INVESTIGATING POSSIBLE SYNERGIES IN INTERMODAL OPERATIONS WITH TRUCK AND RAIL

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Abstract

As the trucking industry continues to examine ways to provide better service at lower cost, many companies are more heavily utilizing intermodal (IM) strategies between truck and rail, especially for those loads that are relatively non-critical in terms of delivery time requirements and that have longer lengths of haul. As IM business grows, supporting dray infrastructure naturally develops around IM rail yards. What is unknown is whether it is best to have a dedicated set of drivers performing dray operations or if efficiency and cost savings can result when utilizing a joint driving fleet to concurrently support IM and traditionally dispatched truckload freight transportation. This paper describes a set of experiments utilizing a comprehensive discrete-event system simulation model and historical data from J.B. Hunt Transport to determine whether or not operating synergies exist when IM dray operations are integrated with local, regional, and long-haul trucking operations. Performance metrics of interest to drivers, customers, and trucking companies are utilized to ensure that the research addresses issues of importance to all constituencies. The results show that there is a trade-off between different performance variables when combining operations, but that generally speaking synergies do exist when considering the needs of professional drivers. Results are more mixed with respect to the needs of carriers and customers, but the authors reach the conclusion that the positive aspects of combining OTR and IM dispatching activities outweigh the negative. Because the evaluative simulation model itself is considered to be a major contribution, it is also described in some detail herein.

1 Introduction

This paper describes an evaluative tool and experimentation to determine the possible synergies between truckload and intermodal (IM) transportation. Intermodal transportation with truck and rail has become a topic of great interest in the transportation industry because of the opportunities it provides, especially financially. However, few trucking companies utilize IM to the greatest extent possible, and many of them tend to operate separate organizational structures for over-the-road (OTR) trucking services and IM services. The reason for this may lie in the fact that there are few tools available to determine the benefits of concurrently operating in both modes. It is possible that operational integration of OTR and IM operations may lead to greater operational flexibility, lower cost, and better customer service than when using the modes independently.

Intermodal freight transportation has been rapidly growing for three decades, and the growth rates still remain quite high. Bektas and Crainic [1] describe the value proposition for IM transportation that results from consolidation efficiencies, schedule reliability, and reduced energy costs. They also cite sources that demonstrate the rapid growth of IM transportation and reveal that the value of multimodal shipments almost doubled in the 10-year period from 1993-2003 alone. Multiple other sources cite similar growth rates from the early 80’s until the present.

Other authors describe the ways that IM can be handled operationally. MacDonald [2], for example, describes non-asset based intermodal marketing companies (IMCs) in comparison to partnerships between trucking & rail companies that own their own equipment. Bradley [3] describes the advantages & disadvantages of these two types of IM companies. IMCs perhaps have an edge in brokering flexibly sized deals for their customers and in finding compatible complementary freight. Truck/rail partnerships, on the other hand, can directly control the location of their assets and have more control of their costs. This paper deals with a truck/rail partnership that owns assets in both OTR and IM dray operations.

As stated earlier, the main objective in this paper is to measure the benefits of concurrent OTR and IM operations. Simulation is chosen to model the two different modes of freight transportation (OTR versus intermodal) due to its ability to model complex stochastic, temporal interactions in a multi-criteria performance environment. The simulation model presented herein is capable of collecting information on driver concerns, customer service concerns, and equipment utilization concerns. The model is heavily verified and validated, and is considered to be sufficiently detailed to represent a separate contribution to the literature in addition to the results of experimentation. While numerous other papers dealing with IM freight transportation modeling exist, they tend to be either very detailed operational simulation models of a specific component of the process or higher-level aggregate planning models. For an example of the former, consider Rizzoli et al. [4] who model the activities of intermodal terminal locations. For an example of the latter, consider Janic [5] who models internal costs (private costs of transportation providers) and external costs (societal costs) for both intermodal and freight transport networks. No other papers were found that described models offering as much operational detail as the current work. The closest models in terms of detail were a series of models written by the authors of this paper, most recently appearing in Taylor and Whicker [6].

For a more comprehensive review of the literature in this area, the reader is referred to Bontekoning et al. [7], who argues that there has been such an increase in IM research that it now should be considered a mature, independent research field.

2. Research Methodology

This section describes the methodology used in this research project by describing the experimental scenarios examined, by describing the simulation language and the data used, by providing a detailed description of the model, by introducing the performance variables employed, and by describing the statistical analysis used to analyze the results.

2.1 Experimental Scenarios

Three different experimental scenarios are considered in this paper:

- Scenario 1: Baseline Scenario. All loads are moved by OTR truck.
- Scenario 2: IM and OTR are ran independently and combined.
    - Scenario 2a: Intermodal loads are run separately.
    - Scenario 2b: Truck loads are run separately.
- Scenario 3: Intermodal and truck loads are run concurrently

The first scenario is a baseline scenario in which it is assumed that all loads are moved using OTR methods. In this case all loads are picked up and delivered to the destination by truck. The second scenario considers the intermodal loads and the truckloads independently. In Scenario 2a, only the IM loads are considered. This portion of the loads (intermodal loads) are picked up by truck and delivered to a rail yard for rail transit. When the load reaches the destination rail yard terminal another truck picks up the load and transports it to its final destination. In Scenario 2b, the remaining OTR loads that are transported solely by truck are taken into account exclusively. The results for these two parts are combined to give the final results for Scenario 2. In the last scenario, both OTR and IM methods are used concurrently. This means that some of the loads will be transported using truck only (OTR) and the remainder will use both truck and rail (IM). In this scenario, there is not separate set of dray drivers. The dray function is performed by 'regular' local, regional, and long-haul OTR drivers.

