7.8 percent rating it in one of the harmful categories (Table 4). Table 5 summarizes the ratings as stratified by company size, carrier type, driver payment method, percent of time-sensitive deliveries, and prior IVHS awareness.

Automatic Toll Collection Details

Type of System Preferred

After a brief description of the two primary ways that automatic toll collection systems can be implemented, survey respondents were asked to indicate which type of automatic toll collection system that their company would favor. Most preferred, was a credit system with monthly billing—chosen by a mean of 55.3 percent of the companies. Least preferred was a debit system from a prepaid account—chosen by a mean of 3.5 percent of the companies. A mean of 21.4 percent of the companies had no preference for either system. Of the responding companies, 19.8 percent did not

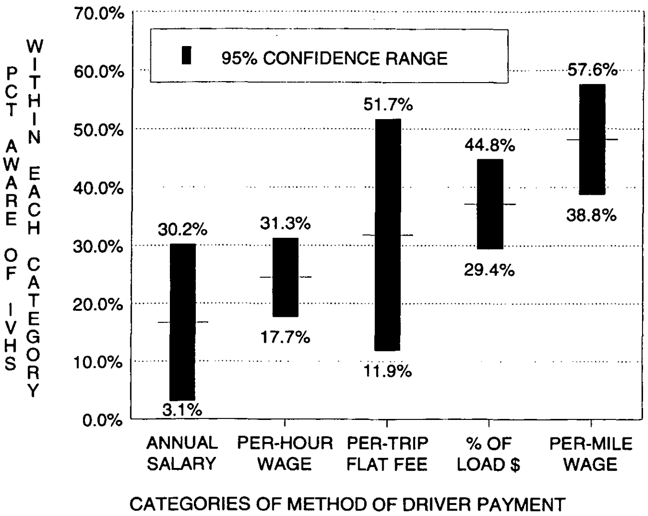

FIGURE 3 IVHS awareness of companies before receiving the survey, grouped by methods by which companies pay their drivers.

favor automatic toll collection. However, of these respondents, 79.6 percent were not aware of IVHS before receiving this survey—a level higher than the average of 66.1 percent of the companies who were not aware of IVHS before receiving this survey.

Willingness To Pay Extra Tolls

Of the companies answering this question, 24.5 percent were willing to pay additional tolls to help pay for constructing, equipping, and maintaining specially equipped bypass lanes next to existing toll plazas for use by AVI-equipped vehicles only. The largest mean willingness is 34.2 percent by companies who currently pay to either three, four, or five toll agencies. The smallest mean willingness is 3.4 percent by companies who currently do not pay any tolls. Of the companies currently paying to one toll agency, 15.9 percent were willing to pay these additional tolls, 24.0 percent of the companies currently paying to two toll agencies were willing to pay these additional tolls, and 28.4 percent of the companies currently paying to six or more toll agencies were willing to pay these additional tolls. Responding companies currently pay tolls to a median of two toll agencies and a mean of between four and five toll agencies.

Of the companies with this willingness, 27.7 percent were willing to pay less than \$0.05 per toll plaza, 26.7 percent were willing to pay \$0.06 to \$0.15 per toll plaza, 20.8 percent were willing to pay \$0.16 to \$0.25 per toll plaza, and 24.7 percent were willing to pay amounts in various categories of extra tolls that were greater than \$0.25 per toll plaza. However, the 90th percentile category of extra tolls is \$0.56 to \$0.70 per toll plaza.

Weigh Station Preclearance Details

Type of System Preferred

After a brief description of the two primary ways that systems for preclearing vehicles and drivers past weigh stations can be implemented, companies were asked to indicate which type of weigh station preclearance their company would favor; 20.8 percent preferred data stored in a central database and 18.1 percent preferred data stored within an on-board AVI transponder. Most preferred was the category "no preference." It was chosen by a mean of 43.6 percent of the companies. Seventeen and a half percent of the companies did not prefer weigh station preclearance. However, of these respondents, 80.0 percent were not aware of IVHS before receiving this survey—a level higher than the average of 66.1 percent of the companies who were not aware of IVHS before receiving this survey.

Data Acceptable for AVI Transponder Storage

Respondents were asked to check off from a list all data items they would be willing to have stored within a transponder. Results, summarized below, include 95 percent confidence intervals appropriate to each group.

By a two-thirds majority (at a 95 percent level of significance), responding companies expressed their willingness to store the following data item within an on-board AVI transponder: proof of liability insurance (67 to 75 percent YES).

