# Hub and Spoke Networks in Truckload Trucking:

## Configuration and Operational Concerns

by

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**Abstract**:

In this paper, the authors discuss the major configuration issues and operational concerns associated with the use of hub-and-spoke transportation networks in truckload trucking in North America. The authors begin with a brief discussion regarding the feasibility of such systems. This discussion is followed by the presentation of an experimental plan developed to evaluate alternative design and implementation strategies. Results of this experimentation are subsequently presented and analyzed. The best alternatives for system configuration and operational strategy are identified and discussed. The authors conclude by demonstrating the potential efficacy of limited hub-and-spoke networks relative to several performance measures and suggest an experimental agenda for sensitivity analysis and extended testing.

## I. Introduction and Background Information

The concept of hub-and-spoke (H&S) networks is not new to the transportation industry. For many years, the airline industry and less-than-truckload (LTL) trucking companies have made use of such networks. In general terms, a H&S network involves a series of nodes (hubs), connected by arcs (spokes) that represent viable transportation alternatives between two nodes. In the airline industry, H&S networks allow airlines to offer a greater variety for service between city-to-city pairs, permit economies of scale in terms of passenger consolidation along frequently traveled spokes, and to a certain extent allow an airline to dominate market share in a particular region. In LTL trucking, breakbulk terminals (hubs) allow load consolidation that is similar to passenger aggregation in airlines.

The idea of using H&S networks in truckload trucking is much newer and less proven. Unlike airlines or LTL operations, truckload truckers do not need to consolidate their loads. Arguably, this takes away a major hubbing incentive. The implementation of H&S networks in this environment, therefore, requires different motivating circumstances. This motivation comes from the desire to better serve customer needs while reducing excessive tour lengths for individual drivers. It is theorized that tour reduction would result in lower driver turnover rates, and thus drastically reduce the cost associated with hiring and training replacement drivers. This cost reduction could be passed on to customers, providing an even greater competitive edge to those companies implementing successful strategies.

## The Hubbing Phenomenon

According to Phillips (1987), U.S. airlines have been forced to develop H&S networks simply to remain competitive following airline deregulation in 1978. As linear routes became highly vulnerable to regional competition, large airlines need alternative business strategies. Hubbing provides increased flight frequency with more city-to-city alternatives, they allow airlines to take advantage of economies in terms of aircraft size, and they allow an airline to develop marketing advantages on a regional basis. Kanafani and Ghobrial (1985) provide insight into the motivation for the airline hubbing phenomenon. Morrison and Winston (1986) explain the economic rationale for H&S operations. Other helpful references include Wheeler (1989), Toh and Higgins (1985), and Brenner et al. (1985).

LTL hubbing provides the opportunity for similar consolidation, only in terms of loads instead of passengers. By using breakbulk terminals (hubs), LTL truckers can achieve similar economies of scale that truckload truckers enjoy by definition. By travelling along well established spokes, LTL drivers return home more often than truckload drivers. Consequently, driver turnover rates are considerably lower in LTL trucking. According to Mele (1989), truckload trucking companies experience as much as 85 to 110% driver turnover each year. Additional information regarding LTL load movement can be found in Braklow et al. (1992). Other references that are insightful for LTL hubbing include Winston (1981), Morrison and Winston (1985), and Barker and Sharon (1981).

Hubbing in truckload trucking is motivated differently. Truckload truckers cannot benefit from increasing the number of city pairs served, nor can they use hubbing to consolidate loads. Because most truckload truckers carry loads point to point, hubbing would likely increase average load circuity. The primary benefit of hubbing in truckload trucking is to reduce tour length. The challenge for researchers is to quantify the trade-offs between savings associated with tour length and driver turnover relative to costs in other areas.

## The HUBNET Simulator

A key tool designed to help in the evaluation of H&S transportation networks is the HUBNET simulator. HUBNET is a knowledge-based, user-friendly simulation system written primarily in the SIMNET II simulation language with a C-shell user interface. The development of HUBNET has been funded by J.B. Hunt Transport, Inc., a large truckload carrier in the United States. The HUBNET system is used as a primary tool to support the work described in this paper, and is also installed on-site at J.B. Hunt Transport, Inc. to support H&S network studies in the field.

