EVALUATION AND REDESIGN OF A COMPANY'S DISTRIBUTION NETWORK

A Record of Study

by

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ABSTRACT

Evaluation and Redesign of a Company's Distribution Network. (August 2004)
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The current Record of Study presents the qualitative and quantitative analysis of a company's network of distribution centers with the purpose of determining the convenience and the feasibility to reconfigure such a network. The study was performed with a multidisciplinary team of people within and outside of the organization. The distribution network was modeled in various forms and different solutions were obtained as new information was gathered from questionnaires, from observation and from the company's databases. Finally a recommendation was formulated to modify the current configuration of the distribution network and the feasibility to implement the suggested solution in practice was evaluated.

ACKNOWLEDGEMENTS

This is a great opportunity for me not only to acknowledge but also to thank the people that helped me in one way or another to succeed during the past few years that I have been pursuing the D. Eng. degree.

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I would like to thank my professors, Dr. Sila Çetinkaya, Dr. Lorraine Eden and Dr. Guy Curry who were the best professors I had during my graduate studies at Texas A&M and then continued to teach me invaluable lessons in their advisory capacity as members of my advisory committee.

Also, I would like to acknowledge and thank Mr. Ben Albrecht for trusting me and giving me the opportunity to collaborate with Multiquip on the elaboration of this project. Working under his supervision was truly an enjoyable learning experience.

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INTRODUCTION

Multiquip, Inc. is a manufacturer and distributor of light and medium-sized construction equipment with its headquarters located in Carson, California. The company purchases components for its manufacturing facilities and finished goods for distribution in the USA on a global basis. Currently the firm's manufacturing and distribution centers are located as follows:

1. Atlanta, Georgia – Distribution center.
2. Boise, Idaho – Manufacturing facility and distribution center.
3. Carson, California – Headquarters and distribution center.
4. Montreal, Canada – Distribution center.
5. Newark, New Jersey – Distribution center.
6. Peosta, Iowa – Distribution center.
7. Puebla, Mexico – Manufacturing facility.

Ninety percent of the company's shipments are concentrated in the US, and one-half of the international shipments go to Canada and Mexico. Domestically the states of California, Texas, Florida and New York concentrate about 40% of the total demand.

The distribution network mentioned above was the subject of study during the course of the year-long internship that is being reported here. Due to the high volume of domestic sales a decision was made during the kickoff meetings to narrow the scope of the study to US demand only.

This Record of Study follows the format and style of the *Journal of Business Logistics.*

The work was done under the supervision of Mr. Ben Albrecht, General Manager of Operations at Multiquip, and it involved working in collaboration with a cross-functional team within the organization and even outside the organization with people in real-estate companies, in competing businesses, in third-party logistics providers, in professional associations and other organizations.

The first part of the project started on June 2003 and was concluded at the end of December 2003. Among other activities, this part of the project involved trips to the manufacturing facility in Puebla, Mexico and the headquarters and distribution center in Carson, California to get acquainted with the company and to observe its operations. Also an assessment of the company's competitive environment was performed, the logistics and operational practices at the distribution centers were analyzed, and data were gathered and analyzed on-site and from a distance via the company's SAP R/3 system.

The second part of the project, which concludes with the presentation of this report and the final examination began on January 2004 and mainly involved the modeling of the company's distribution network with the use of optimization software that is available through the Industrial Engineering Department at Texas A&M University, presenting the results to Multiquip's upper managers and assessing the feasibility of the solution recommended.

It has been agreed with Multiquip, Inc. that proprietary information including demand, cost and sales figures among other types of information would not be disclosed in the elaboration of this report. Hence the analyses and results are given in general form, that is, without revealing information sensitive to Multiquip, Inc.

COMPETITIVE ENVIRONMENT ASSESSMENT

Survey

In times of growth in the economy of an industry it is frequent for its individual members to expand its supplying capabilities in order to satisfy the also increasing demand from its customers. Naturally, when the economy faces a downturn companies focus their attention on the reduction of costs as the satisfaction of demand in itself stops being a constraint and attaining efficiency in its satisfaction becomes the main concern. Along with the national economy, the construction industry in the U.S. found itself in such a downturn at the beginning of this century and Multiquip, being a supplier of construction equipment had a decrease in sales as did all of its direct competitors, and thus reducing costs on the supply side of the equation became a priority.

The first step to assess the efficiency of Multiquip's distribution network and the potential for savings in distribution costs by changing its configuration was to perform an analysis of the company's competitive environment and the way in which competitors operate.

Due to the wide variety of products that are distributed by Multiquip, its number of competitors is also wide and many of them are direct competitors only in a few product lines. Therefore, a list of the most significant competitors was put together, and nineteen companies became the subject of the study in the initial phase of the project.

The study was carried out by sending the nineteen chosen firms a questionnaire about their distribution organization, their delivery commitment, their freight policy and after-sale support. The participation of the firms that filled out the questionnaire which is included on Appendix A was obtained by assuring them that their identity would not be disclosed at any time. Thus, the results of the study will be provided without revealing

the name of any of the companies associated to the different responses. Out of the nineteen companies, five filled out and returned the questionnaires, for a response rate of 26%. However, only one in these five filled it out completely and with detailed responses. The rest of them failed to provide complete or suitable answers to every one of the questions in the questionnaire.

Information about ten of the companies that did not return the questionnaires was gathered from their websites, journals and other web-based publications. Therefore, some degree of information was obtained for fifteen companies, that is, 79% of the total, and no relevant information was obtained for four of the nineteen companies that represent the remaining 21% of the sample.

The answers provided by the participating companies indicated that they have a number of warehousing facilities that ranges between one and six. Also, three of the five indicated that they have third party warehouses, and only two of them said that they also have customers used as distribution centers as is shown on Appendix B.

If we include the information provided by Multiquip in the results, these yield a preference for the state of California to place warehousing facilities, as eight of the twenty four warehouses are located in that state. The states of Iowa, New Jersey, South Carolina, Wisconsin and also Canada ranked second with a total of two facilities each. A summary of these results is shown below in Table 1.

Similarly, a preference for company owned facilities was indicated by the companies' responses. Multiquip's information on this subject will be omitted, but nine of the fifteen warehouses from the competitor's questionnaires belong to this category (53%), while five of them are third party owned (29%), and only three of them are customers used as distribution centers (18%). Table 2 below provides a summary of these results.

TABLE 1
Number of DCs by Location from Questionnaires (Including Multiquip)

Location	*CA*	*IA*	*NJ*	*SC*	*WI*	*CAN*	*CO*	*GA*	*ID*	*IL*	*KS*	*TX*	*Total*
Maquoketa		1											1
Atlanta								1					1
Boise									1				1
Carson	1												1
Cerritos	1												1
Columbia				1									1
Columbia							1						1
Corona	1												1
Fremont	1												1
Ft. Worth												1	1
Germantown					1								1
Itasca										1			1
Montreal						1							1
Newark			1										1
Ontario						1							1
Olathe											1		1
Peosta		1											1
Pleasant Grove	1												1
Riverside	1												1
Rock Hill				1									1
Sacramento	1												1
Swedesboro			1										1
Torrance	1												1
Waukesha					1								1
Total	*8*	*2*	*2*	*2*	*2*	*2*	*1*	*1*	*1*	*1*	*1*	*1*	*24*

TABLE 2
Number of DCs by Type from Questionnaires (Not including Multiquip)

Type	*CA*	*SC*	*WI*	*CAN*	*CO*	*IA*	*IL*	*KS*	*NJ*	*TX*	*Total*
Third Party	1			1	1	1				1	5
Owned	3	2	2					1	1		9
Customer	2						1				3
Total	*6*	*2*	*2*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*17*

Partial information about eight of the other competitors was gathered from their resources online, and other internet-based resources. This information includes the location of some of their distribution centers, but the type of facility it is unknown, as well as the total number of distribution centers that these companies have. Table 3 below shows the locations found to be used by other competitors to place their warehouses. Finally, Table 4 combines the information gathered from questionnaires with the information obtained from other resources and shows the preferred locations for warehousing facilities by city and state.

TABLE 3
Some Locations Chosen by Competitors That Did Not Respond to the Questionnaire

	City	State
1	Torrance	CA
2	Manchester	CT
3	Alpharetta	GA
4	Lawrenceville	GA
5	Davenport	IA
6	Kewanee	IL
7	Wood Dale	IL
8	Hopedale	MA
9	Swedesboro	NJ
10	Honeoye	NJ
11	Portland	OR
12	Troy	OR
13	Dallas	TX
14	West Jordan	UT
15	Appleton	WI
16	Slinger	WI

TABLE 4
Number of Warehouses by Location From Questionnaires

Location	*CA*	*NJ*	*WI*	*GA*	*IA*	*IL*	*CAN*	*OR*	*SC*	*TX*	*CO*	*CT*	*ID*	*KS*	*MA*	*UT*	*Total*
Alpharetta				1													1
Appleton			1														1
Atlanta				1													1
Boise													1				1
Carson	1																1
Cerritos	1																1
Columbia									1								1
Columbia											1						1
Corona	1																1
Dallas										1							1
Davenport					1												1
Fremont	1																1
Ft. Worth										1							1
Germantown			1														1
Honeoye		1															1
Hopedale															1		1
Itasca						1											1
Kewanee						1											1
Lawrenceville				1													1
Manchester												1					1
Maquoketa					1												1
Montreal, Canada							1										1
Newark		1															1
Ontario, Canada							1										1
Olathe														1			1
Peosta					1												1
Pleasant Grove	1																1
Portland								1									1
Riverside	1																1
Rock Hill									1								1
Sacramento	1																1
Slinger			1														1

TABLE 4 Continued

Location	*CA*	*NJ*	*WI*	*GA*	*IA*	*IL*	*CAN*	*OR*	*SC*	*TX*	*CO*	*CT*	*ID*	*KS*	*MA*	*UT*	*Total*
Swedesboro		2															2
Torrance	2																2
Troy								1									1
Waukesha			1														1
West Jordan																1	1
Wood Dale						1											1
Total	*9*	*4*	*4*	*3*	*3*	*3*	*2*	*2*	*2*	*2*	*1*	*1*	*1*	*1*	*1*	*1*	*40*

The combined results from Table 4 yield California as the preferred state for the location of distribution centers with a total of nine. Second to California came New Jersey and Wisconsin with four facilities each, and Iowa, Georgia and Illinois came in third place with three distribution centers each. As far as cities are concerned, only two of the thirty-seven cities were indicated to have more than one warehousing facility. These are Torrance, California and Swedesboro, New Jersey with two facilities in each city.