2.2 The Modeling Language

The discrete-event system simulation language SIMNET II is chosen as the simulation modeling tool. [8]. The structure of the language involves the use of four different node types connected by branches. The four nodes are ‘sources’ that create entities (objects of interest), ‘queues’ that allow waiting to occur, ‘facilities’ that permit a service to be completed, and ‘auxiliaries’ that are infinite capacity, specialized facilities. Branches can be used in coordination with any of the four basic node types to make special assignments or to perform advanced functions. Among these advanced functions are the file manipulation capabilities that make SIMNET II truly unique. These file manipulation capabilities were utilized extensively in the combined OTR/IM model used in this paper. The READ/WRITE capabilities in SIMNET II make it possible to read in the freight data sets from external files and to write data to output files. SIMNET II default output includes statistical data on queue nodes, facility nodes, and global variables. User-defined variables can be requested as observation-based, time-based, or run-end outputs. Additional statistical analysis can be performed external to the language using the output files.

2.3 Description of the OTR/IM Simulation Model

Three types of entities are considered in the simulation model: driver/tractor, load, and trailer entities. The driver and tractor are considered as one type of entity because it is assumed that a driver will always have a tractor. Each of these entities contains attributes holding the specific information that defines that entity. Table 1 describes the attributes for each type of entity.

The simulation model considers only loads being transported inside the continental U.S. This area is divided into 11 separate regions, each of which has a separate trailer pool. The regions, along with boundaries based on lines of latitude and longitude, are depicted in Figure 1. Each trailer pool (each coded as a queue in the simulation model) maintains information about the idle trailers in that region. These regions coincide with intermodal planning regions that were in use at J.B. Hunt Transport, Inc. at the time of the study.

A single detailed flowchart of the simulation code would be overly complex, so we will describe the simulation model at a high-level using several figures. First, Figure 2 shows the ‘segmented’ queues utilized. Segmented queues differ from most other simulated queues because entities do not enter or automatically exit from them when a condition is met, but are manipulated into and out of the queues via SIMNET II file manipulation statements. This enables greater conditional control over driver dispatch, load assignment, and trailer assignment tasks. The last queue in Figure 2 labeled QPOOL(1-11) represents 11 queues for the 11 trailer pools.

As indicated in Figure 3, the simulation starts by reading trailer data from an external file. This data specifies the number of trailers by region along with the exact initial locations of all trailers. Next, load information is read into the model one load at a time until all loads within a specified time window (8 hours in this case) are located. When a load is reached that exceeds the window of visibility, a delay in incorporated until the

Table 1: Description of Attributes

Attribute	Driver/Tractor	Load	Trailer
1	Load #	Load #	Current pool # 0=Driving 1-11 pool numbers
2	Origin Latitude	Origin Latitude	
3	Origin Longitude	Origin Longitude	
4	Destination Lat or Current Lat	Destination Lat	Current Lat
5	Destination Long or Current Long	Destination Long	Current Long
6	Pick-up Date & Time	Pick-up Date & Time	
7	Delivery Date & Time	Delivery Date & Time	
8	Delay Times		
9	Time Until Sleep		
10	Next Load #		
11	Driver Type 1=Local (0-75) 2=Regional (75-300) 3=OTR (300+)	Load Type 1=Local (0-75) 2=Regional (75-300) 3=OTR (300+)	Current Pool # 0=Driving 1-11 pool numbers
12	Trailer Status 0=Bobtail 1-11=Trailer & Pool # 88,99=Dummy	Trailer Status 0=Bobtail 1-11=Trailer & Pool # 88,99=Dummy	Trailer Status 0=unloaded 1=loading 2=loaded 3=unloaded 4=awaiting loading
13		Load Status 1=Truck 2=IM Pick-Up Dray 3=IM Del Dray	