The conceptual development of HUBNET and system architecture are described in detail in Taha and Taylor (1994). Figure 1 provides an overview of the system architecture of the HUBNET system. Those readers interested in detailed information regarding HUBNET are referred to Taha (1993). Those readers interested in detailed information regarding SIMNET II simulation are referred to Taha (1988).

*****Insert Figure 1 Here*****

## II. Experimental Concerns

In this section, the authors describe all aspects of the experimental design considered within this paper. Specifically, the authors describe the differences in operational strategies between current and proposed methods. They also describe the experimental factors considered within this research to support H&S implementation. Furthermore, this section includes brief discussions related to performance measures and verification and validation methods.

### Current Operational Setting

Typically, the truckload trucking industry offers door to door service, taking the most direct route between customer locations. Thus, any excess circuity that may be associated with H&S networks is eliminated. Obviously, this procedure can carry a driver far from his or her home base. Dispatchers must assign available drivers to new loads in an effort to minimize deadhead miles (empty miles from a driver's location to a pickup point) while simultaneously satisfying driver and equipment requests. As pointed out by Powell et al. (1988), dispatchers attempt to position drivers to reduce deadhead (first dispatch empty miles), yet the complexity of this task in large dynamic systems makes it near impossible.

Because truckload trucking organizations know that many of the advantages of hubbing are not possible in their environment, they are understandably reluctant to undertake the massive change in operations that hubbing would require. Instead, these organizations prefer smaller pilot studies to determine the feasibility of H&S implementation in general terms and the efficacy of its use in economic terms.

Currently, truckload truckers are considering at least two limited implementation experiments. The first experiment is with "zone" drivers. In this methodology, drivers are dispatched only within a certain zone and are guaranteed to be home at least one day each week. The second experiment is with very limited H&S implementation consisting of regularly scheduled trips between two hub cities along one lane or spoke. It is conjectured that both of these strategies present viable options for truckload trucking companies if implemented on a partial basis. In other words, the system would likely fail if all drivers are converted to either zone or lane drivers, yet the optimal percentages of drivers that should operate using alternative methods is unknown. As will be shown subsequently, the results of this research strongly support the idea of limited implementation of H&S networks.

### Alternative H&S Settings

Several issues of experimental concern arise when considering the implementation of H&S networks in truckload trucking. Among these issues are the problems associated with allocating drivers among hubs and among types (lane drivers, local drivers, and non-network drivers), based upon freight density analysis and other factors. Also among these issues are the layout of the H&S network in terms of the number of hubs, the hub locations, the spoke or lane locations, and service area allocation. Furthermore, driver usage rules must be considered as a part of experimental design.

To ensure experimental consistency in this study, the number of drivers supporting the H&S network is equal to the number of drivers required to support a non-network solution. In an effort to reduce excess circuity, approximately 75% of all loads considered (those 75% that incur the least circuity through network travel) are moved on the H&S delivery network. Therefore, 25% of all drivers are designated as non-network drivers. These drivers carry 25% of the total freight load using traditional point-to-point delivery methods. Because the percentage of network loads is heavily dependent upon the network configuration, a number of pilot runs are needed to determine the allowable circuity required to fix the percentage of network loads near 75% for all scenarios examined in this paper. Furthermore, the 75% figure is somewhat arbitrarily chosen. Therefore, sensitivity analysis on this initial figure is included in the experimental design for the extended testing presented in Harit et al. (1994). The concept of allowable circuity and corresponding H&S network loading is also discussed in detail in Harit et al. (1994).

Local and lane drivers are allocated to individual hubs in a manner that is directly proportional to the average number of loads using a given hub as a transshipment point, or originating or destinating within the service area for the hub. Lane drivers are those that drive on connecting spokes between hubs. Local drivers are those that pick up and drop off loads within the service area for a given hub. Local drivers are assigned to a particular hub and do not leave the service area for that hub. Non-network drivers are also assigned to home hub locations as a function of load density.

From an experimental viewpoint, this research is classified as a three-factor experiment. The first factor is hub location methodology consisting of three levels; distance-based hubbing, flow-based hubbing, and hybrid hubbing. The second factor is the number of hubs with two levels; 24 hubs and 32 hubs. The third factor is driver usage with two levels; 1-hub tours and 2-hub tours. We will now explain each of these factors and levels in greater detail.