By a simple majority (at a 95 percent level of significance), responding companies expressed their willingness to store the following data items within an on-board AVI transponder: fuel-tax cab-card number (64 to 72 percent YES); U.S. Department of Transportation (USDOT) number (63 to 71 percent YES); vehicle identification number (VIN) (63 to 71 percent YES); commercial driver's license (CDL) number (61 to 70 percent YES); International Registration Plan (IRP) number (61 to 70 percent YES); International Fuel Tax Agreement (IFTA) number (61 to 69 percent YES); Interstate Commerce Commission (ICC) number (61 to 69 percent YES); vehicle registration cab-card number (60 to 69 percent YES); type of authority issued by ICC (58 to 67 percent YES); operating authority registration number (58 to 66 percent YES); type of carrier (i.e., for-hire, contract) (58 to 66 percent YES); registered gross vehicle weight (56 to 64 percent YES); and name of driver (55 to 64 percent YES).

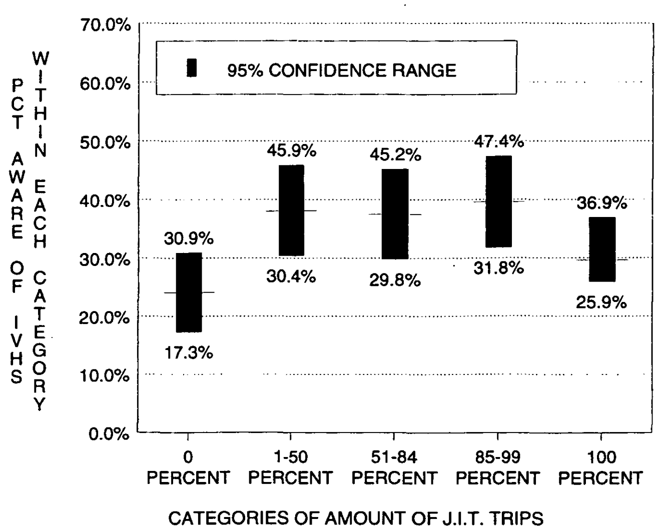

FIGURE 4 IVHS awareness of companies before receiving the survey, grouped by percentage of JIT trips in which delivery is scheduled for time frames of 2 or fewer hours.

TABLE 4 Ratings of IVHS-CVO Concepts

Rating Category	Automatic Toll Payments	Weigh-Station Pre-Clearance	Transparent State Borders	One-Stop-Shopping
7 = "Very Helpful"	27.3%	48.7%	40.1%	54.6%
6	11.5%	15.7%	12.9%	13.2%
5	16.0%	12.6%	13.2%	9.5%
4 = "No Effect"	37.4%	16.3%	28.2%	19.2%
3	2.3%	1.4%	1.5%	0.6%
2	1.6%	1.6%	0.8%	0.4%
1 = "Very Harmful"	3.9%	3.7%	3.3%	2.5%
Mean Rating:	5.04	5.74	5.46	5.91
Total Responding:	487	485	479	484

TABLE 5 IVHS-CVO Concept Ratings by Strata

Stratified By	Automatic Toll Payments		Weigh-Station Pre-Clearance		Transparent State Borders		One-Stop Shopping	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Company Size	p= 0.0042[a]		p= 0.0516		p= 0.6360		p= 0.0075	
1 Truck	5.15	1.66	5.76	1.76	5.61	1.64	6.11	1.50
2-3 Trucks	4.81	1.49	5.46	1.60	5.35	1.53	5.55	1.56
4-7 Trucks	5.23	1.52	5.76	1.63	5.52	1.58	6.01	1.33
8-19 Trucks	4.66	1.53	5.70	1.51	5.33	1.65	5.64	1.69
20+ Trucks	5.31	1.50	6.02	1.41	5.53	1.47	6.20	1.12
Type of Carrier	p= 0.0457		p= 0.0178		p= 0.0324		p= 0.0091	
For-Hire L.T.L.	5.74	1.29	6.22	1.01	6.12	0.99	6.30	1.03
Truckload	5.12	1.57	5.96	1.53	5.66	1.51	6.15	1.29
Contract	4.94	1.79	5.62	1.95	5.23	1.83	5.79	1.89
Private	4.95	1.44	5.60	1.45	5.36	1.50	5.74	1.35
Driver Payment	p= 0.0137		p= 0.0004		p= 0.0190		p= 0.1020	
Annual Salary	4.70	1.53	5.37	1.50	5.40	1.63	5.90	1.54
Per-Hour Wage	4.90	1.39	5.55	1.39	5.27	1.43	5.79	1.33
Per-Mile Wage	5.32	1.53	6.06	1.52	5.72	1.58	6.06	1.30
Per-Trip Flat Fee	4.52	1.66	5.57	1.99	5.05	1.81	5.48	1.89
Pct. of Load $	5.23	1.62	5.90	1.67	5.60	1.61	6.01	1.54
Pct. J.I.T. Trips	p= 0.0014		p= 0.0003		p= 0.0008		p= 0.0018	
0%	4.66	1.55	5.23	1.79	4.97	1.67	5.38	1.74
1% - 50%	5.03	1.46	5.82	1.52	5.60	1.51	6.11	1.27
51% - 84%	5.47	1.51	6.29	1.15	5.87	1.43	6.16	1.32
85% - 99%	5.43	1.56	5.91	1.48	5.71	1.39	6.15	1.28
100%	4.89	1.65	5.67	1.72	5.42	1.59	5.99	1.43
Aware of IVHS?	p= 0.0219		p= 0.0952		p= 0.0004		p= 0.1080	
Yes	5.26	1.46	5.94	1.41	5.84	1.36	6.09	1.31
No	4.93	1.59	5.64	1.65	5.28	1.63	5.81	1.54

[a]p-values < 0.05 indicate that when the concept being rated is stratified in the manner listed, mean ratings are statistically different at a 95% level of significance (based on the Kruskal-Wallis non-parametric one-way test).