A summary of the remaining answers to the questionnaire is shown on Appendix C. The most relevant questions to the present study relate to the type of transportation used and the order-processing time. With respect to the first question, most of the respondents rely on a mix of company owned, common carrier, and contract transportation modes. However only two of them mentioned the use of company owned means of transportation, while the other three options were mentioned by at least three of the six respondents. In reference to the second question five of the six respondents indicated an order processing time smaller than 48 hours, and three of them reported to have order processing times of less than 24 hours.

In general, the responses obtained from the questionnaires indicated the following results about Multiquip's competitive environment:

1. The number of distribution centers per company ranges from one to six.

2. About one-half of these distribution centers are company-owned, while one-third of them are third-party owned and the remaining are customer-based.

3. The location of distribution centers was reported to lie in 15 different states and Canada. California is home to most of the respondent's distribution centers with a total of nine, followed by New Jersey and Wisconsin with four distribution

centers each; Georgia, Iowa and Illinois with three each and the remaining states and Canada with one or two distribution centers only.

4. Most respondents utilize different transportation strategies, but few of them utilize company-owned transportation.

Other Sources of Information

The sample responses that were obtained from the previous survey provide an indication of the prevalent practices in warehousing within Multiquip's competitive environment. However we also looked at other references on warehousing trends and we found a study called "Facility Trends 2001 – 2003"[1] by The Warehousing Education and Research Council (WERC). In this study they looked at the size and composition of warehousing networks and compare their findings to the results of similar studies they have performed in the past. WERC's study includes the responses of about 140 firms that hold membership in the council. The majority of these firms is in manufacturing (40%), and wholesaling (37%), with the rest of them in sectors such as retailing, government, utilities and others.

In terms of warehousing space, WERC's study found that the size of most warehouses in the US is smaller than 500,000 square feet as is shown on Table 5.

TABLE 5
Size of Distribution Centers from WERC's Study

Warehousing Space (square feet)	*Percentage of Respondents*
0 – 100,000	37%
100,000 – 500,000	31%
500,000 – 1,000,000	21%
1,000,000 – 3,000,000	6%
3,000,000 -	5%

Perhaps the most significant finding of WERC's study is the fact that the respondents' overall number of facilities in their network of distribution centers is decreasing. From 2001 to 2003, the size of distribution networks has decreased in number by 4.4% as is reproduced from WERC's study on Table 6.

TABLE 6
Number of Distribution Centers from WERC's Study

Industry	*2001*	*2002*	*2003*	*Change in 2 years*
Electronics / Computing	5.4	5.1	4.7	-14.2%
Pharmaceutical / Medical	2.7	2.5	2.7	0%
Grocery / Food / Beverage	12.5	12.7	12.1	-3.1%
Industrial / Office products	3.4	3.5	3.6	+5.3%
Consumer goods	4.7	4.0	4.1	-15.5%
OVERALL	5.5	5.3	5.2	-4.4%
* Number expected				

According to the analysis, the overall size in warehouse networks is expected to decrease in all sectors. However the industrial sector does show an increasing trend, but they argue that it may be due to the small size of that sector's sample (n=16) and their relatively small network size of 3.5 warehouses. The overall decline in the number of distribution centers is attributed to the slowdown of the economy, which has forced companies in all industries to become more efficient and do the same tasks with fewer resources.

According to WERC, larger and medium sized companies are most likely to have reduced the size of their distribution network during 2002. However, they say, the size of newly built distribution centers is getting bigger. In other words, the trend is for distribution networks to become smaller in number, but the size of the distribution centers is increasing. The factors mentioned to explain this increasing size of facilities include mergers and acquisitions, and "the fact that warehouses are being asked to do more value added services (VAS). In addition to traditional warehousing functions, DC's

are now being called upon as facilities where light manufacturing takes place, customer center call centers are placed and corporate transportation headquarters are located. As the trend for VAS continues, it is probable that size of DCs will continue to increase."

The respondents who have modified the configuration of their distribution networks indicated that the main reason for such changes was sales-related (i.e. inventory turns), as well as overall inventory conditions. Other reasons included the need for increased labor flexibility, acquisitions and mergers, product sourcing changes, customs and duty and transportation costs.

With respect to the type of distribution centers mostly utilized, WERC classifies them as full-line, limited-line, or overflow. Also, they differentiate between private, public or contract facilities; this classification gives them nine possible warehouse combinations. For the purposes followed in our study we are only interested to know the preferences in terms of private, public and contract warehousing. Accordingly, the mix of distribution centers with respect to their contractual agreements is shown on Table 7.

TABLE 7
Type of Distribution Centers from WERC's Study

Type of DC	*1998*	*2002*
Private	65%	73%
Public	27%	14%
Contract	8%	13%

In general terms, three observations can be made. First, private distribution centers are by far the most prevalent, and their usage is increasing. Second, the trend in public warehousing usage is going down, and third, contract warehouses represent a very small part of all warehouses being used, but the trend is for them to become more common.

Conclusions

The results of the survey with Multiquip's list of nineteen competitors yielded limited results in terms of the response rate. Even though response rates for similar studies seldom go beyond forty percent, the small response rate coupled with the small sample size yielded results that couldn't be considered statistically representative of the industry average.

However, some insights could be drawn. First, the number of distribution centers in the competitor's distribution networks seems to be smaller than that of Multiquip. Second, it is known that at least one of the competitors in the study has joined the trend reported by WERC's study, namely, they have reduced their number of warehouses and increased its size with respect to what they had in the past. Third, three of the top six preferred states for warehouse location in the study coincide with states where Multiquip runs its distribution centers, that is, California, New Jersey and Georgia.

In terms of transportation, only two of the respondents indicated that they utilize company owned resources, while four of the five indicated that they use common carrier transportation as one of their transportation means. In second place came the use of contract transportation with three competitors mentioning it as one of their transportation means. However, the difference between these three choices of transportation is too small to draw significant conclusions.

On the freight question, it is clear that all competitors view it as a marketing and sales tool. They offer reduced freight charges to stimulate the placement of larger orders or to close a deal, so any strategy to relocate a distribution center should pay close attention to the selection of sites with good availability of freight carriers and low freight rates.

Finally, the trends reported by WERC's study suggest that Multiquip's number of distribution centers is too large in comparison with industry standards, and it could be reduced thus forcing the remaining warehouses to be more efficient than currently.

GRAVITY CENTER ANALYSIS

The results obtained from the Competitive Environment Assessment supported the opinions of Multiquip managers that a location analysis should be conducted to determine the most advantageous configuration of the firm's distribution network.

In order to obtain an initial solution to the warehouse location problem, a gravity center analysis was performed. The gravity center approach is an analytic tool that finds the single location that will minimize the transportation distance when considering all the shipments to the different customers. Mathematically, this problem solves for the minimum distance between two points in the Euclidean distance case.

The term "gravity center" arises for the following reason: If we were to place a map of the area in which the distribution center is to be located on a heavy piece of cardboard and weights proportional to demands were placed at the locations of demand points, then the gravity center solution would be the point on the map at which the entire system would balance[2].

The mathematical solution to the gravity center problem is given at the location:

$$x' = \frac{\sum_{n=1}^{k} D_n x_n}{\sum_{n=1}^{k} D_n}, \text{ and } \quad y' = \frac{\sum_{n=1}^{k} D_n y_n}{\sum_{n=1}^{k} D_n} \qquad (1)$$

where x_n and y_n represent the coordinate location of either a market or supply source n, and D_n represents the quantity to be shipped between facility and market or supply source n.

The demand data considered in this analysis covered the period of January, 2002 to August, 2003. Such information was downloaded from Multiquip's SAP R/3 system and it included the name and zip code of each customer as well as the dollar amount that was demanded during those 20 months. Coordinate locations for supply and demand points were given by the longitude and latitude of the different locations' zip codes which were available for the execution of this project from a commercial database. Given the great number of Multiquip customers or demand points, they were aggregated in two stages:

1. First, "shipped to" customers were aggregated into clusters according to the three-digit zip code, thus reducing its number from 10,307 individual customers to 846 customer zones. So for example, all customers in zip code areas starting with the three digits 989 were put together into one customer zone as shown on Table 8.

TABLE 8
Example of Demand Aggregation (First Phase)

Location Zip Code	*Gross Sales @ cost (01/02 to 08/03)*	*New Customer Zone*	*Gross Sales @ cost (01/02 to 08/03)*
98901	$ 3,712		
98909	$ 174		
98944	$ 275		
98902	$ 400		
98926	$ 760		
98903	$ 3,489		
TOTAL	$ 8,810	989	$ 8,810
* These numbers do not represent real sales figures			

2. It has been documented in the literature that aggregating large amounts of data achieves a significant reduction in variability, and forecast demand is much more accurate at the aggregated level. Furthermore, the aggregation of data into about 150 to 200 points usually results in no more than about 1% error in estimation of total transportation costs[3]. Therefore, the previous 846 customer zones were further aggregated into 141 demand clusters by geographical proximity, with all

of them having about the same demand level. In other words, assuming that the total domestic demand for the 20 months mentioned above equaled $11,635,650, then dividing this amount by 141, it would yield clusters of about $82,522. Table 9 shows an example of this aggregation stage.

TABLE 9
Example of Demand Aggregation (Second Phase)

Customer Zone	*Domestic Gross Sales @ cost (20 months)*	*New Demand Cluster*	*Domestic Gross Sales @ cost (20 months)*
984	$ 20,852		
985	$ 3,557		
986	$ 5,686		
988	$ 7,256		
989	$ 10,810		
990	$ 6		
991	$ 130		
992	$ 25,385		
993	$ 2 270		
994	$ 48		
TOTAL	$ 76,000	142	
* These numbers do not represent real sales figures			

With the demand and location information aggregated in this fashion, a local gravity center was obtained for each of the 141 demand clusters. As it was explained before, the gravity centers were obtained in the form of a coordinate pair, one coordinate indicating the location's longitude and the other one its latitude, and seldom did these coordinates coincide with an actual city. Thus the distance from the gravity center to each of the individual locations in the demand clusters was calculated and the closest city was then chosen to be the cluster's gravity center.

Finally a "global" gravity center analysis was performed in three scenarios that follow along with its results.