The hub location methodology is probably the most complex experimental consideration. The distance-based hubbing method is heuristic driven. In distance-based hubbing, hubs are placed in locations that are convenient in terms of being one-day of driving time from one another. Additional hubs are allocated within this structure in areas characterized by high freight density. Flow-based hubbing techniques attempt to place hubs in regions characterized by low imbalance between originating and destinating loads, while restricting feasible solutions to those that satisfy some degree of closeness between hubs. To allocate hubs in this manner, we have divided the Continental United States, Northern Mexico, and Southern Canada into a series of sixty-five $4^\circ$ x $4^\circ$ lat./long. grids and used the following simple Integer Programming (IP) formulation to place hubs within grid locations:

Minimize:

$$Z = \sum_{j=1}^{65} |C_j| X_j$$

subject to:

$$\sum_{j=1}^{65} A_{ij} X_j \geq 1 \quad for \ \forall \ i \qquad (2)$$

$$\sum_{j=1}^{65} X_j = \# hubs \qquad (3)$$

$$X_j = 0 \ or \ 1 \quad for \ \forall \ j \qquad (4)$$

In the above formulation, $|C_j|$ is the absolute value of the load imbalance for lat./long. grid j; i.e., the absolute value of (loads in - loads out). $X_j$ is a binary decision variable that is 1 if a hub is assigned to grid j and 0 otherwise. $A_{ij}$ is 1 if grid i is contiguous to grid j and 0 otherwise. The objective function (1) seeks to locate hubs in areas of low freight imbalance. The first constraint (2) ensures that while a hub cannot be in each grid location, each grid has at least one hub in a contiguous grid. The second constraint (3) ensures that the correct number of hubs (24 or 32) are assigned. Finally, the last constraint (4) ensures that each $X_j$ is a binary integer. The final hubbing methodology considered is that of hybrid hubbing. This methodology is largely based upon heuristics, expert judgement, and the location of existing terminal locations for J.B. Hunt Transport, Inc., who graciously provided supporting case study data. It is called a hybrid method because it includes some aspects of flow-based or density-based hubbing, and includes some aspects of distance-based hubbing.

The second major experimental factor is the number of hubs in the H&S network. In this study, we have used two levels for this factor; 24 and 32. The 24-hub scenario is representative of a small network that minimally covers the study region in North America. The 32-hub scenario is representative of a larger network that permits additional coverage in critical regions.

The third major experimental factor is that of driver usage rules. Two levels exist for this factor; 1-hub rules and 2-hub rules. Under 1-hub rules, lane drivers are not allowed to travel more than 1 hub from home before transferring his or her load. The next load must bring the driver to his or her home hub. Under 2-hub rules, drivers are allowed to travel 2 hubs from home. Obviously, this factor attempts to examine the trade-off between efficient load movement and driver tour length. Other scenarios involving N-hub rules with increasing penalty functions to force the driver home did not perform well relative to 1-hub and 2-hub rules and have been dropped from the factorial design.

Although not a part of the experimental design presented in this paper, extended testing and sensitivity analysis on the percent of non-network versus network loads have been performed. Additional testing has been completed regarding the allocation of drivers to support network solutions. The results of this testing are presented in Harit et al. (1994).

For convenience, a coding scheme has been developed to aid in identifying scenarios within the factorial design. Let (HLM/#H/TL) represent a scenario with hub location methodology (HLM) which is equal to D for distance-based, F for flow-based, and H for hybrid; number of hubs (#H) equal to 24 or 32, and tour length (TL) equal to 1 or 2 hubs from home. For example (H/32/1) represents a scenario in which 32 hubs are placed according to the hybrid method. Drivers are permitted to travel one hub from home.

A final experimental consideration is that of service area allocation to hubs. Using the HUBNET user interface, 2° x 2° lat./long grids are assigned to the nearest hub. As a tie-breaker, grids are assigned to minimize freight density imbalance.

**Measures of Performance**

Five primary and many secondary measures of performance are used to determine the efficacy of H&S networks in this study. The five primary performance measures include lane driver tour length, local driver tour length, average miles per driver per day, first dispatch empty miles as a function of trip miles, and average circuity as a function of trip miles. Obviously, these measures are selected to demonstrate the trade-offs existing between tour length and traditional measures of efficiency in truckload trucking when using an H&S transportation network.