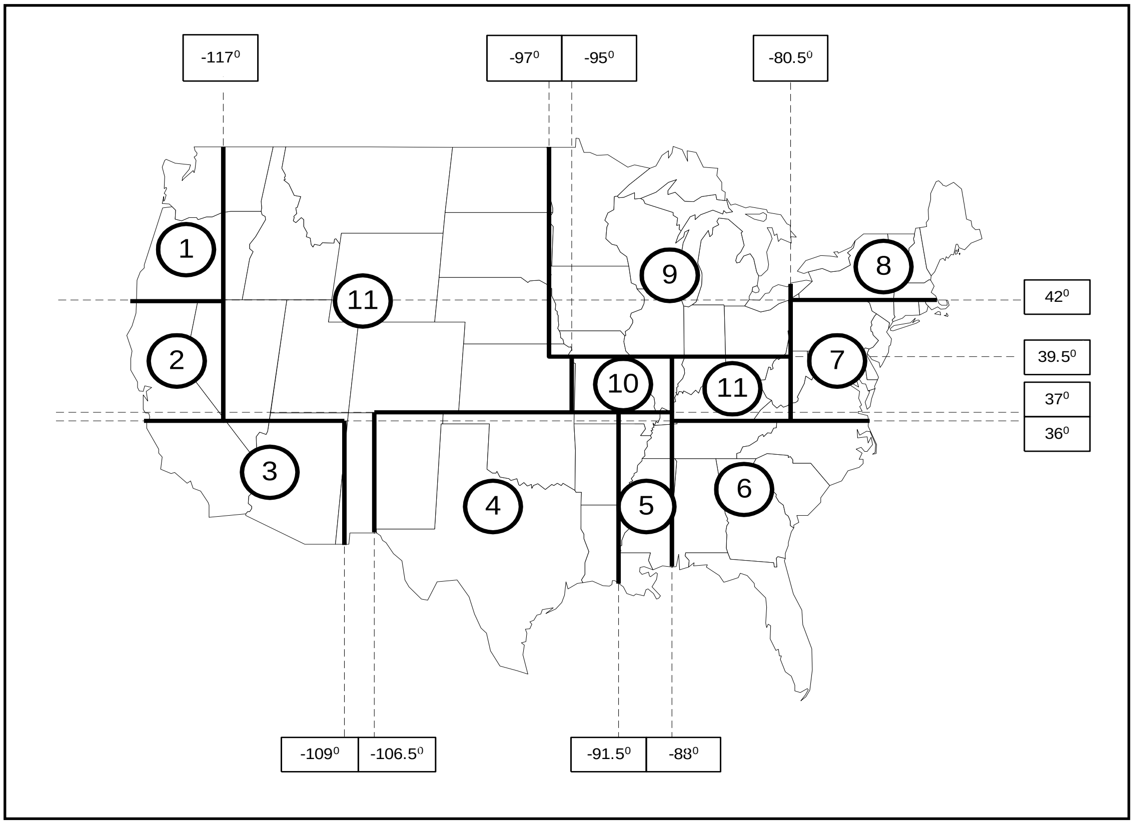

Figure 1: Regional Boundaries

load is within the specified time window. This process is repeated until the last load is read or the end of the simulation run is reached.

The load entities continue on (via Tab A) to a driver/load assignment module to locate a driver to carry each load. The driver/load assignment module is shown in Figure 4. First, the model tries to locate an available driver, then a driving driver, then a sleeping driver within 50 miles of the load origin. The driver must also be of the same 'type' as the load (local, regional, or OTR). If no driver is found, the allowable deadhead (empty repositioning move) distance is increased to a user specified limit (1000 miles in this case, which is effectively infinite) and a driver is again sought for the load. If no driver is found at this point, and the number of drivers in the system is still less than a specified maximum, a driver is created using a SIMNET II file manipulation statement. It is by this driver creation process that system initialization is completed. Drivers are created by loads at a high rate during the first few days of simulated operation, but this process tapers as drivers completing their loads become geographically and realistically