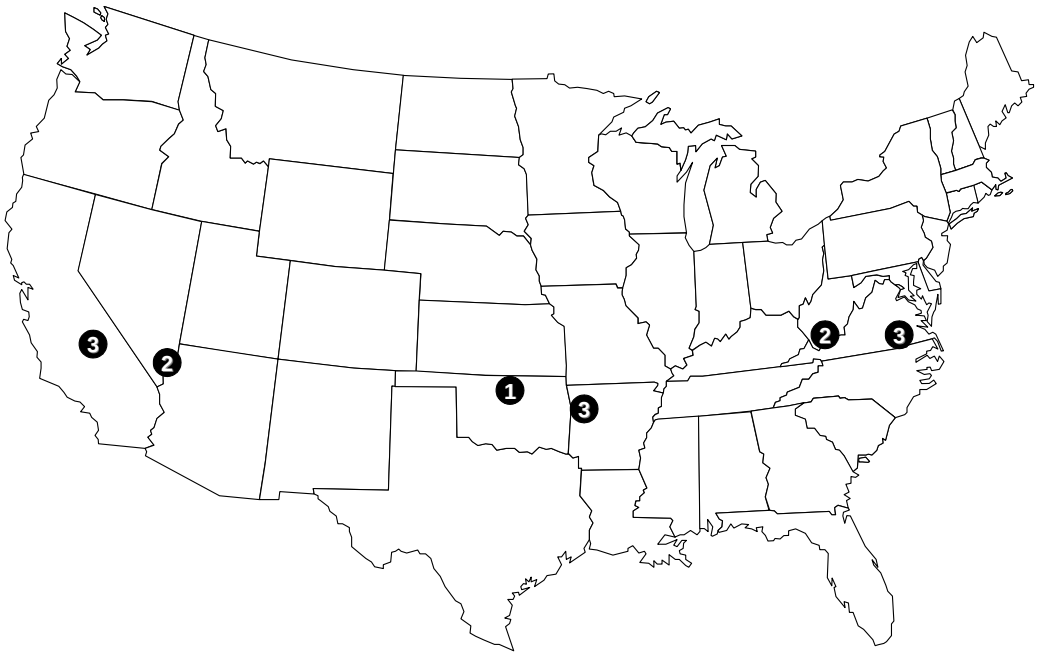
1. First, an overall center of gravity was found for the whole of the US conterminous territory. The resulting location was Medford, Oklahoma, about 100 miles north of Oklahoma City. The map on Figure 1 shows this location labeled with the number 1.

2. Second, the national territory was split into East and West with the eastern boarders of Texas, Oklahoma, Kansas, Nebraska, South Dakota and North Dakota separating the two blocks. The resulting demand is almost perfectly divided at 50% per block. The eastern gravity center where a distribution center would be located is in Welch, West Virginia, about 70 miles south of Charleston, WV and the western gravity center falls in the border between Arizona and Nevada. The nearest city is Henderson, Nevada, which is only 17 miles southeast of Las Vegas. The icons labeled with the number 2 on Figure 1 show the location of these centers of gravity.

3. Finally, if we split the national territory into eastern, central and western blocks, we get the following DC locations: Altavista, Virginia for the eastern block, about 100 miles southwest of Richmond, Virginia. Fayetteville, Arkansas for the central block in the northeast of the state, 110 miles east of Tulsa, Oklahoma. The western gravity center is in the city of Independence, California, about 90 miles east of Fresno, California. These locations are shown in Figure 1 with the label "3".

The location of the gravity centers show graphically the heavy weight that four states have for Multiquip as demand hubs, comprising about forty percent of domestic sales. These states are California (20%), Texas (8%), Florida (7%) and New York (4%). The location of a single gravity center in the US is centered between the Eastern and Western blocks, and closer to the south where Texas is. As we increase the number of distribution centers, their location is dispersed but it always centers between the four main states.

FIGURE 1
Centers of Gravity for One, Two and Three Geographic Zones



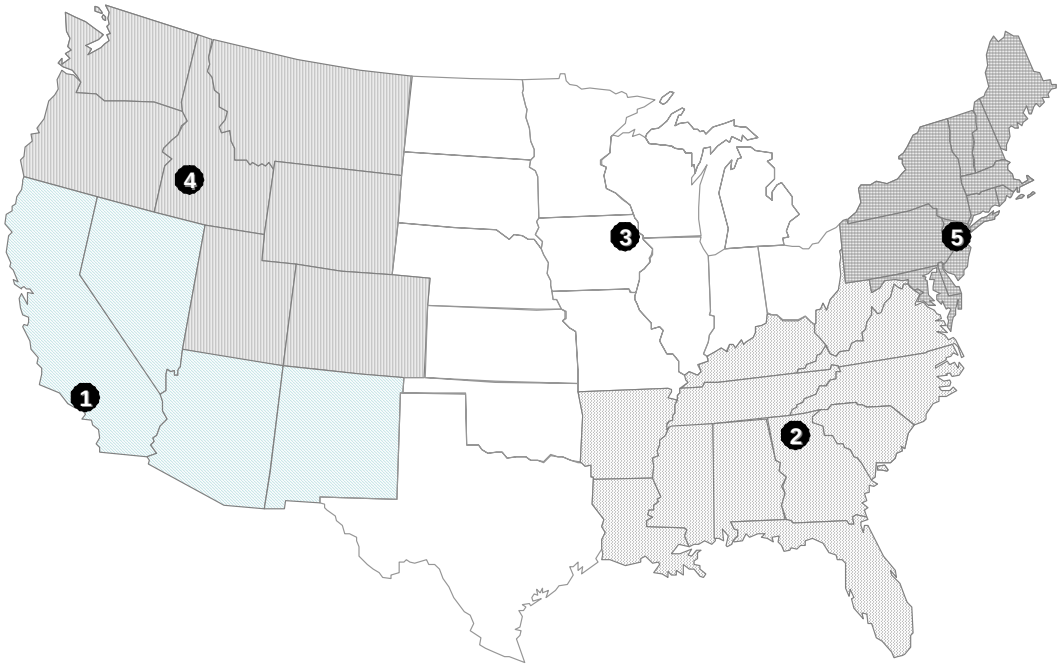
ANALYSIS OF CURRENT DISTRIBUTION PRACTICES

The core business of Multiquip is the distribution of construction equipment, some of which it manufactures and some of which it purchases, but the core business activity is distribution. Therefore the main cost drivers are related to inbound and outbound transportation. On the supply side Multiquip receives finished product and parts from about 700 suppliers while on the demand side it ships product to more than 10,000 customers, hence the weight of outbound transportation costs is far greater than that of inbound transportation. Having that in mind, the next step in the analysis of Multiquip's distribution network was to study the company's current distribution practices and the associated outbound distribution costs associated to them.

The current policies have assigned a number of states to each of the five distribution centers. In other words, each state's demand should be supplied from only one distribution center. In practice this is followed as closely as possible, but sometimes it is necessary to violate this policy due to inventory fluctuations, unexpected demand changes or other special circumstances. An analysis was performed to compare the distribution practices under the current policies to the optimal distribution practices without changing the number or location of the current distribution centers.

More specifically, the distribution network was modeled mathematically to minimize the total shipping cost from the existing distribution centers in Carson, Atlanta, Peosta, Boise and Newark to the different demand clusters. These distribution centers and their current service areas are identified graphically on Figure 2.

FIGURE 2
Current Configuration of Distribution Centers and Service Areas



Definitely, the most important piece of information for such formulation is the set of freight rates for transportation from distribution center *i* to demand location *j* of product *k*. The *i* demand locations are given by 137 of the 141 demand clusters obtained before. The remaining four clusters were ignored because they are located outside of the conterminous United States, so these clusters include customers in Alaska, Hawaii, and Guam.

With respect to the *k* product categories, some sort of aggregation strategy was needed. Thus we looked at how the carriers that provide MQ with transportation services calculate their freight rates. Their rating system is based on the National Motor Freight Classification which includes 23 different classes ranging from 500 to 35; in all cases, the higher the class, the greater the relative charge for transporting the goods. Some of the factors involved in determining a product's rating class include product density, difficulty of handling and transporting and liability for damage. In the case of MQ, its products fall into 9 of the 23 different categories which provide with a good aggregation strategy for modeling purposes. A list of these is shown on Table 10, along with examples of the types of actual products that are included in each class.

TABLE 10
Aggregation of Products into Nine Classes

Product Class	*Examples of products included in product class*
50	Plate compactors.
60	Vibrator heads.
70	Generators, trowel handles and blades.
77.5	Dewatering pump accessories.
85	Rammers and accessories, dewatering pumps.
100	Walk-behind trowels.
150	Ride-on trowels.
250	Mixers.
300	Light towers.

Freight rates were then obtained from Southern Motor Carrier's Complete Zip Auditing and Rating (CzarLite) engine. This software offers a market-based price list derived from studies of LTL pricing on a regional and interregional basis and therefore provides with very good estimates of actual freight rates for individual carriers. For the purposes of this analysis an average shipment was considered to range between 17,500 and 25,000 pounds. The use of freight rates for shipments in that range effectively overestimates the shipping cost of many orders and underestimates that of a few, but on average the total error in shipping cost estimation is relatively small. Consequently, the freight rates downloaded represented the transportation cost of such average shipment for each combination of distribution centers and customer zones. Finally, the demand data were transformed from dollar value to weight in pounds by considering the average weight of a product in each of the nine aggregation categories.

Mathematically, the solution to minimize the transportation cost of Multiquip's current distribution network can be modeled as an assignment problem. A simplified version of the Warehouse Location Problem was formulated as is shown below:

FORMULATION 1

Indices

i	demand clusters	$i = 1,\ldots,137$
j	distribution center	$j = 1,\ldots,5$
k	product families	$k = 1,\ldots,9$

Parameters

c_{ijk} cost to transport 1 unit of product k from distribution center j to demand cluster i

d_{ik} annual pounds of product k required by demand cluster i

Variables

x_{ijk} fraction of demand d_{ik} supplied from distribution center j

$$\text{Minimize} \qquad z = \sum_{i=1}^{137}\sum_{j=1}^{5}\sum_{k=1}^{9} c_{ijk} d_{ik} x_{ijk} \qquad (2)$$

$$\text{Subject to} \qquad \sum_{j=1}^{5} x_{ijk} = 1, \qquad i = 1,\ldots,137;\ k = 1,\ldots,9 \qquad (3)$$

$$x_{ijk} \geq 0 \qquad i = 1,\ldots,137;\ j = 1,\ldots,5;\ k = 1,\ldots,9 \qquad (4)$$

The linear nature of this mathematical formulation does not allow us to consider the economies of scale associated to the transport of larger shipments. Hence the solution to the model is equivalent to comparing the cost to satisfy the demand at a customer zone from each of the five possible distribution centers and choosing the one with the lowest cost and multiplying it by its associated demand. Then, repeating the process for all of the 137 demand clusters in each of the 9 product categories and adding up the 1233 subtotals would result in the same solution as the linear programming formulation does.