**Verification and Validation**

The validity of supporting load density data is guaranteed by using actual historical data supplied by J.B. Hunt Transport, Inc. The HUBNET code has been verified by a number of test runs designed to heavily stress the system in areas of critical concern. Additionally, HUBNET is installed and in use by J.B. Hunt Transport, Inc. This should help to ensure the validity of the code and the effectiveness of technology transfer. Because J.B. Hunt Transport, Inc. has not implemented a complete H&S network at this time, the validity of results is even more important because actual comparisons with field data are not possible at this time. Regarding the validity of the simulation results themselves, a replication design is used to ensure the independence of data between runs.

## III. Analysis of Results

In this section, we discuss the results of the experimentation described above. We begin with a discussion of HUBNET use and computational requirements. Subsequently, we present the results of the experimentation, which includes statistical analysis of validated HUBNET output via Analysis of Variance (ANOVA) methods.

**HUBNET Performance**

The HUBNET simulator has proven to be an effective and user-friendly tool for analyzing H&S networks in truckload trucking operations. Of particular value is the graphical network builder which allows for simple "what-if" analyses in terms of network configuration. Figure 2 shows a typical input screen that enables the user to graphically build the network in terms of hub locations, spoke locations, and service area allocation. The screen shown in the figure involves the placement of hubs.

******Insert Figure 2 Here******

The computational needs of HUBNET, on the other hand, are considerable for the experiments conducted in the course of this study. Each scenario consists of five independent replications of 5000 loads each. Each replication requires more than one hour of CPU time on a Sun 690 mini-computer.

**Performance Evaluation**

The performance of each of the twelve experimental conditions of the factorial design are now discussed relative to one another and relative to the current methods employed in the truckload trucking industry. Figures 3 through 7 present the performance of the experimental conditions in terms of the five performance criteria. Because the first dispatch empty miles and the average circuity miles are considered proprietary by J.B. Hunt Transport, Inc., these performance measures are presented in terms of their percentage relative to trip miles. The average miles driven per driver per day is also considered proprietary. Therefore, this performance measure is presented as a percentage, with the 100% baseline for this calculation being the miles per driver per day for the traditional point-to-point delivery system.

*****Insert Figures 3 Through 7 Here******

Examination of Figure 3 reveals that the most dominant experimental feature affecting network lane driver tour length is that of driver usage rules. Obviously, the 2-hub TL rule would result in longer tour lengths than the 1-hub rule. The surprising element is that the tour length is increased much more than the factor of two that would seem intuitive. It would appear that it is much more difficult than expected to obtain a load going in the right direction when a driver is more than one hub from home. Figure 4 is also very interesting. With respect to local driver tour lengths, the 2-hub rule generally provides improvement over the 1-hub rule. Upon first inspection, it may appear that the 32-hub networks perform better than similar 24-hub networks. Intuitively, one may think that 32-hub scenarios would have better performance relative to local driver tour length, because service areas are smaller. However, this anticipated result is subsequently shown, using ANOVA, to be insignificant for this experimental design. The observed system behavior under the 2-hub rule is less intuitive, but is a result of the hubs being fed more efficiently by lane drivers under the 2-hub TL rule. Interestingly, this efficient feeding by lane drivers is accomplished with longer lane driver tour lengths. The most significant factor relative to local driver tour length, however, seems to be that of network design configuration. This is confirmed by ANOVA results later in this paper. The hybrid configuration provides much better performance than either the flow-based or distance-based hub layout designs. This result is also somewhat intuitive, because the hybrid system provides smaller service-areas than distance-based methods for those areas with dense freight traffic. While the flow-based system does not necessarily result in large service areas in dense freight regions, it also does not explicitly use freight density as a criterion for service area allocation. The hybrid method, on the other hand, uses freight density as a primary consideration for hub location and consequently for service area allocation.