TABLE 6 Ratings of How Various IVHS-CVO Scenarios Will Affect Safety, Competition, and Enforcement

Effect Category	Future amount of trucking safety as compared to today's level if "Gold-Card" pre-clearance is implemented	Amount of a "level-playing-field" between carriers with and without on-board AVI transponders	Amount of enforcement efforts AVI-equipped veh. would be subject-to vs. non-equipped vehicles
Much More	13.7%	9.1%	13.3%
Somewhat More	33.0%	22.8%	26.9%
No Change	43.8%	39.6%	55.3%
Somewhat Less	7.9%	18.1%	3.4%
Much Less	1.6%	10.4%	1.1%
Total Responding:	482	468	409

By no clear statistical majority (at a 95 percent level of significance), responding companies may or may not be willing to store the following data items within an on-board AVI transponder: medical certificate validation (48 to 57 percent YES) and proof of financial responsibility (48 to 57 percent YES).

By a simple majority (at a 95 percent level of significance) responding companies are not willing to store the following data items within an on-board AVI transponder: bill of lading (60 to 69 percent NO); commodity shipped (60 to 69 percent NO); hazardous-material training certificate validation (61 to 70 percent NO); Commercial Vehicle Safety Alliance (CVSA) number and expiration (64 to 72 percent NO); fleet limitation certificate validation (64 to 72 percent NO); and axle spacings (65 to 73 percent NO).

By a two-thirds majority (at a 95 percent level of significance), responding companies are not willing to store the following data items within an on-board AVI transponder: oversize or overweight load permit number (67 to 75 percent NO); location of vehicle's port of entry into state (69 to 77 percent NO); date and time vehicle last entered a weigh station (72 to 79 percent NO); hazardous-material product identification number (72 to 79 percent NO); location of last weigh station vehicle entered (72 to 80 percent NO); and amount of driving and on-duty time remaining (74 to 82 percent NO).

"Gold Card" Preclearance Concept

Companies were given a short description of the concept of issuing a "Gold Card" to consistently safe motor carriers who are in compliance with all safety, registration, permitting, and tax requirements. The "Gold Card" carriers would be allowed to bypass all weigh stations until their next inspection or until a random inspection found violations that would cancel the card. When asked if they would be willing to have their fleet be subject to more frequently scheduled safety and compliance checks for "Gold Card" certification and weigh station preclearance based on weigh-in-motion weights only, 58.5 percent answered in the affirmative.

Effect of Preclearance on Trucking Safety

Companies were asked to indicate their beliefs about the future level of trucking safety compared with today's level if certain vehicles and drivers are precleared past weigh stations based on precertification and weigh-in-motion weights only; 46.7 percent of the companies stated that trucking would be either "much safer" or "somewhat safer," and 9.5 percent of the companies stated that trucking would be either "somewhat more dangerous" or "much more dangerous" (Table 6).

Automatic Vehicle Identification Transponder Details

Current AVI Use by Indiana-Based Interstate Motor Carriers

Of the companies surveyed, only 6 out of 492 respondents reported having vehicles presently equipped with an AVI transponder. Of those companies, installation is on an average of 50.9 percent of their vehicles. The make of AVI transponders used in those installations are as follows: 90.9 percent from Lockheed IMS (750 power units in one company), 8.1 percent from Amtech (67 power units over four companies), and 1 percent from Qualcomm (8 power-units in one company). No other makes were reported in use.

Effects of AVI Transponders on Enforcement and Level Competition

Companies were also asked how having an AVI transponder or similar data transfer device on board company vehicles would affect (or presently affects) the concept of a "level playing field" and their exposure to regulatory enforcement. Regarding the degree to which there would be (is) a "level playing field" of competition between carriers with or without AVI transponders on board their vehicles, 31.9 percent of the companies stated that there would be either "much more" or "somewhat more" of a level playing field. Alternatively, 28.5 percent of the companies stated that there would be either "much less" or "somewhat less" of a level playing field (see Table 6). Regarding the perceived level of enforcement that vehicles in their company's fleet would be (are) subject to for registration, permitting, and tax requirements, 40.2 percent of the companies stated that there would be either "much more" or "somewhat more" enforcement. Alternatively, only 4.5 percent of the companies stated that there would be either "much less" or "somewhat less" enforcement (Table 6).