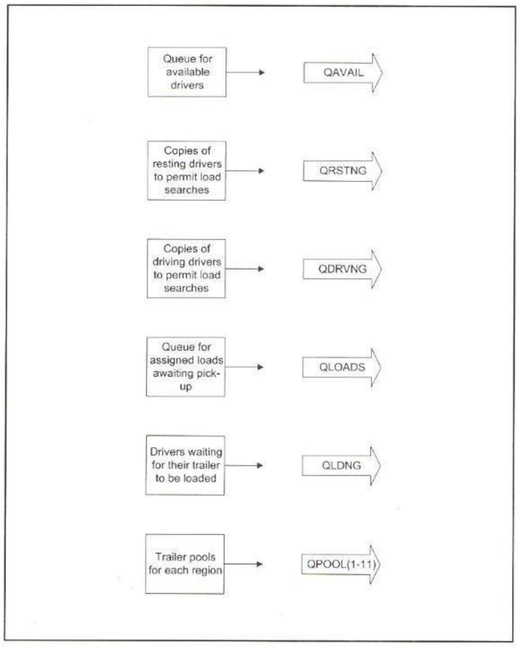

Figure 2: Segmented Queues

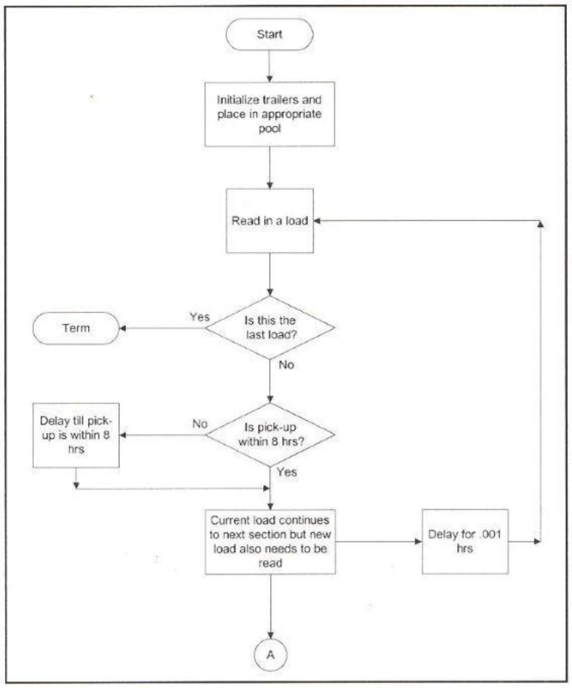

Figure 3: Initialization of Trailers and Loads

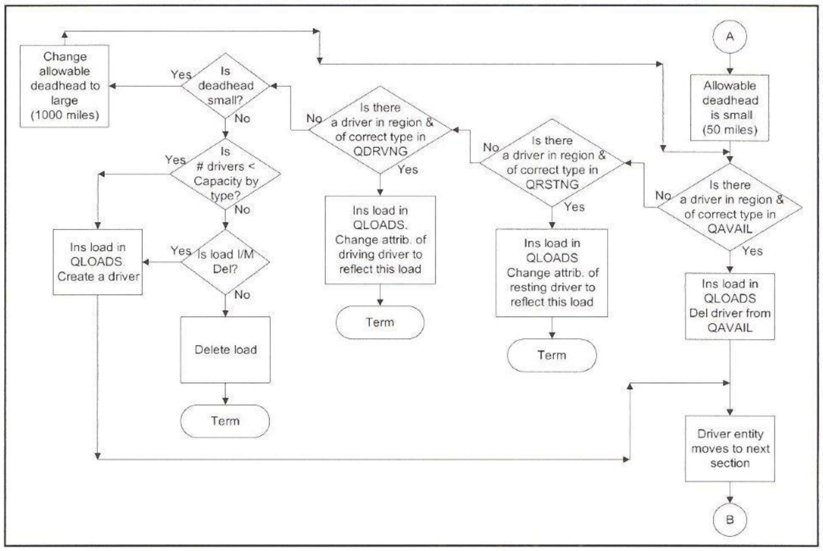

Figure 4: Driver Assignment

dispersed using real load data. The transient period for this activity is nominally completed in approximately one week of simulated time, but a transient period of two weeks is utilized prior to collection of output to fully ensure steady state operation. If the load entity traversing the driver/load assignment module happens to be an intermodal delivery, a driver is still created even if driver maximums have been reached, because the load is already in progress and cannot be deleted from the system. This is a rare event once steady state is achieved. If the load is not an intermodal delivery and no suitable driver is found, the load is deleted from the system and counted to quantify the lost opportunity.

In almost all cases, a suitable driver is identified after the transient period has ended. When the driver is currently in the 'available' queue (QAVAIL), the entity continues to the trailer location module via Tab B. If the assigned driver is currently driving or resting, the driver is notified of his or her next load via manipulation of Attribute 10, and the load entity is placed in the queue (QLOADS) with an identifying load number where it awaits pick-up from the assigned driver when he or she becomes available.

The trailer location module is entered via Tab B as in Figure 5. If the load is an intermodal delivery, it already has an assigned trailer/container and skips this section of the code. Similarly, drivers who currently have an empty trailer attached to the tractor he or she is driving skip this section of code. When a trailer is required, however, the closest trailer in the current pool location is located. If the closest trailer happens to be 'spotted' at the load site, the model signals the located trailer can be immediately loaded and the driver skips the remainder of the code in the trailer location module. If the available trailer is at a different site, the driver 'bobtails', or drives without a trailer to retrieve it. In this case, the pool is adjusted to indicate that the trailer is now attached to a tractor. As with driver initiation, whenever no trailer is found, one is created. The trailer is initially placed at the geographical center of the region and the driver bobtails to that location. Again, this is a very rare event after the 2-week transient period is completed. Drivers exit this section of code and enter the dispatch module via Tab C.