The miles per driver per day for the hybrid scenarios are quite low compared to distance-based or flow-based hub scenarios, as noted in Figure 5. Furthermore, the 32-hub scenarios result in fewer miles than their 24-hub counterparts. With 32 hubs in the system, drivers spend less time driving and more time waiting for loads. This is not necessarily a bad result if 24-hub scenarios result in more circuity and first dispatch empty miles. It is shown subsequently in this paper that this is indeed the case. Figures 6 and 7 indicate that distance-based hub layouts perform poorly in terms of first dispatch empty miles and in terms of circuity. This somewhat negates the outstanding performance of the distance-based hub location methodology in terms of miles per driver per day. The hybrid layout, on the other hand, results in relatively strong performance in terms of circuity and first dispatch empty miles. As mentioned earlier, the 32-hub layouts perform better than 24-hub layouts in terms of first dispatch empty miles and circuity, making their performance in terms of average miles per driver per day more attractive. Circuity, in point-to-point methods, is brought about by the desire to get drivers to their home base as often as possible.

**Comparative Performance**

The objective of this section of the paper is to identify the "best" of the H&S network designs according to the five primary performance criteria used. To aid in this selection, Table 1 is presented. In Table 1, each scenario is rated according to five ratios that indicate performance relative to the best observed performance among all twelve primary scenarios. For example, the (H/32/2) scenario provides the best performance among all candidates in terms of local driver tour length and first dispatch empty miles (indicated by 1.00 values in Table 1). Similarly, it is only 1% worse than the (F/32/1) and (F/32/2) scenarios in terms of average circuity. However, it is 555% worse than (H/32/1) in terms of lane driver tours and achieves only 75% of the average miles per driver per day achieved by the (F/24/1) scenario.

*****Insert Table 1 Here******

Based on the information presented in Table 1, the (H/32/1) scenario is selected as the best scenario. It is the best performer in terms of lane driver tour length and ties for first in first dispatch empty miles. It is only 1% behind the best scenario for circuity. The performance for local driver tour length is 28% lower than the best scenario, yet much better than all 2-hub driver rule scenarios. Furthermore, the local driver tour length is less than one day on the average, which is acceptable. The only disappointing feature of the (H/32/1) scenario is that it achieves only 77% of the miles per driver per day that the best scenario achieves. This is not a large concern when comparisons are made to other H&S scenarios, because many of these other scenarios are higher in terms of miles per day at the expense of first dispatch empty miles or circuity. No revenue is generated for this wasteful driving, so the (H/32/1) scenario is selected as the best H&S network configuration based on the factorial design presented earlier.

The selection of this baseline is important, because additional testing and sensitivity analysis is desired. Adding to the factorial design of experiments would have been cost prohibitive and time prohibitive in terms of the CPU requirements to examine a full factorial experimental design. By selecting a strong baseline and fixing some of the H&S system parameters, additional sensitivity analysis is possible through factorial experiments. This reduces the computational requirements for the extended testing by a factor of twelve. This sensitivity analysis and additional testing is presented in Harit et al. (1994), along with discussion concerning H&S implementation and business strategy.

The performance of the (H/32/1) baseline compared to current point-to-point delivery methods of operation is also interesting and important. The largest improvement associated with H&S operations is in the area of driver tour length. Using the (H/32/1) scenario, average tour length for over-the-road drivers is less than two days. This represents almost a 90% improvement over existing dispatching methods with point-to-point deliveries. Local drivers get home even more frequently. Total miles per driver per day are reduced by 14.6% in (H/32/1) compared to the point-to-point delivery system. This is a significant reduction. Related problems are noted in terms of circuity and first dispatch empty miles as a percent of total trip miles. Circuity increases from 3.5% of trip miles to 12.1% of trip miles. First dispatch empty miles increase from 5.6% of trip miles to 8.2% of trip miles.

It is not immediately clear whether the H&S network approach is a viable option based on this performance evaluation. This is largely dependent upon the cost of high driver turnover. Would drivers be willing to drive fewer miles per day and accept the inevitable lower wages in return for more time at home with their families? It is, however, immediately clear that additional H&S evaluation is needed to determine network efficacy in truckload trucking in general terms. It is also clear that it would be prudent to test H&S systems in limited implementation plans as opposed to making a basic change in operational techniques. Both of these points are addressed in greater detail in Harit et al. (1994).