Amount of Mandatory IVHS-CVO Participation Preferred

The survey indicated that 70.3 percent of the companies expressed that IVHS should be a voluntary program if it included law enforcement's ability to electronically read a truck's AVI transponder

TABLE 7 How Much Money Companies Are Willing To Pay or Have Paid for AVI Transponders

Statistic Being Reported	Reported Value of Each Transponder Type Based on Those Willing to Spend Money for an A.V.I. Transponder		
	Type - I	Type - II	Type - III
Mean Value	$177	$266	$537
Standard deviation	231	318	918
95th Percentile Value	$750	$1000	$2000
Median Value	$100	$150	$250
% Not Willing to Spend Any Money On Each Type of Transponder	52.7%	48.7%	54.3%

while it was moving down a roadway in order to check for motor carrier fuel tax payments and compliance with other requirements.

When asked what type of motor carriers should be required to purchase and maintain an on-board AVI transponder for each of the vehicles in their fleet if this above system scenario was mandatory, a mean of 61.1 percent of the companies stated that it should be mandatory for all motor carriers traveling in Indiana. Only 4.2 percent stated that it should be mandatory for Indiana-based interstate motor carriers only.

Value of AVI Transponders

After a brief description of the capabilities of each of the three primary "types"/models of AVI transponders (i.e., Type I is read only, Type II is limited read/write, and Type III is read/write with a communication interface to connect with an on-board fleet-management computer), companies were asked how much money per truck their company would be willing to pay (or have paid) for each type of transponder and its associated installation costs. These results are summarized in Table 7.

As a reference point, those companies that presently have AVI transponders on their vehicles indicated a mean value of $166 for each Type I transponder (with a standard deviation of $355), a mean value of $255 for each Type II transponder (with a standard deviation of $529), and a mean value of $383 for each Type III transponder (with a standard deviation of $793).

IMPLICATIONS OF RESULTS/CONCLUSIONS

Survey results have quantitatively confirmed many of the Indiana trucking industry's concerns and perceptions about IVHS-CVO that were previously only known in a qualitative manner through interviews or case studies of limited scope. In addition, a comprehensive database is now available for further investigations of significant data relationships regarding potential CVO users. This new knowledge, in conjunction with results from the full IVHS-CVO institutional issues study that this survey was but one part of, is enabling decision-makers to be more confident that their actions are commensurate with CVO user/stakeholder needs and desires. In fact, the first in a series of high level meetings between leaders of the Indiana Department of Transportation, the Indiana Department of Revenue, the Indiana Bureau of Motor Vehicles, and the Indiana State Police took place during in the summer of 1994 to initiate processes to implement "one-stop shopping" in Indiana—this survey's highest rated concept/user-service. Furthermore, survey results and additional information in the full report are enabling them to minimize the risks of making costly errors that can sometimes appear when new programs are placed on a fast track, especially risks that have often forced promising new initiatives to the back burner without funding due to a lack of confidence that anticipated benefits of a desired magnitude will actually become reality. Most certainly, understandings gained from this survey are major benefits to have in today's world of fiscal constraints in government, and narrow profit margins in the trucking industry.

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Improving National Travel Estimates for Combination Vehicles

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In each annual publication of *Highway Statistics*, FHWA estimates overall travel by broad type of vehicle and type of highway, in the VM-1 table, based on estimates of travel provided by each of the states. These published vehicle miles of travel (VMT) estimates provide control totals for policy and research studies throughout U.S. Department of Transportation (DOT) and by outside the department. Several sources of systematic bias, which together create a tendency to overcount combination vehicles, have been reported and analyzed in a series of studies. In addition, FHSA's inclusion of vehicles towing light trailers along with other combination vehicles produces some misunderstanding and misapplication of data. If light vehicles were excluded from FHWA's combination truck VMT estimates, the published numbers would be closer to VMT estimates from other sources, notably those of the Truck Inventory and Use Survey (TIUS). If FHWA further compensated for the temporal distribution bias that appears to be prevalent in state classification studies, its published numbers would be very close to TIUS estimates of combination truck VMT. This paper presents several recommendations that FHWA may wish to consider in order to improve its estimates of truck VMT, especially for combination vehicles.

This paper explores the possible problem of overestimating combination vehicle travel and suggests methods usable in the short and long terms to compensate for this overcounting. In this discussion, we begin by evaluating alternative vehicle miles of travel (VMT) estimates and describing specific mechanisms which contribute to a possible overestimation of combination vehicle travel. We then describe how combination vehicle travel estimates would decrease if we exclude light combination vehicles. Finally, we recommend ways to improve vehicle class travel estimates in FHWA's VM-1 table, focusing especially on estimates of combination vehicle travel.