The data were downloaded from the company's SAP R/3 system and then organized in Microsoft's Excel and Access. The model was formulated in AMPL© and solved with CPLEX 7.1©. The solution resulted in savings of 9.5% with respect to the current practice which was shown graphically on Figure 2. In contrast, the alternative solution to the current configuration is represented on Figure 3 below. The main result of this analysis is the benefit that could be achieved by reassigning the states of Texas, Ohio, Indiana, Missouri, Michigan and Oklahoma that are currently served from Peosta to be served by Atlanta instead. The resulting savings in outbound freight costs are broken down by reassigned state on Table 11 below.

Although Multiquip's main objective in conducting this study was to minimize costs it should not be done at the expense of customer service. Thus a measure of customer service was defined as the proportion of demand that can be supplied in one day, which occurs when the demand cluster is within 600 miles of its servicing distribution center.

FIGURE 3
Suggested Configuration of Current Distribution Centers and Service Areas

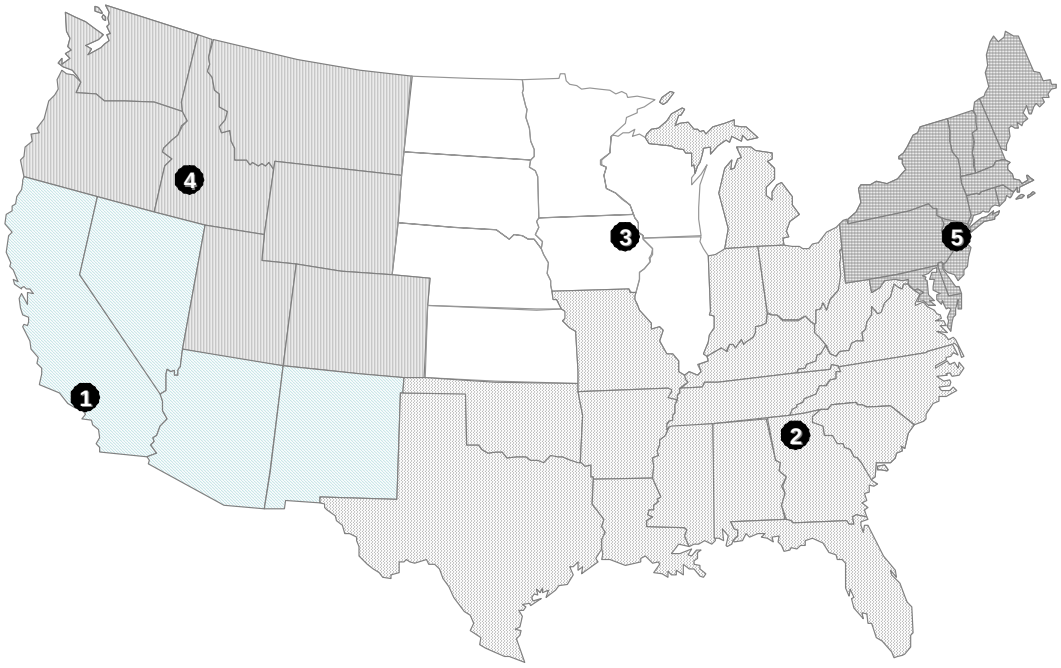


TABLE 11
Changes from Current to Recommended Configuration of Current Distribution Centers

State	*Original Servicing DC*	*Suggested Servicing DC*	*% Annual Savings in Outbound Freight Cost*
Texas	Peosta	Atlanta	5.57
Ohio	Peosta	Atlanta	1.59
Indiana	Peosta	Atlanta	0.75
Missouri	Peosta	Atlanta	0.65
Michigan	Peosta	Atlanta	0.56
Oklahoma	Peosta	Atlanta	0.37
Total Savings			9.49%

The United States Geological Survey suggests an approximation to measure fairly long distances while taking into account the curvature of the earth:

$$D_{ab} = 138 \sin^{-1} \sqrt{\sin\left(\frac{lat_a - lat_b}{2}\right)^2 + \cos(lat_a) \cdot \cos(lab_b) \cdot \sin\left(\frac{lon_a - lon_b}{2}\right)^2} \qquad (5)$$

The formula is very convenient for its input data are the latitude and longitude coordinates of the two points of interest. However, this equation underestimates the actual road distances, so the literature suggests multiplying the value of D_{ab} by a factor of $\alpha = 1.14$. In our case the list of points is given by the customer locations' zip codes and their coordinates are known, so using this formula we calculated the customer service level in the current scenario to be 82% and 78% in the suggested scenario. Multiquip decided to define a minimum service level of 75%, so the suggested scenario is equally satisfactory in cost as it is in service level.

For the sake of completeness a slight modification to the mathematical model was made. The modification involves the introduction of a set of binary decision variables y_j to limit the number of distribution centers, where y_j takes on the value of 1 if the corresponding distribution center remains open or 0 if it does not, and a is a constant representing the number of distribution centers that the will remain open.

FORMULATION 2

Minimize $$z = \sum_{i=1}^{137} \sum_{j=1}^{5} \sum_{k=1}^{9} c_{ijk} d_{ik} x_{ijk} \qquad (6)$$

Subject to $$\sum_{j=1}^{5} x_{ijk} = 1, \qquad \text{i = 1,…,137; k = 1,…,9} \qquad (7)$$

$$-x_{ijk} + y_j >= 0, \qquad \text{i = 1,…,137; j = 1,…,5; k = 1,…,9} \qquad (8)$$

$$\sum_{j=1}^{5} y_j = a \tag{9}$$

$$x_{ijk} \geq 0 \qquad \text{i = 1,…,137; j = 1,…,5; k = 1,…,9} \tag{10}$$

$$y_j \in \{0,1\} \qquad \text{j= 1,…,5} \tag{11}$$

The solution to the model for the each one of the five scenarios of interest, as well as its resulting service levels are summarized on Table 12. From there one can see the relative importance of each distribution center from an outbound distribution perspective. The best one in terms of location is the one in Atlanta, Georgia, followed by Carson, California; Newark, New Jersey; Boise, Idaho; and Peosta, Iowa. Also we see that with the current set of locations it would be impossible to satisfy the minimum customer service level of 75% with less than 5 distribution centers.

TABLE 12
Summary of Results for Current Practices and Alternatives

Scenario	*Locations*	*% Savings*	*% Service Level*
Current Practice – 5 DCs	GA, CA, NJ, ID, IA	0	82
Alternative – 5 DCs	GA, CA, NJ, ID, IA	9.49	78
Alternative – 4 DCs	GA, CA, NJ, ID	9.13	74
Alternative – 3 DCs	GA, CA, NJ	5.78	66
Alternative – 2 DCs	GA, CA	0.81	52
Alternative – 1 DCs	GA	-52.43	29

As a result of the present analysis a suggestion was made to Multiquip that if it eventually decided not to modify the current configuration of its distribution network, it could still achieve attractive savings in its annual outbound freight expenditures as indicated previously on Table 11.

ANALYSIS OF POTENTIAL LOCATIONS

The results that were obtained during the previous stages of the analysis provided us with enough preliminary information that reinforced our initial thoughts that a reconfiguration of the distribution network was advisable and feasible. Furthermore, to this point we had already gathered a substantial amount of information and a simplified formulation of the Warehouse Location problem had already proven to be a viable option to model Multiquip's distribution network.

Selection of Potential Locations

The next step in the study was to develop a list of potential locations to establish new distribution centers or to consolidate existing ones. To begin with, we looked at the current literature on the subject to find the ratings of different cities for the location of new distribution facilities. Such a list was compiled by Expansion Management[4], and it ranks cities according to criteria such as rail road availability, taxes and fees, interstate highways, and other categories. The list of cities listed in this article provides the reader with very few surprises as most of the locations are among the largest cities in the country. In other words one would only need to write a list of the main cities in each state and it would probably look very similar to the list in the referred article. Therefore it was decided to use the list only as a reference, but we needed to develop a list of potential locations in accordance to the company's specifics.

The solution to obtain a suitable list of locations was to divide the US conterminous territory into a number of zones with just about the same demand level and then to determine the center of gravity for each of these zones. Also the six locations resulting from the gravity center analysis were included in our list of potential sites. The full list of gravity centers found, which would serve as potential locations is given next on Table 13 and Figure 4 contains a map depicting its locations.

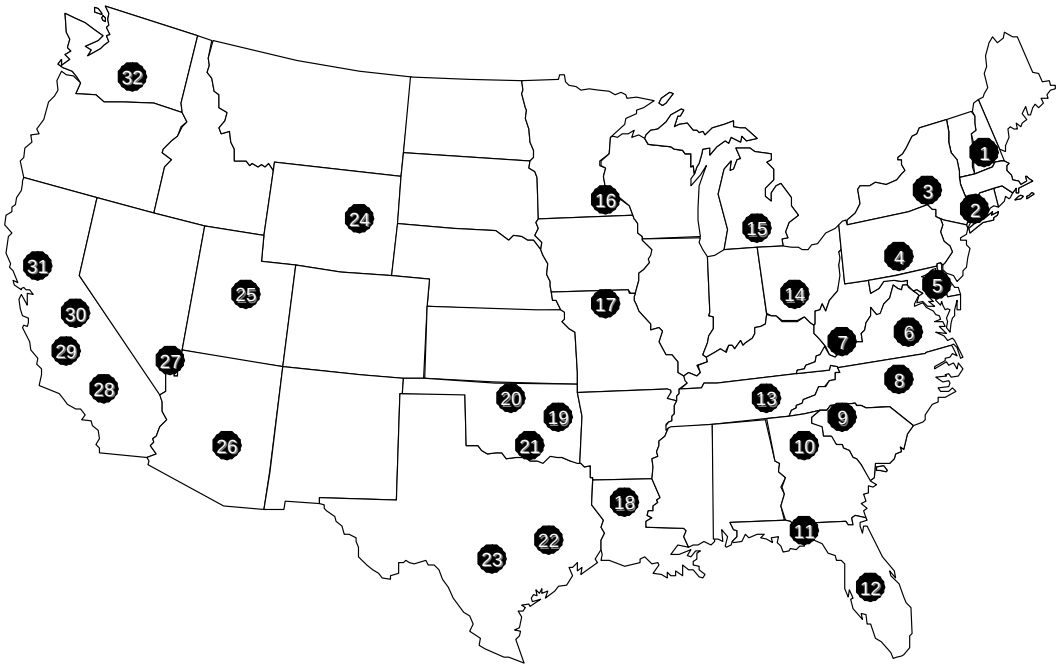
TABLE 13
Potential Locations

Number	*Zip Code*	*City*	*State*	*Number*	*Zip Code*	*City*	*State*
1	03103	Manchester	NH	17	63501	Kirksville	MO
2	06902	Stamford	CT	18	71203	Monroe	LA
3	12777	Monticello	NY	+19	74103	Tulsa	OK
*4	17111	Harrisburg	PA	+20	74631	Blackwell	OK
*5	20018	Washington	DC	21	74820	Ada	OK
+6	23909	Farmville	VA	22	77449	Huntsville	TX
+7	24801	Princeton	WV	23	78028	Kerrville	TX
8	27705	Durham	NC	24	82602	Casper	WY
*9	29301	Spartanburg	SC	25	84501	Price	UT
*10	31206	Macon	GA	26	85541	Payson	AZ
11	32301	Tallahassee	FL	+27	89077	Henderson	NV
12	33876	Sebring	FL	*28	92505	Riverside	CA
*13	37228	Nashville	TN	29	93204	Avenal	CA
*14	43215	Columbus	OH	+30	93720	Fresno	CA
15	49224	Albion	MI	31	95691	West Sacramento	CA
*16	55906	Rochester	MN	32	98901	Yakima	WA