## Results of ANOVA Testing

In Tables 2 through 6, the results of ANOVA testing are presented for each of the five primary performance criteria. These results are important because they statistically validate the findings discussed in the Performance Evaluation section of this paper. For the lane driver tour length criterion, as shown in Table 2, only the tour length (TL) is a significant factor at an alpha level of 0.05. TL is in fact highly significant at the 0.01 alpha level. Throughout the remainder of this paper, a result is said to be statistically significant if found to be significant at the $\alpha = 0.05$ level and highly significant if found to be significant at the $\alpha = 0.01$ level. The ANOVA
test presented in Table 2 supports the previous discussion regarding the 2-hub versus 1-hub driver rules.

*****Insert Tables 2 through 6 Here******

For the local driver tour length criterion, as shown in Table 3, both TL and the hub location methodology (HLM) are statistically significant. As discussed previously, the number of hubs (#H) criterion affects local driver tour length due to the service area size. Surprisingly, this result is not statistically significant as a main effect. We also discussed the fact that the 2-hub TL rule seems to result in more efficient hub feeding by lane drivers. The 2-hub rule seems to be a strong alternative strategy in terms of freight movement, but seems to be a poor alternative relative to driver tour length. These results are supported by the ANOVA testing, which shows the TL main effect to be statistically significant. The HLM is highly significant for this measure of performance, with the best performance indicated for those scenarios which tend to place hubs with small service areas in regions of high freight density. The hybrid scenario is best in this regard.

Table 4 presents the results of ANOVA testing for the average miles per driver per day criterion. In this case, the main effects HLM and #H are statistically significant with HLM once again attaining a highly significant level. Obviously, distance-based hub locations would result in more miles per driver per day. The #H result is also intuitive, because 32-hub scenarios have fewer inter-hub miles than 24-hub scenarios. The reader should use caution, however, in using these results without considering circuity and first dispatch empty miles.

Tables 5 and 6 present the results of ANOVA testing for the first dispatch empty miles and average circuity criteria, respectively. Because the circuity and first dispatch empty miles are calculated in the HUBNET simulation pre-run, these criteria are not affected by replication effects. For these criteria, differences are brought about only when the scenarios are changed in terms of #H or HLM. Therefore, TL is not included in the ANOVA testing for these criteria. In Tables 5 and 6, it is clear that HLM and #H are highly significant as main affects. Additionally, the interaction affect of HLM/#H is highly significant in both cases. As #H increases, the distance from a hub to pick-up and delivery points decreases and circuity also decreases. Obviously, as #H approaches infinity, we would optimize performance relative to these two criteria. With a reasonable number of hubs, however, we cannot achieve the same level of performance that is achievable with the current point-to-point pick-up and delivery method. The hybrid hub location method once again performs well due to hub proximity to dense freight regions, with well positioned transshipment hubs along dense freight paths. The HLM/#H interaction effects are more subtle but are evident in Figures 6 and 7. The interaction affect is perhaps most easily described by discussing the difference in performance between 24-hub and 32-hub scenarios as HLM varies. In this regard, Table 7 is helpful. Table 7 presents the difference between 24-hub and 32-hub scenarios for circuity and first dispatch empty miles as a percent of total trip miles. For first dispatch empty miles, Table 7 indicates that this percent difference is greater for some HLM scenarios than others. The percent difference is least for flow-based hub location methods, which is intuitive. The percent difference is higher for distance-based hub locations, and highest for the hybrid method of hub location. This indicates that the hybrid method is more greatly affected by the shift from 24 to 32 hubs for this measure of effectiveness. For the circuity performance measure, this disparity in percent difference is also apparent, only the distance-based HLM provides the greatest difference with the hybrid HLM results indicating the smallest difference. This result is also intuitive in that the hybrid hubs are well placed relative to freight density. The addition of more hubs does not buy as much in performance as in the distance-based HLM.

*****Insert Table 7 Here*****

## IV. Concluding Remarks

Hub-and-spoke networks have been used successfully in a number of transportation systems. It is still not clear whether or not H&S systems can be profitable in the truckload trucking industry. This paper represents the first efforts known to the authors in quantifying the effects of H&S in truckload trucking, and therefore provides a first and unique contribution in this area. We will now discuss our findings in general terms.

The simulation architecture presented in Taha and Taylor (1994) and the HUBNET system developed by Taha (1993) have proven to be effective for evaluating H&S networks in truckload trucking. The only disappointment in this regard is the considerable computational requirements associated with running the actual simulation scenarios.