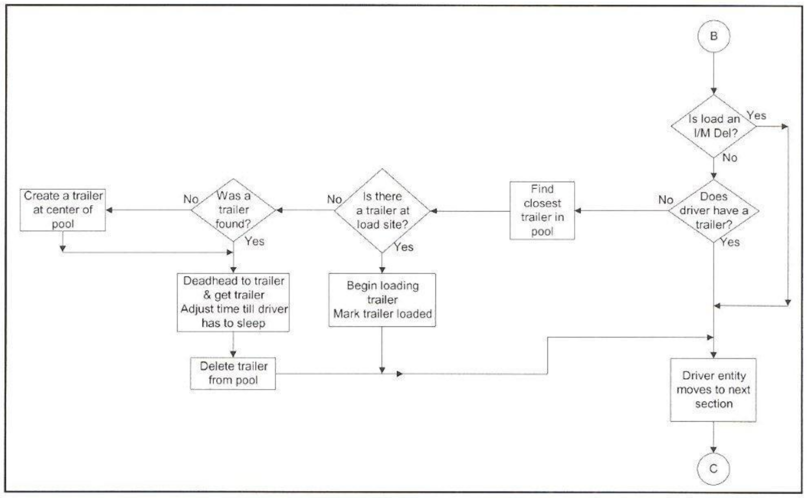

Figure 5: Trailer Location

The Dispatch module (See Figure 6) begins with a an empty ‘deadhead’ move to retrieve the load. Once at the load location, the driver’s equipment and assignment status must be assessed. If the driver is assigned to an intermodal delivery dray and is bobtailing, he or she simply attaches a new trailer/container and begins driving to the destination. If a driver assigned to an intermodal delivery dray has a trailer, the trailer must be dropped at the yard prior to attaching a new trailer. Other drivers must also assess their equipment and assignment status. Drivers who are bobtailing either pick up a spotted & preloaded trailer or pick up another trailer. Drivers with empty trailers must always delay for loading. Once loaded, appropriate delays for delivery are started and a copy of the driver entity is created and placed in QDRVNG, so it can be accessed and considered for a ‘next load’ assignment during the drive. The combined driver/trailer/load entity then proceeds to a destination module via Tab D.

Once the driver has reached the destination (See a flowchart for the destination module in Figure 7), the model first determines if the completion is for an intermodal pick-up dray. If so, the trailer is unhooked & made available for the train and the trailer is deleted from the origin trailer pool. If the load is not an intermodal pick-up, the model determines whether or not the trailer will be a ‘live’ or immediate unload or if the trailer will be dropped for later unloading. The percentage of live unloads is user specified with a default value of 50%. If a live unload is specified, the driver delays for unloading, the copied entity from QDRVNG is removed, and the driver either moves to a next load (if specified on the driver's Attribute 10) or moves into a required rest period. If a live unload is not specified, the driver disconnects his or her trailer which is then delayed for unloading at a later time before re-entering the trailer pool. The driver then proceeds to a next load or a rest break. Driver entities then depart for either the trailer location module via Tab B or to the driver rest module via Tab E.

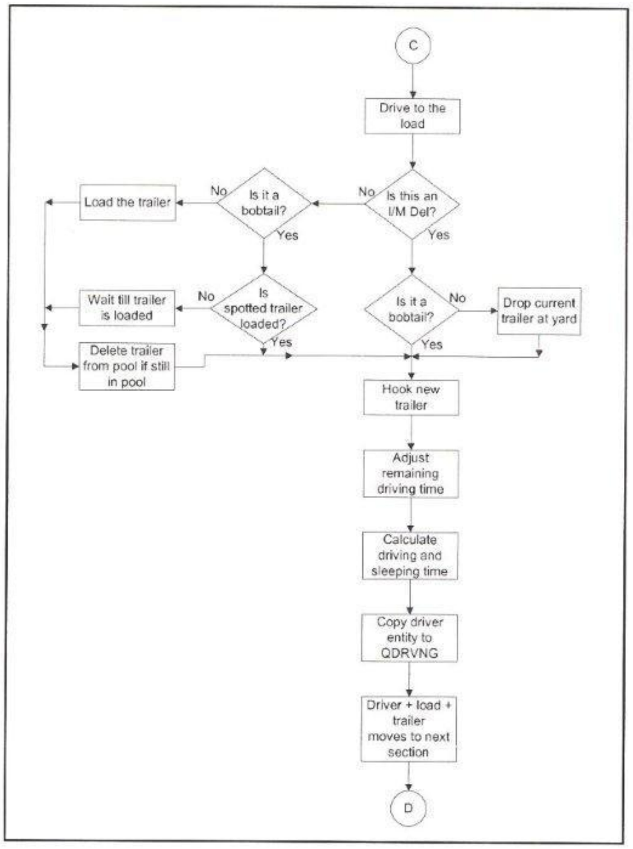

Figure 6: Driver Dispatch

Driver entities that enter the driver rest module in Figure 8 do so via Tab E while a copied entity is made available in the segmented queue QRSTNG so drivers can be considered for next loads while on their mandated rest break. Upon completion of rest time, drivers continue to the trailer location module via Tab B if a next load was assigned during rest, and to the segmented available driver queue QAVAIL if no load is assigned. In both cases, the copied entity in QRSTNG is deleted.

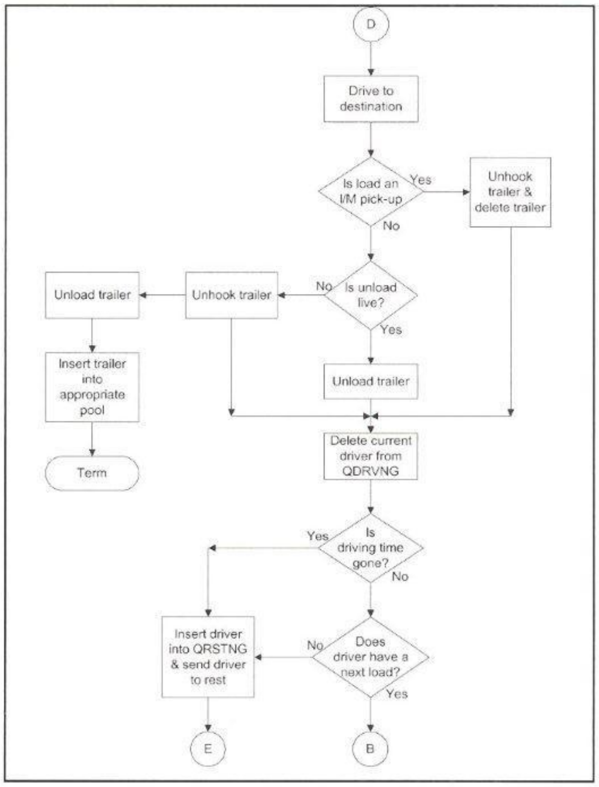

Figure 7: Destination Activities

Additionally, several assumptions are taken into consideration by the model:

- Drivers can be 'on duty' for 10 hours at a time, and each 10-hour duty span must be separated by an 8-hour rest period. On duty time includes load/unload time, and required rest time is also included in all driving time, based on the driver's need for rest as held in Attribute 9.
- Loads are scheduled for pick-up at the time that they become available as determined by the user specified visibility window, with a default value of 8 hours.
- Loading time is exponentially distributed with a mean of two hours.
- The time required to hook a trailer to a tractor is exponentially distributed with a mean of a quarter of an hour.
- The live unload time is exponentially distributed with a mean of two hours; otherwise, unloading time is exponentially distributed with a mean of eight hours.

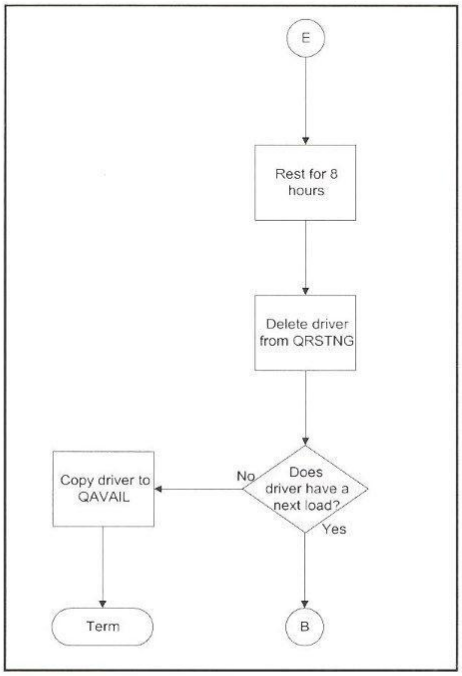

Figure 8: Driver Rest Activities

2.4 Verification and Validation of the Model

The code is verified utilizing the SIMNET II $TRACE function, which permits the developer to follow individual entities through each line of code. Multiple test scenarios were developed to force activation of each line of code while verifying each entity and each attribute during activation.

Validation was achieved by several means. First, the OTR code was verified by comparison with similar code previously developed by the authors. The IM code was new, and was verified via observation during both small runs and larger extreme value runs. In all cases, output was validated via ‘sanity checks’ with industry experts at J. B. Hunt Transport, Inc.

2.5 The Research Data

The model in this research project uses the SIMNET II READ function to read in the data set on load and trailer information. Actual historical data is provided by J. B. Hunt Transportation, Inc. (JBHT). This enables the model to be tested using a real dispatch system. The JBHT data sets indicate whether the loads were originally moved via OTR or intermodal means. These data sets are very detailed and are highly proprietary.

2.6 Performance Measures

Several performance variables are considered. From the company's standpoint the average number of miles per driver per day driven loaded and unloaded are noted. Unloaded miles are divided into bobtail and deadhead miles. Because the company needs to know how many drivers are needed to transport all the loads, the maximum number of drivers for all three types (local, regional, and over-the-road) are also noted. From the driver's standpoint, the average distance that each type of driver travels per day is determined because wages are based on miles driven. Finally from the customer's standpoint, the average lateness per load and the percentage of loads delivered late are determined. Table 2 shows a list of these performance variables.

Table 2: Performance Variables

Variables	Units	Description
LOADED	Miles	The average number of miles traveled loaded per load
BOBTAIL	Miles	The average number of miles traveled per load to get a trailer
DEADHEAD	Miles	The average number of miles traveled per load to get a load
MAX_OTRD	# of Drivers	The maximum number of OTR drivers needed
MAX_REGN	# of Drivers	The maximum number of regional drivers needed
MAX_LOCL	# of Drivers	The maximum number of local drivers needed
MI_OTRDR	Miles/Driver*Day	The average number of miles driven by OTR drivers per day
MI_REGDR	Miles/Driver*Day	The average number of miles driven by regional drivers per day
MI_LOCDR	Miles/Driver*Day	The average number of miles driven by local drivers per day
LATE_HRS	Hours	The average number of hours that each load was delivered late
LATE_PCT	Percent	The percentage of loads that were delivered late

2.7 Statistical Analysis

Before the three scenarios are run, the length of the transient period and an appropriate number of replications are determined. The length of the transient period is calculated by determining the point in simulation time when steady state is reached, i.e. the number of trailers and drivers for all three types reaches a maximum. As specified earlier, steady state is achieve in approximately one week of simulated operation but a conservative transient period of two weeks is utilized. Statistics are collected during the third complete week of operation in each of ten independent replications for each scenario. This is a relatively small number of replications, but the simulation runs are quite lengthy, and ten replications is sufficient to generate relatively tight confidence intervals.