* Location included in Expansion Management's list of top logistics metros

+ Location obtained from Gravity Center Analysis

FIGURE 4
Potential Locations



In the end, it was decided to also include the current locations in the potential locations analysis in addition to the 32 new locations listed on Table 13 before. Once again, freight rates were obtained from CzarLite for every combination of the 137 demand locations, 37 supply locations and 9 product classes, that is, 45,621 individual freight rates.

Model Formulations with Set of Potential Locations

The freight rates downloaded from CzarLite were used to define a new mathematical model for Formulation 2 as stated before and it was executed with instructions to minimize the annual freight costs to satisfy all demand in different scenarios, with different values of *a* distribution centers. A summary of the model results for these scenarios is included on Table 14.

At the same time, the model Formulation 2 was further modified to find the optimum solution while specifically taking the target service level of 75% into account. For that purpose the distances between every source-destination combination were calculated and an index λ_{ij} with a value of 1 was associated to every distance equal to or smaller than 600 miles, and an index λ_{ij} with a value of 0 for every distance greater than the same distance. Then a constraint is placed for the sum over *i*, *j* and *k* of the product of the demand levels times their associated indices λ_{ij} times their associated decision variables x_{ijk}, to be greater than or equal to *s* percent level of the total annualized demand, with *s* being equal to 75% in our case. The modified formulation is provided below on Formulation 3.

FORMULATION 3

Minimize $\sum_{i=1}^{137}\sum_{j=1}^{5}\sum_{k=1}^{9} c_{ijk} d_{ik} x_{ijk}$ (12)

Subject to $\sum_{j=1}^{5} x_{ijk} = 1,$ i = 1,…,137; k = 1,…,9 (13)

$-x_{ijk} + y_j >= 0,$ i = 1,…,137; j = 1,…,5; k = 1,…,9 (14)

$\sum_{i=1}^{137}\sum_{j=1}^{5}\sum_{k=1}^{9} \lambda_{ij} d_{ijk} x_{ijk} \geq sD$ (15)

$\sum_{j=1}^{5} y_j = a$ (16)

$x_{ijk} \geq 0$ i = 1,…,137; j = 1,…,5; k = 1,…,9 (17)

$y_j \in \{0,1\}$ j= 1,…,5 (18)

The results for the execution of this model with different values of *a* for the number of distribution centers are summarized on Table 15.

In general, the solutions to the formulation without the 600-mile constraint tend to show a preference for one location in Nashville, TN, and one or two in California and the East Coast. In fact, we know that California is the single most important market for Multiquip, but the solutions call for over 70% of the customer orders being served from distribution centers in Nashville and the East Coast. The main drawback to the solution of the model in these scenarios is the significant reduction in service level, with only the 5-facilities scenario satisfying the 75% minimum requirement.

When the service level constraint is introduced into the formulation, the solution to the scenario with five facilities is identical to that of the previous model without the distance constraint. However there is no solution to the model with only one or two distribution

centers. Therefore we can conclude that the minimum number of distribution facilities for MQ to satisfy its demand with 75% service level constraint is three.

In particular, the scenario with five distribution centers splits the service area of the West Coast into a northern and a southern region, and the East Coast into a southern, a central and a northern section, with Nashville as its main distribution center, covering almost 50% of all demand assigned to it for both models. The solution to distance-constrained scenario with four facilities is almost identical, with the exception that the West Coast is all assigned to a unique distribution facility in southern California. Finally, the constrained scenario with three facilities is interesting because it suggests a location in Tulsa, as opposed to the corresponding unconstrained model which suggested location in Nashville. In both instances of the two-facility scenario the West Coast is still assigned to a location in southern California, and the East Coast is serviced from North Carolina.

TABLE 14
Summary Results of Potential Locations Model without Service Level Constraint

Scenario	Chosen Locations	% of Demand	% Savings	% Service Level
5 DCs	Riverside, CA	16	22	77
	West Sacramento, CA	12		
	Stamford, CT	15		
	Sebring, FL	10		
	Nashville, TN	47		
4 DCs	Riverside, CA	16	18	71
	West Sacramento, CA	12		
	Durham, NC	33		
	Nashville, TN	38		
3 DCs	Riverside, CA	28	13	70
	Durham, NC	33		
	Nashville, TN	38		
2 DCs	Riverside, CA	28	5	53
	Nashville, TN	72		
1 DC	Nashville, TN	100	-49	29

TABLE 15
Summary Results of Potential Locations Model with Service Level Constraint

Scenario	Chosen Locations	% of Demand	% Savings	% Service Level
5 DCs	Riverside, CA	16	22	77
	West Sacramento, CA	12		
	Stamford, CT	15		
	Sebring, FL	10		
	Nashville, TN	47		
4 DCs	Riverside, CA	32	13	76
	Stamford, CT	16		
	Sebring, FL	9		
	Nashville, TN	43		
3 DCs	Riverside, CA	28	6	77
	Durham, NC	49		
	Tulsa, OK	24		
2 DCs	There is no feasible solution			
1 DC	There is no feasible solution			

Having obtained the results summarized on Table 15, it was decided to further increase the amount of information embedded in the modeling efforts. Second to acquisition and outbound freight costs, Multiquip's bill is affected by lease and labor costs. The first of these costs are fixed in nature, but the second are not as the number of people may vary in proportion to sales volume. For the purpose of this project it was decided to handle labor costs as fixed because the number of people required to work at a distribution center does not normally vary, and any requirements for labor additional to the normal demand is covered by working overtime.

Labor rates were obtained from the Bureau of Labor Statistics, which is part of the U.S. Department of Labor. The Bureau's internet portal provides information as recent as 2002 about wages by area and occupation and it further opens it up by state. In our case, the Standard Occupational Classification System (SOC) provides average hourly wages for transportation and material moving occupations, and more specifically for "First-Line Supervisory/Managers of Transportation and Material-Moving Machine and Vehicle Operators" under the SOC code number 53-1031. In the states considered in our modeling efforts as potential locations for new distribution centers, the average hourly

salaries for workers in this category range from $18.68 in Utah to $26.42 in the state of Washington.

Average rental rates for warehousing space are not as readily available as labor rates are. Therefore the acquisition of estimates for this cost driver was made in coordination with a large real estate company that is headquartered in California. They conducted a survey of the areas of our interest to determine general market conditions and average rental rates for each one of the potential locations considered in this study. The results of our work in this area ranged from a minimum of $3.17 per square foot per year in Tennessee to $5.81 in Connecticut.

In order to use the rental and labor costs in a warehouse location model we made some estimates of the square footage and the number of labor hours required by an average distribution center based on the current requirements in Multiquip's existing facilities. The set of fixed costs was included in a modified version of the model shown in Formulation 3 above by including the binary decision variable *y* in the objective function multiplied by its associated rental and labor fixed costs represented by the coefficient *f*. The resulting formulation is shown below and a summary of the results is given on Table 16.

FORMULATION 4

Minimize $$\sum_{j=1}^{5} f_j y_j + \sum_{i=1}^{137}\sum_{j=1}^{5}\sum_{k=1}^{9} c_{ijk} d_{ik} x_{ijk} \qquad (19)$$

Subject to $$\sum_{j=1}^{5} x_{ijk} = 1, \qquad \text{i = 1,…,137; k = 1,…,9} \qquad (20)$$

$$-x_{ijk} + y_j >= 0, \qquad \text{i = 1,…,137; j = 1,…,5; k = 1,…,9} \qquad (21)$$

$$\sum_{i=1}^{137}\sum_{j=1}^{5}\sum_{k=1}^{9} \lambda_{ij} d_{ijk} x_{ijk} \geq sD \qquad (22)$$

$$\sum_{j=1}^{5} y_j = a \qquad (23)$$

$$x_{ijk} \geq 0 \qquad \text{i = 1,…,137; j = 1,…,5; k = 1,…,9} \qquad (24)$$

$$y_j \in \{0,1\} \qquad \text{j= 1,…,5} \qquad (25)$$

TABLE 16
Summary Results of Potential Locations Model with Service Level Constraint and Fixed Costs

Scenario	Chosen Locations	% of Demand	% Freight Cost Savings	% Service Level
5 DCs	Riverside, CA	28	12	78
	Durham, NC	25		
	Sebring, FL	9		
	Nashville, TN	38		
4 DCs	Riverside, CA	28	12	78
	Durham, NC	25		
	Sebring, FL	9		
	Nashville, TN	38		
3 DCs	Riverside, CA	28	6	77
	Durham, NC	49		
	Tulsa, OK	24		
2 DCs	There is no feasible solution			
1 DC	There is no feasible solution			

The results obtained for the fixed-costs scenario are very similar to the non-fixed-costs scenario, except for one thing: the introduction of fixed costs into the formulation shows the sub-optimality of having five distribution centers to supply the company's domestic demand.

The solution to this point comes down to having a minimum of three distribution centers and a maximum of four. In the four-facility scenario one of the distribution centers must be placed in California and it will supply the demand of the West Coast which as mentioned before concentrates about 20% of total demand in California. A second distribution center to supply the demand from the central states should be placed in

Tennessee and the East Coast is split in two sections: the first one is located in Florida and serves only the distribution in that state and the second one remains in North Carolina.