The results of experimentation indicate that H&S networks perform well relative to some performance criteria and poorly compared to others. The key improvement is in the area of driver tour length. This improvement, however, is obtained at the expense of other important criteria such as average miles per driver per day, circuity, and first dispatch empty miles. Only a detailed cost comparison using company specific data would reveal whether or not this is a worthwhile trade-off. Therefore, the authors are not prepared to make a blanket statement regarding the efficacy of the H&S system at this point. However, the authors are prepared to make two statements based on the results of the factorial experimental design evaluated and presented within this paper. Firstly, an opportunity seems to exist for limited implementation. Secondly, additional testing is needed.

Limited implementation of H&S networks could prove very beneficial in truckload trucking. With limited implementation, it would be possible to establish regular driving lanes between two high density city pairs that are well separated in terms of distance. In this way, drivers would be assured of regular work and would be more or less guaranteed mileage minimums. This type of limited network could be extended between many potential city pairs that have regular and heavy traffic. As a result, capacity could be sold to customers according to a regular schedule, potentially contributing to an increase in the market share for freight between high volume city pairs. The majority of loads could still be handled according to more traditional methods until a near-optimal percentage of network loads could be determined. Limited implementation is rapidly becoming a necessity under current operating conditions because of the increasing intermodal emphasis in truckload trucking. With more freight movement via rail, trucks constantly pick up and drop off loads at fixed railroad terminal locations. These fixed locations are de facto hubs, which are fed by a service area on one end with dispersion to another service area on the other end.

Additional testing is needed to support H&S implementation. At this point, we have identified solid baseline configurations, but have not optimized H&S configurations. This further testing and sensitivity analysis is taken up in Harit et al. (1994). Specifically, they address the idea of limited implementation by performing sensitivity analysis on the percent of jobs carried by the H&S network. Furthermore, they perform sensitivity analysis on the number of drivers available to support the system. Finally, these authors present a discussion on the implications of H&S usage for truckload operations.

While the analysis of H&S systems in truckload trucking is far from complete, this paper provides an important first step in quantifying the potential costs and benefits. Based on the results presented herein, it would appear that H&S networks can play at least a limited role in the truckload trucking industry.

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Table 1. Relative Performance for Major H&S Scenarios

| | Measure of Performance* | | | | |
|---|---|---|---|---|---|
| Scenario | (1) | (2) | (3) | (4) | (5) |
| (H/24/1) | 1.18 | 1.48 | 0.89 | 1.17 | 1.35 |
| (F/24/1) | 1.06 | 2.49 | 1.00 | 1.42 | 1.40 |
| (D/24/1) | 1.15 | 2.33 | 0.97 | 1.47 | 1.84 |
| (H/24/2) | 6.20 | 1.29 | 0.83 | 1.17 | 1.35 |
| (F/24/2) | 5.65 | 1.98 | 0.92 | 1.42 | 1.40 |
| (D/24/2) | 6.63 | 1.85 | 0.97 | 1.47 | 1.84 |
| (H/32/1) | 1.00 | 1.28 | 0.77 | 1.00 | 1.01 |
| (F/32/1) | 1.13 | 2.26 | 0.91 | 1.35 | 1.00 |
| (D/32/1) | 1.20 | 1.96 | 0.97 | 1.28 | 1.25 |
| (H/32/2) | 5.55 | 1.00 | 0.75 | 1.00 | 1.01 |
| (F/32/2) | 6.39 | 1.77 | 0.91 | 1.35 | 1.00 |
| (D/32/2) | 5.93 | 1.66 | 0.94 | 1.28 | 1.25 |

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*(1) Lane Driver Tour Length
(2) Local Driver Tour Length
(3) Miles Per Driver Per Day
(4) First Dispatch Empty Miles as a Percent of Trip Miles
(5) Circuity Miles as a Percent of Trip Miles