Once all three scenarios are completed (40 replications), Duncan's Multiple Range Test is performed on the results. This test was selected due to its ability to detect differences between means when differences really do exist [9]. This test also avoids greatly increasing the Type I error, or the experiment-wise error rate, which is the probability of finding a significant difference when in reality there is no significant difference [10]. Throughout this paper, an alpha value of 0.05 is assumed.

3. Results of Experimentation

This section considers the results obtained for the three scenarios. Tables 3, 4, and 5 show the performance variables results obtained for the three scenarios. These are divided into results from the company's standpoint (Table 3), the driver's standpoint (Table 4), and customer's standpoint (Table 5). In all cases, to protect the proprietary nature of the findings as based on data provided by J.B. Hunt Transport, Inc., the values of the various performance metrics are presented as a ratio with the baseline values obtained in Scenario 1. For all metrics, Scenario 1 values are reported as 1.00. A higher value obtained in Scenario 2 or 3 would result in a reported value greater than 1.00 while a lower value would be reported as less than 1.00. In some cases, a larger value is desired and in others a lower value is desired. This will be clarified as the results are discussed.

Also, it is important to note that while Scenario 1 may produce good values relative to some metrics, the scenario is primarily included as a basis for a validated baseline. Full conversion of all loads to OTR would be cost prohibitive and would not provide a pragmatic solution. The most important comparisons are therefore between Scenarios 2 and 3.

From the company's standpoint, three performance variables are noted in Table 3; the maximum number of drivers needed, the loaded miles traveled per load, and the unloaded miles traveled per load. The latter is sub-divided into bobtail miles per load and deadhead miles per load. When considering the total number of drivers for all three types, there is a decrease of approximately 6.9% when operations are run concurrently (Scenario 3) instead of separately (Scenario 2). This statistically significant reduction in the workforce means that synergy does exist in combined OTR/IM operations when considering the maximum number of drivers required to move the frieght. Similar reductions in the driving workforce are apparent at all three sub-divisions of labor (OTR, regional and local), but these reductions are statistically significant only for regional and local drivers. Intuitively, this makes sense, because it is local and regional drivers that would be primarily responsible for IM dray moves in combined OTR/IM dispatching alternatives.

Table 3: Results From the Carrier Viewpoint

Maximum Number of Drivers (Local + Regional + OTR)				
Scenario	**Average**	**Duncan's Comparison Test**		
		Scenario 1	**Scenario 2**	**Scenario 3**
1	1.000	N/A	Significant	Significant
2	1.144	Significant	N/A	Significant
3	1.065	Significant	Significant	N/A
Average Bobtail Miles per Load				
Scenario	**Average**	**Duncan's Comparison Test**		
		Scenario 1	**Scenario 2**	**Scenario 3**
1	1.000	N/A	Significant	Significant
2	1.248	Significant	N/A	Significant
3	1.450	Significant	Significant	N/A
Average Deadhead Miles per Load				
Scenario	**Average**	**Duncan's Comparison Test**		
		Scenario 1	**Scenario 2**	**Scenario 3**
1	1.000	N/A	Significant	Significant
2	1.405	Significant	N/A	Significant
3	1.563	Significant	Significant	N/A
Average Loaded Miles per Load				
Scenario	**Average**	**Duncan's Comparison Test**		
		Scenario 1	**Scenario 2**	**Scenario 3**
1	1.000	N/A	Significant	Significant
2	0.391	Significant	N/A	Significant
3	0.420	Significant	Significant	N/A

On the other hand, the results considering the number of miles traveled show that there is a significant increase in both the loaded and unloaded miles from Scenario 2 to Scenario 3. Because drivers have to travel longer distances to obtain a trailer, pick up the load, and deliver the load in Scenario 3, synergy does not exist when considering these variables alone. All of these results are statistically significant as indicated in Table 3. Thus, from the viewpoint of the carrier, synergies exist in combined OTR/IM operations in terms of the number of drivers required, but not with respect to other measures of effectiveness. Even so, the 6.9% reduction in the required driving force will reduce the expense of recruiting and training drivers; a very significant category of cost. The increases in loaded and unloaded miles, while important and while statistically significant, are likely not as practically significant due to the fact that the baseline values in Scenario 1 were fairly small at the outset. The incremental cost increases associated with these metrics will likely not be enough to overcome the savings in driver recruiting.

From the driver's standpoint, perhaps the most important measure of system performance is that of miles per driver per day. Driver compensation is generally determined by this metric, and it is therefore of vital importance to drivers. Table 4 shows the results of experimentation for this important metric, divided into results for OTR, regional and local driving fleets. The results show performance improvement for all three driver groups when combined OTR/IM dispatching operations replace separate dispatching operations. For OTR and regional drivers, the positive difference between Scenarios 2 and 3 are statistically significant. In fact, combined operations are so favorable for these two driver groups that there is no significant difference between Scenario 3 and the ‘OTR only’ Scenario 1. The improvement during combined OTR/IM dispatch is not statistically significant for local drivers. Because the results show an average increase in the distance traveled for each driver type from Scenario 2 to Scenario 3, synergy exists from a driver perspective in combined operations (at least for regional and OTR drivers).