When it comes to the three-facility scenario the configuration changes in two ways: First, the distribution center to supply the demand in the central region shifts to the West, from Tennessee to Oklahoma; and second, the East coast is served by only one section.

Even though there is a six percent differential in freight shipping costs between the two options in favor of the 4-facility scenario, when fixed costs are included the difference between both solutions comes down to three percent. When this small economic benefit is weighed against the logistical complication of operating an additional distribution center practically devoted to supplying the demand of just one state, the scale leans over to the three-distribution center scenario.

Finally, the suggested reconfiguration of Multiquip's distribution network is the three distribution center solution that was mentioned before with annual savings in freight shipping costs of six percent. The map on Figure 5 shows the location of the three distribution centers and their corresponding service areas. It is quite interesting to note the fact that the final suggested configuration turned out to be quite similar to the "rough-cut" solution yielded by the three-gravity center analysis previously noted on Figure 1. Once again the explanation is given by the heavy weight that the states of California, Texas, New York and Florida have due to their high demand levels.

Tables 17 and 18 provide detailed descriptions of the percent outflows from different perspectives. Table 17 shows the distribution of outflows traveling from each distribution center to its destination state. There we can see that by placing the East Coast distribution center in North Carolina we are putting it halfway through the two major demand centers in the zone which are New York and Florida and right on the state

that ranks third in demand, which intuitively makes sense. Similarly, the central zone is heavily weighted in Texas and so its location in the zone is very close to it. The Eastern location from a state standpoint is very straightforward as 60% of the zone's demand is from California.

FIGURE 5
Final Recommended Configuration with Three Distribution Centers

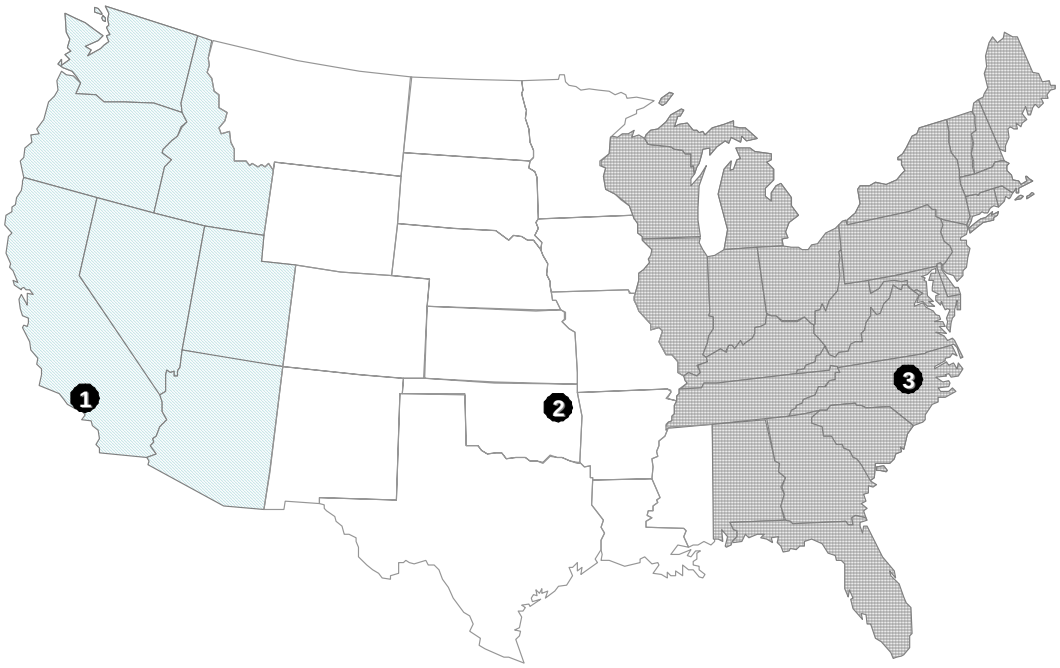


TABLE 17
Distribution of Product Outflows by Source Distribution Center

From NC Total Outflow: 49%				*From OK Total Outflow: 24%*				*From CA Total Outflow: 28%*			
Outflows by destination		*Outflows by Pounds of Product*		*Outflows by destination*		*Outflows by Pounds of Product*		*Outflows by destination*		*Outflows by Pounds of Product*	
To:	*Flow*	*Product*	*Flow*	*To:*	*Flow*	*Product*	*Flow*	*To:*	*Flow*	*Product*	*Flow*
FL	17.5%	50	8.9%	TX	37.1%	50	5.4%	CA	60.5%	50	9.7%
NY	10.6%	60	0.1%	CO	11.4%	60	0.0%	AZ	15.7%	60	0.1%
NC	6.6%	70	16.7%	MO	9.7%	70	22.2%	NV	7.2%	70	19.7%
PA	6.1%	77.5	0.7%	MN	5.6%	77.5	0.1%	UT	6.1%	77.5	0.3%
OH	5.9%	85	18.3%	NM	5.5%	85	20.2%	WA	4.9%	85	25.9%
GA	5.1%	100	9.3%	AR	5.2%	100	11.9%	OR	3.5%	100	4.5%
VA	4.4%	150	3.3%	OK	4.6%	150	3.3%	ID	2.1%	150	2.1%
CT	4.1%	250	42.1%	LA	4.5%	250	35.2%			250	35.5%
TN	4.1%	300	0.7%	IA	3.1%	300	1.6%			300	2.2%
MD	4.0%			MS	2.6%						
NJ	4.0%			KS	2.5%						
IN	3.6%			NE	2.5%						
IL	3.6%			SD	2.5%						
MI	3.5%			MT	1.4%						
AL	3.5%			WY	1.3%						
SC	3.3%			ND	0.5%						
KY	2.7%										
MA	2.2%										
WI	1.6%										
NH	1.5%										
ME	1.1%										
WV	1.0%										
DE	0.0%										
RI	0.0%										

TABLE 18
Distribution of Product Outflows by Product Family

Distribution Center	*Product Family*								
	50	60	70	77.5	85	100	150	250	300
California	32%	43%	29%	18%	34%	15%	20%	25%	47%
North Carolina	53%	47%	43%	74%	43%	53%	54%	53%	25%
Oklahoma	15%	10%	28%	8%	23%	33%	26%	21%	29%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

The distribution center-percent flows in terms of weight are also broken down by product family on Table 17. On average those percentages should also reflect the composition of inventories per facility, if not in quantity of product at least in density or floor space usage, and in general they are very similar for all three distribution centers. We can see that in all three cases products in the 250 family (mixers) will occupy most of the floor space with at least 35% of the total. In second place products in the 70 and the 85 product families which represent generators and trowel accessories and rammers and dewatering pumps respectively, are almost equally represented in all three locations. Together, product families 70, 85 and 250 represent 75 to 80 percent of the total pounds shipped out of any distribution center.

A different perspective to look at the composition of product outflows is shown on Table 18. There we can see the how each of the nine product families are distributed across the three distribution centers. In all but one case the facility in North Carolina ships out most of each product family with at least 40% of the total. The extreme case is that of dewatering pumps accessories in product family 77.5, which is shipped out of North Carolina 74% of the time. The one case where the eastern distribution center does not dominate product outflows is light towers in product family 300. In this case about half of the product outflows are shipped out of the distribution center in California and the other half is almost equally shipped out of the other two facilities.

Sensitivity of Solution

The solution to the model with three distribution centers seems to be very robust, but still, it was decided to analyze the sensitivity of the solution. Due to the large amount of variables and constraints it is not simple to draw conclusions from the output that CPLEX 7.1 © generates with the analysis of sensitivity. However it did allow us to observe general tendencies, and then different scenarios were be evaluated. A summary of the results obtained in this scenario analysis follows:

The suggested location for an eastern distribution center would shift from North Carolina to a new location under either one of two scenarios: if the fixed costs (labor and lease) associated to Durham, North Carolina rose beyond 224%, or if the respective freight shipping costs rose beyond 18%, the new Eastern location would be Harrisburg, Virginia. However either of these scenarios would also change the location of the other two distribution centers from Tulsa, Oklahoma to Macon, Georgia in the central part of the country and from Riverside, California to Henderson, Nevada on the West Coast. The scenario would not be attractive anymore from an outbound transportation cost perspective, as this cost would increase by 5% with respect to the current situation. However the first scenario is practically impossible to occur, and the second is highly unlikely, for as it was mentioned before the shipping freight costs utilized downloaded from CzarLite correspond to cost structures that are representative of the market as opposed to individuals freight carriers, so an 18% differential seems excessive.

The solution to the West Coast location would easily shift the location of its distribution center in Riverside, California to the current location of Carson in that state. It would only take a 0.5% increase in freight shipping cost or a combined 1% increase in labor and lease costs. Therefore it may seem that the model is very sensitive to changes in cost for the eastern distribution center, however if we re-run the model by removing Riverside from the set of potential locations then it follows that Carson becomes the new model solution. In this case it would take a 12.5% increase in freight shipping costs or a combined increase of 53% in labor and lease costs to switch the location of the western location to Fresno, California. It is clear then that either Riverside or Carson is the best location for a distribution facility on the West Coast. However, freight shipping costs from Carson would bring the total savings in this area down from 6% to 5%.

In the central region, placing the distribution center in any of the three Oklahoma locations makes no difference from a cost perspective. In any case, Tulsa should be the

selected location due to its better access to highways, and in general because of its better infrastructure. Therefore the question to ask here would be: In which scenario would the selected location of a distribution center in the central region stop being in the state of Oklahoma? The answer to this question is when either shipping freight costs out of all Oklahoma locations increased beyond 12.5% or when labor and lease costs in combination increased beyond 48%. In either of these two scenarios the selected location for a distribution center in the central region would be Monroe, Louisiana. The savings associated to this scenario would be about four percent of shipping freight costs and the service level would be 75%. Once again it seems quite unlikely that the cost structures in Oklahoma would turn out to be so much higher than our estimates, so the location of a distribution facility in Tulsa, Oklahoma seems quite reasonable.

Size of Distribution Centers

After defining the number and location of distribution centers in the company's distribution network, we faced the challenge of determining the right size for each of the facilities.

In order to estimate the size requirements we decided to utilize inventory turnover ratios for each product family as suggested by Simchi-Levi[3]. An inventory turnover ratio ρ is calculated as the ratio of the total annual flow f_k of each product family k through the distribution center to its corresponding average inventory level i_k, that is: $\rho_k = f_k / i_k$, and therefore $i_k = f_k / \rho_k$. The process to get these estimates is summarized on Table 19.