Table 2. ANOVA Results for the Lane Driver Tour Length Criterion

Analysis of Variance Table--Lane Driver Tour Length

| Source | DF | SS | MS | F Value | Sig. Level |
|---|---|---|---|---|---|
| HLM | 2 | 1231.2 | 615.6 | 0.10 | 0.9033 |
| TL | 1 | 707306.1 | 707306.1 | 117.06 | 0.0001 |
| #H | 1 | 368.7 | 368.7 | 0.06 | 0.8059 |
| HLM/TL | 2 | 501.5 | 250.8 | 0.04 | 0.9594 |
| HLM/#H | 2 | 3886.6 | 1943.3 | 0.32 | 0.7265 |
| TL/#H | 1 | 246.0 | 246.0 | 0.04 | 0.8409 |
| HLM/TL/#H | 2 | 2785.7 | 1392.9 | 0.23 | 0.7950 |
| Error | 48 | 290027.5 | 6042.2 | | |
| Total | 59 | 1006353.2 | | | |

Table 3. ANOVA Results for the Local Driver Tour Length Criterion

Analysis of Variance Table--Local Driver Tour Length

| Source | DF | SS | MS | F Value | Sig. Level |
|---|---|---|---|---|---|
| HLM | 2 | 2143.1 | 1071.5 | 8.97 | 0.0005 |
| TL | 1 | 532.5 | 532.5 | 4.46 | 0.0400 |
| #H | 1 | 240.6 | 240.6 | 2.01 | 0.1624 |
| HLM/TL | 2 | 46.4 | 23.2 | 0.19 | 0.8240 |
| HLM/#H | 2 | 3.1 | 1.6 | 0.01 | 0.9871 |
| TL/#H | 1 | 1.1 | 1.1 | 0.01 | 0.9249 |
| HLM/TL/#H | 2 | 11.9 | 6.0 | 0.05 | 0.9514 |
| Error | 48 | 5735.2 | 119.5 | | |
| Total | 59 | 8713.9 | | | |

Table 4. ANOVA Results for the Average Miles Per Driver Per Day Criterion

Analysis of Variance Table--Miles Per Driver Per Day

| Source | DF | SS | MS | F Value | Sig. Level |
|---|---|---|---|---|---|
| HLM | 2 | 33890.3 | 16945.2 | 17.29 | 0.0001 |
| TL | 1 | 1946.8 | 1946.8 | 1.99 | 0.1652 |
| #H | 1 | 6213.6 | 6213.6 | 6.34 | 0.0152 |
| HLM/TL | 2 | 238.0 | 119.0 | 0.12 | 0.8859 |
| HLM/#H | 2 | 2575.5 | 1287.7 | 1.31 | 0.2783 |
| TL/#H | 1 | 287.2 | 287.2 | 0.29 | 0.5908 |
| HLM/TL/#H | 2 | 858.7 | 429.4 | 0.44 | 0.6479 |
| Error | 48 | 47049.8 | 980.2 | | |
| Total | 59 | 93060.0 | | | |

Table 5. ANOVA Results for the Percent First Dispatch Empty Miles Criterion

Analysis of Variance Table--Percent First Dispatch Empty Miles

| Source | DF | SS | MS | F Value | Sig. Level |
|---|---|---|---|---|---|
| HLM | 2 | 10335.3 | 5167.7 | 778.57 | 0.0001 |
| #H | 1 | 2617.3 | 2617.3 | 394.33 | 0.0001 |
| HLM/#H | 2 | 306.2 | 153.1 | 23.06 | 0.0001 |
| Error | 54 | 358.4 | 6.6 | | |
| Total | 59 | 13617.2 | | | |

Table 6. ANOVA Results for the Percent Circuity Criterion

Analysis of Variance Table--Percent Circuity

| Source | DF | SS | MS | F Value | Sig. Level |
|---|---|---|---|---|---|
| HLM | 2 | 32259.8 | 16129.9 | 98.84 | 0.0001 |
| #H | 1 | 55943.2 | 55943.2 | 342.79 | 0.0001 |
| HLM/#H | 2 | 2968.8 | 1484.4 | 9.10 | 0.0004 |
| Error | 54 | 8812.8 | 163.2 | | |
| Total | 59 | 99984.5 | | | |

Table 7. HLM/#H Interaction Effects

% Difference Between 24-Hub and 32-Hub Scenarios

| | Hybrid | Flow-based | Distance-Based |
|---|---|---|---|
| % First Dispatch Empty Miles | 0.768% | 0.080% | 0.278% |
| % Circuity | 3.036% | 3.718% | 4.622% |