Table 4: Results from the Driver Viewpoint

<table>
<tr><th colspan="5">Distance Traveled per OTR Driver per Day</th></tr>
<tr><th rowspan="2">Scenario</th><th rowspan="2">Average</th><th colspan="3">Duncan's Comparison Test</th></tr>
<tr><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th></tr>
<tr><td>1</td><td>1.000</td><td>N/A</td><td>Significant</td><td>Not Significant</td></tr>
<tr><td>2</td><td>0.842</td><td>Significant</td><td>N/A</td><td>Significant</td></tr>
<tr><td>3</td><td>0.929</td><td>Not Significant</td><td>Significant</td><td>N/A</td></tr>
<tr><th colspan="5">Distance Traveled per Regional Driver per Day</th></tr>
<tr><th rowspan="2">Scenario</th><th rowspan="2">Average</th><th colspan="3">Duncan's Comparison Test</th></tr>
<tr><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th></tr>
<tr><td>1</td><td>1.000</td><td>N/A</td><td>Significant</td><td>Not Significant</td></tr>
<tr><td>2</td><td>0.902</td><td>Significant</td><td>N/A</td><td>Significant</td></tr>
<tr><td>3</td><td>0.994</td><td>Not Significant</td><td>Significant</td><td>N/A</td></tr>
<tr><th colspan="5">Distance Traveled per Local Driver per Day</th></tr>
<tr><th rowspan="2">Scenario</th><th rowspan="2">Average</th><th colspan="3">Duncan's Comparison Test</th></tr>
<tr><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th></tr>
<tr><td>1</td><td>1.000</td><td>N/A</td><td>Significant</td><td>Significant</td></tr>
<tr><td>2</td><td>0.799</td><td>Significant</td><td>N/A</td><td>Not Significant</td></tr>
<tr><td>3</td><td>0.834</td><td>Significant</td><td>Not Significant</td><td>N/A</td></tr>
</table>

Finally, from the customer perspective, the results in Table 5 show that there is no statistically significant difference in the ‘average hours late’ metric between Scenario 2 and Scenario 3. However, Scenario 3 is statistically significantly worse than Scenario 2 in terms of the percentage of loads delivered late. While these results tend to indicate that synergy does not exist for combined OTR/IM dispatch from the customer perspective, it should be noted that only a very small percentage of loads are delivered late in any of the three scenarios examined, and that average lateness is in fact highly negative, indicating a tendency toward early delivery. In fact, very few additional loads become late as a result of combined dispatch, and most loads only become ‘less early’. Some may argue that this result is even a positive one, because loads are delivered closer to specified target values.

Table 5: Results from the Customer Viewpoint

Average Late Hours per Load				
Scenario	**Average**	**Duncan's Comparison Test**		
		Scenario 1	**Scenario 2**	**Scenario 3**
1	1.000	N/A	Significant	Significant
2	2.426	Significant	N/A	Not Significant
3	2.085	Significant	Not Significant	N/A
Ratio of Loads Delivered Late				
Scenario	**Average**	**Duncan's Comparison Test**		
		Scenario 1	**Scenario 2**	**Scenario 3**
1	1.000	N/A	Significant	Not Significant
2	0.824	Significant	N/A	Significant
3	0.926	Not Significant	Significant	N/A

4. Conclusions

This paper addresses the operational efficiency of combined OTR/IM operations at a level of detail that has heretofore not appeared in the published literature. The detailed evaluative simulation model explicitly models three types of entities, three different types of driving fleets in 11 regions (excluding the separate dray fleet in Scenario 2), and 11 regional equipment pools. The model includes positional & status tracking of trailers in the field, even when not attached to power. It provides realistic visibility to load availability within a user defined window, it explicitly models the very complex driver/load/trailer assignment algorithm, and it explicitly models the convergence of driver/power, trailer and load entities. Furthermore, the model includes load/unload activities under a variety of conditions, bobtail, deadhead and driving activities, and even models required rest time.

The results of experimentation with the simulation model show that there is a trade-off between different performance variables when combining OTR and IM dispatching operations. Definite synergy exists when considering the needs of professional drivers, but this synergy is not as apparent when considering measures of effectiveness specific to the customer and the carrier. Even so, from a pragmatic viewpoint and from a cost viewpoint, merging the two types of dispatch appears to be beneficial in the test case observed. Only a detailed cost analysis performed by each specific carrier would reveal if such synergy exists in combined operations in their company. The most important tradeoff to consider would be the cost savings associated with a decrease in driver needs compared to the cost increases associated with the small mileage increases in bobtail miles, deadhead miles, and loaded miles. It would also be necessary to determine the financial impact resulting from the small increase in the number of loads delivered late.

It is the authors' suspicion that a well-engineered solution will show that synergy is possible in combining operations for many carriers. However, the advantages might not be as great as originally expected.

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