The VM-1 table annually published in *Highway Statistics*, derived from travel estimates reported by the states, contains the official FHWA estimate of overall travel by broad type of vehicle and type of highway, as well as vehicle population, person-miles of travel, and fuel consumption by type of vehicle. These numbers provide control totals for virtually all FHWA policy studies, and for many other studies and programs throughout the U.S. Department of Transportation (DOT). NHTSA, for example, derives accident rates using their accident figures and the travel estimates in VM-1.

The widespread use of VM-1 requires FHWA to proceed with caution in revising the table or the methods used to derive the numbers. By the same token, many users inside and outside DOT deserve to expect the highest level of accuracy possible in the numbers published in VM-1.

In a previous analysis in 1991, sponsored by the Association of American Railroads (AAR), we critically reviewed the main source for the VM-1 table: the Highway Performance Monitoring System (HPMS) areawide travel reporting form, focusing on heavy trucks. We surveyed the states to find out more about how they derive the data reported to FHWA (*1*).

In a 1992 study, we suggested that FHWA might consider eliminating the areawide form and moving instead to a system of having states submit raw classification data, as they now submit raw truck weight data (*2*). This would shift the analysis burden to FHWA, but would allow better knowledge of the likely accuracy of combination vehicle VMT estimates.

In a third study, we analyzed 1 year's worth of 24-hr classification data from six stations in Southern California to assess the temporal variation in travel by various types of vehicles. Most of the stations were in either a heavily urbanized or fringe urban area in a single state, so we cannot generalize the results, but we found that the classification sampling times favored by nearly all states would have resulted in substantial overcounting of combination of vehicles at these six stations. We also found significantly different time-distribution patterns even on these nearby Interstate highways.

In addition to these evaluations, we made extensive use of available WIM data as part of an earlier research contract sponsored by FHWA to review and enhance cost allocation methods (1990–1991). We found many inconsistencies between the axle data and the classification of the vehicle, and recommended to FHWA a procedure to correct classification data based on our findings.

All of these studies share a common thread in finding that the procedures currently used by the states to report travel data to FHWA may tend to be overcount combination vehicles, or at least heavy combination vehicles.

EVIDENCE OF THE PROBLEM

Raw vehicle classification data reported by states under the HPMS areawide reporting system contains many apparent anomalies and inconsistencies. As previously reported in studies cited above, reported travel by combinations in some states fluctuates wildly from year to year. One state, for example, reported that overall combination vehicle travel quintupled from one year to the next. Statewide combination travel comprised 5.3 percent of statewide total traffic one year, whereas the next year it comprised 28 percent of statewide total traffic.

Also as reported previously, few states compensate for the systematic bias caused by weekday classifications, when trucks comprise a larger portion of the traffic stream than they do on weekends. FHWA cannot adequately compensate for the states' failure to account for this bias because of inadequate data and insufficient information submitted by the states.

Not surprisingly, given the poor raw material, FHWA-truck VMT estimates on the VM-1 table disagree substantially with other notable national truck VMT estimates.

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The Census Bureau's quinquennial Truck Inventory and Use Survey (TIUS) provides perhaps the most reliable (but unfortunately only periodic) alternative source of national VMT estimates. Table 1 compares 1987 TIUS estimates with 1987 Highway Statistics VM-1 truck VMT estimates. As shown in the table, FHWA and TIUS estimates for pickup and van VMT agree very closely, whereas FHWA overestimates other single-unit truck VMT by 36 percent, and combination VMT by 51 percent compared with TIUS. We derived the TIUS-based estimates from the public use tape, adjusting to account for off-road travel, travel by combination power units without trailers, and travel by government vehicles.

How accurate are TIUS estimates? No one really knows, since no good alternative source exists. The large sample of vehicles included in TIUS, however, should produce accurate estimates of annual miles of travel by vehicle type, absent systematic bias in the responses.

FHWA has often contended that survey respondents underreport miles of travel and that actual counts produce more reliable answers. They base this assessment on experience with household surveys and reporting of individual trips. Consider, however, the findings of the University of Michigan's Transportation Research Institute (UMTRI), in their National Truck Trip Information Survey (NTTIS). UMTRI compared (*a*) actual truck odometer readings, (*b*) operators' estimates of annual miles, and (*c*) annual mileages implied by quarterly single-day trip reports.

Affirming FHWA's conventional wisdom that trip surveys tend to underreport miles traveled, UMTRI found that truck drivers reported fewer miles in trip logs than could explain their odometer readings (by 35 percent for single units and 33 percent for combinations). More important for our analysis, however, UMTRI found that operators systematically overestimated annual mileages (by 38 percent for single units and 28 percent for combinations). This implies that any systematic bias in TIUS may overestimate travel, not underestimate it.