TABLE 19
Process to Estimate Distribution Center Capacities

Step	*Description*	*Source of Information*
1	Gather inventory turnover ratios ρ_k for each product family k.	Accounting department.
2	Determine annual flows f_{jk} through each of the j distribution centers and for each product family k.	Solution to model formulation 4 in 3-facility scenario.
3	Determine average inventory levels $i_{jk} = f_{jk} / \rho_{jk}$ in each distribution center for each product family.	Steps 1 and 2.
4	Determine average floor space requirement s_k of product family k	Product specifications
5	Multiply s_k by i_{jk} for every k and every j in order to compute total floor space requirements S_{jk} in each distribution center.	Steps 3 and 4
6	Observe stacking levels l_k for product family k	Stacking strategy
7	Compute t_{jk}, the actual amount of square feet required by product family k in distribution center j as follows: $t_{jk} = S_{jk} / l_k$.	Steps 5 and 6
8	Compute T_j, the total space required in distribution center j as follows: $c \sum_j t_{jk}$ for product family k, where c is an adjustment factor to account for the maximum inventory level and any space required for aisle space, material handling equipment, etc.	Step 7

Following this procedure with the actual data, we estimated the following capacities for the company's distribution centers as shown on Table 20. These capacities represent an upper bound on the capacity requirements; however they have a number of assumptions built into the analysis including stability of demand to reflect the historic demand during 2002 and 2003. Even so, these estimates should be very reasonable for the establishment of the new facilities if it was decided to do so.

TABLE 20
Recommended Distribution Center Capacities

Distribution Center	*Estimated Square Feet Required*
North Carolina	51,700
Oklahoma	25,900
California	26,400

FEASIBILITY OF EASTERN DISTRIBUTION CENTER

For some time, the company's decision makers had felt that Multiquip's distribution network could be sized down without compromising its service level standards by identifying the appropriate number and location of its distribution centers. After the results so far discussed on this document were presented the company's upper managers they made the decision to pursue the suggested solution and to redirect the team's efforts towards the execution of their decision.

Due to contractual circumstances in the current distribution centers, the schedule to execute the network's reconfiguration should start by evaluating the feasibility to consolidate the eastern facilities currently located in Georgia and New Jersey into one facility in the state of North Carolina.

The market for contract warehousing in North Carolina had already been assessed in collaboration with the real estate company mentioned before during the industrial market research phase to obtain average lease rates. The conclusion was that vacancy in the state for contract warehousing started to decline during first half of 2003, after it reached its highest level during the last five years towards the end of 2002. At this moment warehousing space availability should not be considered a major constraint, and average asking lease rates in the state for warehouse space are $4.95 per square foot per year. Moreover, thirty eight available facilities were identified in the cities of Durham, Raleigh and Charlotte with asking lease rates ranging from $2.00 to $6.25 per square foot per year.

Contract warehousing is only one of the options available to provide a company with warehousing space. Due to previously satisfactory experience with public warehousing as an alternative to lease a facility, an assessment of the feasibility to partner with a third party logistics provider (3PL) was performed. 3PLs in the state of North Carolina were

researched and contacted to inquire on their space availability and their ability to handle the company's warehousing needs. A total number of 10 3PLs expressed their interest to partner with Multiquip and initial quotes were requested from each one of them. In order to facilitate their task to put together a quote for Multiquip's business a summary of the company's warehousing needs was sent to them. The format sent is included on Appendix D. Naturally, the form was sent to the 3PLs with all the information filled in, but the company's proprietary information is omitted here for obvious reasons. Six of the ten 3PLs that had originally expressed interest on the project provided us with proposals that are feasible from an economic and a business standpoint. Their asking lease rates ranged from $3.00 to $6.60 per square foot per year, and they also provided quotes for labor, throughput and other measures to allow us to make comparisons.

After reviewing the information gathered on contract and public warehousing in North Carolina, the feasibility to locate a consolidated distribution center in the state was confirmed, and upper management decided in favor of the second type of arrangement. Public warehousing is the most attractive option to Multiquip because it does not tie up resources in the acquisition of fixed assets, and also it gives the company the flexibility to terminate the contractual arrangement with the 3PL at any given moment since this type of arrangements are not fixed on a long term basis. Furthermore, previous experience with public warehousing has proven to be very efficient for the handling of Multiquip's warehousing needs.

A 3PL's ability to adequately satisfy the needs of a warehousing partner goes far beyond its availability of space and attractive lease rates. Thus the importance to carefully assess the fit of both companies cannot be overlooked. This is why it has been recommended that managers at Multiquip spend enough time visiting the candidate 3PLs in North Carolina and getting familiar with their facilities, their capabilities and limitations, and most importantly their people to assess the likelihood of a cultural fit.

RECOMMENDATIONS AND CONCLUSIONS

As a result of all the technical and non-technical work and analysis performed on Multiquip's competitive environment and current configuration of its distribution network the following recommendations and conclusions are formulated:

1. Multiquip should have a minimum number of three distribution centers, and a maximum of four. Having less than two facilities makes it impossible for the company to satisfy its minimum service level requirements, and having more than four facilities is not cost effective. Furthermore, a number of three distribution centers should be the best strategy, because the cost increment with respect to having four facilities is only 3% of freight shipping, labor and lease costs, and it makes more sense from a logistics stand point to operate a less complex network of distribution centers.

2. The demand on the East coast should be supplied from a 50,000 square feet distribution center located in North Carolina. On the west coast, the distribution center currently located in Carson, California is adequately located in that city. A third distribution center with storage capacity of 25,000 square feet should be placed in the state of Oklahoma to supply the demand in that section of the country. A graphic description of these locations and the customer zones associated to them is shown on Figure 6. Similarly, a detailed summary of the product flows leaving each distribution center is given on Tables 17 and 18.

3. The location of a distribution facility in North Carolina is feasible in either of these forms of warehousing: contract or public. However preference is expressed for a public warehousing solution for it allows more flexibility on both partnering parties and it has proven to be a successful strategy for Multiquip in the past.

Also the availability of freight carriers in North Carolina was verified and most of the carriers that currently work with Multiquip on the east coast were found to provide their services out of North Carolina.

4. Savings associated with the suggested solution will be in the order of 5% of outbound freight shipping costs, 30% of lease, labor, utilities and other facilty-related costs and savings in inventory holding costs that have not been quantified in this study, but will surely result from the reduction of safety stocks following the consolidation of the distribution centers.

5. The east coast consolidation should be carried out as a first step in the reconfiguration of Multiquip's distribution network. Upon completing this phase the current business situation should be reassessed in order to validate the recommendations listed here.

6. Further analysis should be conducted to determine alternative distribution strategies. For example, the possibility for Multiquip to partner with large customers to hold small inventories in strategic locations could be explored.

7. Even if Multiquip decided not to pursue the consolidation recommendations listed on this document, savings in the order of 9% in outbound shipping costs could be realized by reassigning the demand that is generated in some states to the current distribution centers as indicated on Table 11 and Figure 4.

It is the author's opinion that the results and recommendations made to Multiquip during the course of this project have been useful, and if implemented they could have an impact in the bottom line of the company through the potential cost savings.

It is also important to mention here that this project was a great learning process to the author, not only because of the technical challenges associated with the solution of problem, but also because of the challenges associated with determining and obtaining data and having to work with many different people of different backgrounds, in different locations and even from different organizations. Working on this project gave the author exposure to non-technical problems including communications and business etiquette that are seldom encountered in school projects, and in that sense the objectives of the internship were accomplished as stated in the Doctor of Engineering brochure: "(1) to enable the student to demonstrate and enhance his or her abilities and to apply the knowledge gained from technical training in making a significant contribution of practice concern to the intern's employer, and (2) to enable the student to function in a nonacademic environment and become familiar with the employer's approach to problems in addition to traditional approaches of engineering design or analysis".

REFERENCES

[1] Wilson, Gary, "Facility Trends 2001-2003" *Warehousing Education and Research Council*, (September 2002): pp. 1-12.

[2] Nahmias, Steven, *Production and Operations Analysis, 4th, Ed. ,* McGraw Hill, Boston, Mass. (2001).

[3] Simchi-Levi, David, Kaminsky, Philip and Simchi-Levi, Edith, *Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies*, Irwin/McGraw Hill, Boston, Mass (2000).

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APPENDIX A

QUESTIONNAIRE FOR MANUFACTURERS AND DISTRIBUTORS OF CONSTRUCTION AND POWER EQUIPMENT

1. This questionnaire is for manufacturers and distributors of construction and power equipment. The questionnaire solicits information on your business's distribution organization, delivery commitment, freight policy and after-sale support in the US.

2. The information you provide will be used for an academic project in the Industrial Engineering department at Texas A&M University and it will be treated confidentially. The information gathered will be shared with all the participating companies who would like to have it, without revealing anyone's identities.

3. Please return this questionnaire by e-mail or fax, and direct any questions to:

Sergio A. Burgos
Doctor of Engineering Student, Texas A&M University
E-mail: sergiob@tamu.edu
Phone: (979) 777-1139
Fax: (979) 458-1089

4. Please designate an individual from your organization to verify any unclear answers or receive additional information:

Contact Person	
Company	
Name	
Title	
Address	
City/St/Zip	
Phone	
Fax	
E-mail	

Please keep a copy of this questionnaire in the event I need to contact you for clarification. Thanks.

APPENDIX A

Continued

I. Distribution Organization

A. How many distribution centers does your organization have?	

B. Does your organization use customers as distribution centers (Yes/No)?	

C. Please indicate the location of your organization's distribution centers. Also indicate whether they are company-owned (CO), third party warehouses (3P) or customers used as distribution centers (CUS).

	City	*State*	*CO / 3P / CUS*		*City*	*State*	*CO / 3P / CUS*
1				*26*			
2				*27*			
3				*28*			
4				*29*			
5				*30*			
6				*31*			
7				*32*			
8				*33*			
9				*34*			
10				*35*			
11				*36*			
12				*37*			
13				*38*			
14				*39*			
15				*40*			
16				*41*			
17				*42*			
18				*43*			
19				*44*			
20				*45*			
21				*46*			
22				*47*			
23				*48*			
24				*49*			
25				*50*			

APPENDIX A

Continued

D. Does your organization use common carrier, contract or company-owned transportation? Explain below.

II. Delivery Commitment

A. What is the order processing time for items in stock?	

B. What is your organization's back order policy? Explain below

III. Freight Policy

A. What is your organization's FOB point? Explain below

B. Is freight used as a marketing or sales tool? Explain below

APPENDIX A

Continued

IV. After-Sale Support

A. How is your organization's after-sale service provided? Is it through company-owned service centers, third-party authorized centers or through the dealer network? Explain below.

B. Provide a description of your organization's warranty policy

APPENDIX B

WAREHOUSE LOCATION AND TYPE FROM QUESTIONNAIRES

Multiquip			
	City	*State*	*CO / 3P / CUS*
1	Carson	CA	n/a
2	Fremont	CA	n/a
3	Boise	ID	n/a
4	Peosta	IA	n/a
5	Atlanta	GA	n/a
6	Newark	NJ	n/a
7	Montreal	CAN	n/a
Competitor 1			
	City	*State*	*CO / 3P / CUS*
1	Sacramento	CA	CUS
2	Pleasant Grove	CA	CUS
3	Corona	CA	3P
4	Ft. Worth	TX	3P
5	Columbia	SC	CO
6	Swedesboro	NJ	CO
Competitor 2			
	City	*State*	*CO / 3P / CUS*
1	Olathe	KS	CO
2	Columbia	CO	3P
3	Torrance	CA	CO
4	Cerritos	CA	CO
5	Itasca	IL	CUS
6	North Bay, Ontario	Canada	3P
Competitor 3			
	City	*State*	*CO / 3P / CUS*
1	Riverside	CA	CO
2	Maquoketa	IA	3P
3	Waukesha	WI	CO
Competitor 4			
	City	*State*	*CO / 3P / CUS*
1	Germantown	WI	CO
Competitor 5			
	City	*State*	*CO / 3P / CUS*
1	Rock Hill	SC	CO

APPENDIX C

RESPONSES TO REMAINING QUESTIONS FROM QUESTIONNAIRES

Delivery Commitment

Organization	*Choice of transportation*	*Order processing time*	*Backorder policy*
Competitor 1	Common carrier	24 hours	If equipment is on backorder, the customer is notified and they are the first to get it when more equipment comes in
Competitor 2	UPS for parts, common carrier for parts and small equipment, trucking companies for larger equipment, and company owned transportation for some sales.	Orders placed by 3 p.m. are shipped the same day 96% of the time	We will inform the customer, and we'll tell them when we expect the product to be available. Then we will automatically ship the equipment to them as soon as it is available.
Competitor 3	Contract transportation and common carrier	1 to 6 days	The customer can choose to have the items placed on backorder status, and shipped to him when they're available.
Competitor 4	Company owned and UPS	24 to 24 hours	n/a
Competitor 5	Contract transportation and UPS	Within 12 hours of order	n/a
Competitor 6	Common carrier	48 hours	Ship when available. If over 60 days contact customer to verify order before shipment.

Freight Policy

Organization	*Is Freight used as a marketing tool?*	*FOB point*
Competitor 1	Yes. Freight rates vary with order size, customer type, etc. Freight charges are waived for special promotions.	FOB plant, customer takes ownership when material is shipped.
Competitor 2	Yes, freight varies with order size and other factors.	FOB warehouse. Free freight for full truckload orders
Competitor 3	Yes, freight is normally paid for by the company.	FOB Plant.
Competitor 4	Yes, freight is used to get customers to order up	Freight is negotiated, but it's normally paid by company
Competitor 5	Yes	FOB delivered on large orders
Competitor 6	Yes, freight is sometimes used to close a deal	FOB warehouse

APPENDIX C

Continued

After Sale Support		
Organization	*How is your after-sale support provided?*	*Provide a description of your warranty policy*
Competitor 1	Dealers for some products and field service personnel	Different for all products. Warranty is determined by manufacturer but we have modified it with some product lines as a marketing and sales tool
Competitor 2	After-sale service is provided by two company-owned Service Centers, 75 Authorized Service Centers and some of the dealer network.	Most machines carry a standard 1-year warranty, some machines and engines carry 2 years. Parts standard warranty is 90 days, complete engines carry 1-year warranty.
Competitor 3	Network of company-owned and authorized service centers	30-Day, Warranty. If you're dissatisfied for any reason, just present your proof of purchase for a full refund within 30 days of purchase. One-Year Free Service contract. Full One-Year Warranty. We'll repair any defects due to faulty materials or workmanship at no cost to customer — for one year from the date of purchase
Competitor 4	Authorized service centers	2 and 5 year warranty plans
Competitor 5	Over 800 authorized centers worldwide	5 year transferable warranty
Competitor 6	10 authorized service centers	Three full years on parts and labor - with engines covered for at least two years by manufacturer

APPENDIX D

DATA SUMMARY FOR DISTRIBUTION CENTER QUOTATION

1. Cities/Areas interested in North Carolina: Winston-Salem, Charlotte, Durham, Greensboro, Chapel Hill, Raleigh, etc.

2. What are the products? Construction Equipment

3. Product specifications/ Inventory breakdown
Maximum Number of SKUs
Maximum no. units per pallet
Minimum no. units per pallet
Pallet size used
Racking necessary?
Inventory turns per year
Maximum footage required
Minimum footage required
Time period of requirement
List special characteristics / requirements::

4. Inbound information
Floor loaded
Palletized
Avg. inbounds/day
Avg. inbounds/week
Avg. inbounds/month
Avg. number of cases per inbound truck:

5. Outbound information
Product freight classification
No. of orders per day
Are orders in pallet quantities?
Special characteristics/requirements:

6. Date requirement to begin

APPENDIX E

FINAL OBJECTIVES DOCUMENT

On the following four pages, the final objectives document is reproduced as presented and approved on February 11, 2004.

Final Internship Objectives

By

Sergio A. Burgos-Fuentes

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF ENGINEERING

February 2004

Major Subject: Engineering

(Industrial Engineering)

February 11, 2004

To: Doctor of Engineering Advisory Committee
From: Sergio A. Burgos-Fuentes
Re: Final Internship Objectives

The current document presents a statement of the final objectives for my internship experience for your review and approval. These objectives are outlined, including the accomplishments that will ultimately be reported in the Record of Study. My final internship objectives parallel the objectives stated in my internship proposal without major variations.

The internship project is taking place at Multiquip, Inc., a manufacturer and distributor of light and medium-sized construction equipment. Founded in 1972, Multiquip is currently headquartered in Carson, California, and has five distribution centers distributed across the nation.

The overall final objective will be to determine the optimum design for MQ's distribution network and its logistics practices so as to minimize the company's annual costs of supplying its demand, while maintaining an acceptable service level. More specifically, this objective includes:

- Determination of the optimum number, location, and size of distribution centers.
- Determination of the geographic areas to be served out of each distribution center.

- Determination of the optimum mix of company owned, contract, customer-based and space-only distribution methods.
- Identification of specific facilities in the chosen locations.
- Determination of the optimum number of carriers.
- Determination of the optimum schedule to implement the suggested solution.

Some specific activities associated with the preliminary objectives include:

- Conducting research to determine competitive market requirements.
- Collecting and analyzing MQ data to determine shipping patterns and transit time requirements.
- Working with a Real Estate consulting firm to identify specific facilities in potential sites.
- Researching third party logistics providers for fit and value added potential.
- Reviewing MQ logistics processes and systems for improvement potential.
- Preparing reports, presentations and recommendations to management.

The technical and non-technical aspects of the analysis will be described in detail in the Record of Study and then discussed and defended in the final examination.

Doctor of Engineering Internship Proposal

Final Internship Objectives

By

Sergio Armando Burgos-Fuentes

Approved as to scope and content by:

Dr. Donald R. Smith Chair of Advisory Committee	Dr. Guy L. Curry Member
Dr. Sila Çetinkaya Member	Dr. Lorraine Eden Member
Mr. Ben Albrecht Internship Supervisor	Karen Butler-Purry Coordinator, College of Engineering

February 2004

APPENDIX F

INTERNSHIP SUPERVISOR'S FINAL REPORT

The following is the letter written on behalf of Sergio Burgos by his internship supervisor, Mr. Ben Albrecht.

MULTIQUIP

Evaluation of Internship Project
Evaluation and Design of Multiquip, Inc. Distribution Network

Final Report
May 7, 2004

The purpose of this document is to provide an evaluation of the internship project conducted for Multiquip, Inc., by Mr. Sergio Burgos-Fuentes.

The initial objectives of the project were:

- Determination of the optimum number, location, and size of distribution centers.
- Determination of the optimum mix of company owned, contract, customer-based and space-only distribution methods.
- Determination of the optimum number of carriers.

Through the course of the project Mr. Burgos provided findings and recommendations outside the scope of the original objectives, which expanded the project slightly and provided additional benefit to Multiquip, Inc. (MQ). The following objectives were added to the final scope of the project:

- Determination of the geographic areas to be served out of each distribution center, both current configuration and recommended configuration.
- Identification of specific facilities in the chosen locations.
- Determination of the optimum schedule to implement the suggested solution.

The project required Mr. Burgos to use both academic research techniques, and "world of work" techniques to gather data, test and validate hypotheses, determine direction for further investigation, and to prepare the findings for presentation to corporate management. The project also required interaction with not only the project supervisor, but also several department managers at MQ, as well as several outside suppliers in a variety of industries such as real estate, public warehousing, and transportation management.

In my opinion, Mr. Burgos did a fine job of analyzing our distribution network, based on the results of this project. The objectives were fully satisfied, and Mr. Burgos provided frequent feedback and reports as would be expected in a business environment. The level of communication throughout the project was adequate, without requiring too much direction or input. Mr. Burgos functioned well independently, met all of the project milestones, and provided good research with solid data to support his findings and recommendations.

In the final analysis, the best evaluation of Mr. Burgos' project is that MQ is embarking on a reorganization of our distribution network, based on the results of this project. The findings and recommendations made good business sense, and should provide benefit for years to come.

Ben Albrecht
General Manager, GCE Operations
Multiquip, Inc.
Carson, California

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VITA

Sergio Armando Burgos Fuentes

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Puebla, Pue., Mexico, 72540

Mr. Burgos was born on April 14, 1974 in the city of Puebla, Mexico to Mr. Sergio Armando Burgos-Ochoategui and Mrs. Maria Magdalena Fuentes Guevara. He received his B.S. degree in industrial engineering from the Universidad de las Americas, Puebla, Mexico in 1997 and his M.S. degree in industrial engineering from Texas A&M University in 2001 before entering the Texas A&M University's Doctor of Engineering Program in the Fall of 2001. Mr. Burgos also received a Graduate Business Certificate from Mays Business School at Texas A&M University in 2001. Mr. Burgos specializes in Distribution and Logistics and his previous industry experience includes working as an industrial engineering analyst for Tubos de Acero de Mexico, S.A. from July of 1997 to July of 1999.

The preparer of this Record of Study was Sergio Armando Burgos Fuentes.