To further support TIUS estimates, consider diesel fuel consumption. When you replace missing and invalid responses on the TIUS data tape with averages for particular vehicle types, TIUS estimates diesel consumption in 1987 at 16.62 billion gallons for vehicles within its scope. When you add diesel-burning private and commercial buses (0.51 billion gallons), diesel automobiles (1.24 billion gallons), and spillage/evaporation (0.09 billion gallons), you get a TIUS-based estimate of 18.46 billion gallons of taxable diesel consumption in 1987, slightly above the 18.42 billion gallons reported by *Highway Statistics*. In other words, TIUS reports sufficiently high VMT to explain reported diesel fuel consumption.

As further evidence of the problem, consider our recent brief analysis of data from continuous classification stations. We obtained 24-hr classification data for 12 full weeks (the first complete week of each month) throughout the year for six stations in California. We tabulated the weighted average percent trucks for all hours, and then for the common hours during which various states take typical classification counts for reporting HPMS areawide data.

Some states classify for 14–16-hr periods, some for 6–8 off-peak hours, and some collect data only during the summer months. Virtually all states classify only on weekdays; some also avoid Mondays and Fridays.

This analysis produced striking findings. As shown Table 2, every candidate period of classification produced overestimates of truck travel. We interpret these findings as evidence of the systematic time period bias that occurs because of weekday daylight-hour traffic counting. This systematic error ranges from an overcounting of combinations of from 14 to 61 percent for these particular six traffic classification stations.

This analysis may or may not typify the national situation, and reliable state-by-state correction factors obviously require much more analysis. This analysis implies, however, the need for very large correction factors to state-reported HPMS areawide data. If a state classifies for 10 hr on all weekdays during the summer months, for example, they should reduce combination travel estimates by 30 percent and single-unit truck travel estimates by 16 percent. If a state classifies for only 6 hr on Tuesdays to Thursdays, they need to reduce combination travel estimates by 56–61 percent.

In summary, we have found ample evidence to suggest significant overreporting of truck VMT on the VM-1 table. TIUS, comparisons with diesel consumption, and the nature of the classification sampling process itself all suggest very large overestimates of combination vehicle travel and slightly smaller overestimates of single-unit truck travel.

DEFINITION OF COMBINATION VEHICLES

Part of the problem of overreporting may stem directly from differing definitions of combination vehicles. The HPMS Field Manual defines 13 vehicle classes for which states report areawide classification data. Three of these classes include light passenger vehicles, one includes buses, three include single-unit trucks, and the remaining six include combination trucks.

The six combination truck classes include all vehicles with a power unit (either a tractor or straight truck) and one or more additional units (either full or semi trailers). Two-axle, four-tire power units with "recreational or other light trailers" are not included as combinations but are retained in one of the light passenger vehicle classes.

Except for two-tire, four-axle trucks towing medium or heavy trailers, the HPMS field manual draws the boundary between light passenger vehicles and single-unit trucks based on the number of tires. If a vehicle has six or more tires, it is a single-unit or combination truck. If it has four tires, it is not.

TABLE 1 Comparison of 1987 Travel Estimates (in Millions of Miles)

Vehicle Type	Adj TIUS	VM-1	Difference
Pickups and Vans	417,612	416,008	- 0.4%
Single-Unit Trucks	36,571	49,613	+35.7%
Combination Trucks	57,268	86,334	+50.8%

TABLE 2 Truck Overcount Ratios by Time Period

Sample Time Period			Single-Units	Combinations
6 to 8	M to F	All Months	1.050	1.141
6 to 8	M to F	May to Sept	1.104	1.201
6 to 8	T to Th	All Months	1.089	1.180
6 to 8	T to Th	May to Sept	1.139	1.232
8 to 6	M to F	All Months	1.114	1.244
8 to 6	M to F	May to Sept	1.159	1.304
8 to 6	T to Th	All Months	1.148	1.283
8 to 6	T to Th	May to Sept	1.185	1.332
0 to 4	M to F	All Months	1.380	1.508
0 to 4	M to F	May to Sept	1.428	1.567
0 to 4	T to Th	All Months	1.426	1.558
0 to 4	T to Th	May to Sept	1.462	1.605

As described previously, the manual draws the line between single-unit trucks and combinations based on whether or not the power unit is towing a trailer. If it is a truck, and if it is towing a trailer, the vehicle is a combination truck. Tractors operating without trailers are single-unit trucks. A U-haul truck towing an automobile is a combination truck, as is a utility truck with a wood chipper behind it.

In contrast to the HPMS field manual, FHWA policy studies tend to limit the class of vehicles known as "combinations" to only those vehicles with a heavy or cargo-carrying trailer. Although the 1982 Federal Highway Cost Allocation Study grouped light and heavy combinations, subsequent cost allocation studies, truck size and weight studies, and revenue forecasting studies appear to have settled on a new, common definition of vehicle classes.

In the current classification system, combinations are divided by whether they are tractor-semitrailer or truck-trailer combinations. Further, truck-tractors include only trucks with full trailers, and specifically exclude utility trailers.

EXCLUDING VEHICLES WITH LIGHT TRAILERS FROM COMBINATION TRAVEL ESTIMATES

One of the most promising ways to achieve greater consistency between the VM-1 table and other estimates of combination truck travel may be to exclude vehicles with light trailers from the combination truck category. We have analyzed both TIUS and Truck Weight Study data to gain further insight into how great a difference this might make in combination travel estimates, as well as to what types of such vehicles are currently classified as combinations for VM-1 purposes.

Our TIUS analysis first focused upon single-unit trucks towing trailers. Table 3 summarizes the miles of on-road vehicle travel indicated in TIUS for various types of truck-trailers.

Trucks with utility trailers should be classified as combinations, according to the HPMS Field Manual, but were excluded from the earlier TIUS-based estimate of 57.268 billion VMT. Therefore, the estimated combination base travel from TIUS would be 62.233 billion miles for 1987. As derived from the table above, trucks with utility trailers and truck-trailer combinations with average weights less than 26,000 lb together comprise 8.44 percent of that estimate.

In addition to excluding trucks with utility trailers and truck-trailers with average weights less than 26,000 lb, we probably should exclude truck-trailers with average weights greater than 26,000 lb if they consist of a heavy single-unit and a light trailer. Unfortunately, TIUS does not indicate separate weights for the trailers and power units.

Similarly, TIUS collects information only about the most common configuration in which a truck operated during the survey year. Since trailers are detachable, we should expect that some of the miles attributed to truck trailers actually apply to single unit trucks, and vice versa. The implicit assumption is that these two phenomena precisely balance, but this assumption may be far in error.

As another way of approaching the problem, we analyzed truck weight data collected by the states and submitted to FHWA. As part of a research project with FHWA several years ago, we analyzed two million "seven-card" format truck weighings to estimate the classification error rates for each of the truck classes used by FHWA's Office of Policy. We recompiled our findings for this project to analyze the ratio of light vehicles in each of the truck trailer and tractor-semitrailer combination truck classes, and present our findings in Table 4.

In this table, we have included only those weighings with light axle loadings or implausibly long axle spacings, under the assumption that either of these occurrences indicates either a light combination or an erroneous grouping of two or more vehicles. Also, we used a hierarchy, looking first for light axles and then for long spacings, so the two categories are mutually exclusive.

Notice that the apparent inclusion of light vehicles or vehicles towing light trailers in each vehicle class ranges from 2.18 percent (for vehicles classed as triples) to 90.45 percent (for vehicles classified as five-axle truck-trailers). Also notice that about 80 percent of the weighings came from the predominant five-axle tractor-semitrailer class.

To develop an overall estimate of the inclusion of vehicles with light trailers in the combination class of the VM-1 table, we must combine the class-by-class results in the previous table. Table 5 compares three methods of combining these results, with the results of each method underlined and placed to the right.

Method 1 simply averages the 11 class rates of light trailer inclusion, and derived an estimate of overall light-trailer inclusion of 26.32 percent. Although this method is popularly used, it is mathematically indefensible. We included it here to indicate how far you can err by closing your eyes and spitting out numbers.

Method 2 groups all the weighings without regard to vehicle class, which is equivalent to assuming that the weighings analyzed here represent travel by the various vehicle classes. Using this method, we derived an estimate of 12.84 percent. This method is better than the first, but the implicit weighting resulting from using raw data can be improved upon by some type of stratification.

Method 3 stratifies the weighings by HPMS vehicle class. The HPMS classes for 5 and 6 axle doubles had to be combined because the Office of Policy classes, the basis for the original analysis, also combine these vehicles. We then weighted the resulting light trailer estimates by the 1990 VMT of each of these classes.

TABLE 3 1987 TIUS VMT (in Billions)

Type of Trailer	Average Weight (Thousand Pounds) <10	10-16	16-26	>26	Total
One Semi-Trailer	0.002	0.002	0.006	0.021	0.031
Double Trailers	0.000	0.000	0.000	0.004	0.004
One Full Trailer	0.033	0.073	0.173	0.904	1.183
Utility Trailer	3.083	0.546	0.462	0.875	4.965

TABLE 4 Inclusion of Light Vehicles with Combinations as Indicated by Weighings in Truck Weight Study

Vehicle Class	Total Weighings	Light Axles	Long Spacings	Percent Light
CS3	25900	6590	207	26.24
CS4	117454	52027	3869	47.59
CS5	1234272	70533	12592	6.73
CS6	19679	1299	190	7.57
CT4	19511	11005	412	58.52
CT5	30770	4977	22853	90.45
CT6	3275	28	550	17.65
DS5	78712	2754	7825	13.44
DS7	13692	718	50	5.61
DS9	5025	591	89	13.53
TS7	3944	83	3	2.18

TABLE 5 Alternative Estimates of Overall Inclusion of Light Vehicles

Method 1: Unweighted Average of 11 Vehicle Classes: 26.32%

Method 2: Sum of Weighings, Ignoring Class:

Total Weighings	Light Axles	Long Spacings	
1552234	150605	48640	12.84%

Method 3: Subtotal and Weight by State-Reported Classifications:

HPMS Class	Weighings	Light Axles	Long Spacings	Percent Light	1990 VMT
4A1T_CMB	162865	69622	4488	45.50%	20547.4
5A1T_CMB	1265042	75510	35445	8.77%	76177.4
6A1T_CMB	22954	1327	740	9.00%	2801.5
5A2T_CMB	78712	2754	7825	13.44%	5157.7
6A2T_CMB					913.8
7A2T_CMB	22661	1392	142	6.77%	1752.2
			Weighted Average:		16.04%

We derived the VMT estimates from the state-reported classification data compiled by FHWA on their "VCVMT90" spreadsheets, combining all states and highway types. The resulting estimate is that 16.04 percent of all combination VMT reported by FHWA in the VM-1 table results from vehicles towing light trailers. If FHWA decided to reclassify such vehicles as either passenger vehicles or as single-unit trucks, they would have to reduce their reported combination VMT estimates on the VM-1 by this amount.

Note that reducing VM-1 combination travel by 16.04 percent in 1987 would have narrowed about half the gap between VM-1 and TIUS, lowering the reported VM-1 travel from 86,331 million VMT to 72,484 million VMT, compared with the TIUS heavy combination VMT of 57,268 million. We would still have to lower FHWA VM-1 VMT another 21 percent to match TIUS exactly, but this appears to be a modest decrease compared with the temporal variation analysis presented earlier. In fact, the Southern California monitoring stations suggest a decrease of at least 30 percent. Thus, the entire gap between the combination VMT reported by FHWA and by TIUS can be explained by these two factors alone.

RECOMMENDATIONS

None of the analyses presented above should be construed as complete enough to accurately adjust current VM-1 estimates. Nevertheless, the results of these analyses indicate a need for improvements in the way FHWA derives VM-1 estimates, and we have several ideas that FHWA may wish to consider in their efforts to improve these estimates for combination vehicles.

Specifically, we recommend that FHWA consider implementing the following:

- Systematic consideration of temporal count variations,
- A new definition of combination vehicles,
- New guidance to states, and
- When necessary, FHWA corrections to state-reported data.

The California data, as have other such 24-hr data, indicate a strong need to consider and adjust for the consequences of using short time period classification data (defined as anything less than 24-hr, 7-day, 4-season data). Ideally, each state should use its 24-hr monitoring stations as a basis for the areawide classification data reported annually to FHWA. Only 24-hr, 7-day data can account for the systematic temporal variations in travel by various vehicle classes.

Clearly, the limited geographic coverage of 24-hr classification stations requires that they be supplemented by shorter duration counts at many more locations. We suggest that each state needs to develop a set of characteristic distribution curves covering highways of various types and locations, and this may not be quite as easy as it sounds. Even primitive temporal correction, however, is undoubtedly better than no temporal correction, which is the normal case now.

Our second recommendation is based on our assessment that the inclusion of light vehicles and vehicles towing light trailers in the VM-1 entry for combinations is widely misinterpreted and misconstrued. Many sources use the VM-1 table as a basis for estimates of combination travel, and the fact that this includes an uncommon definition of combinations is usually not well understood. We recommend two courses of action: (*a*) include estimates for travel by truck-trailers separate from estimates for tractor-trailer combinations and (*b*) exclude light trailers and light trucks from either category.

We realize that developing a separate estimate for truck trailers requires a change in the HPMS areawide VMT reporting form, but we view it as desirable. States are now inconsistent in their definition and determination of truck trailers, and FHWA must annually clarify to and quiz the states on how they classify various types of truck trailers. We suggest that it might be easier for everyone to have a consistent definition and one that allows distinction between the two types of vehicles.

Similarly, we think it would be desirable to exclude light trailers from the estimates for truck trailers. Light trailers are often of dubious interest for the kinds of policy studies or other known FHWA studies using VM-1 data. We think it much more important to be able to distinguish between single-unit trucks and combination trucks.

We also suggest that FHWA may find it desirable to instruct and give more guidance to the states on the need for good quality VMT and classification data. The Traffic Monitoring Guide certainly is a good step in that direction, but the next steps are to tighten up the classification data requirements and work to help states implement them.

Finally, the quality of VM-1 data would improve if FHWA were to more actively evaluate the data submitted by each state, considering its derivation and comparing it with other sources, to the extent possible. We suggest that FHWA take on a new willingness to adjust the state-submitted data as required to compensate for its shortcomings and inconsistencies. If a state classifies only during summer daylight weekday hours, for example, FHWA might want to use a regional or national correction factor to adjust the state numbers.

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