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A Simulation Approach for Establishing Limits on Quality Expenditures

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This article proposes a methodology for quantitatively specifying the hidden cost of quality in a dry goods distribution warehouse. Determining this cost is particularly important in manual paced environments since it is difficult to estimate the potential savings of quality improvements. We develop a simulation approach for predicting the manpower requirements as a function of a percentage error function. This method will quantitatively set a maximum expenditure limit for any proposed quality improvement effort. The methodology could also be adapted to any other flexible manual paced operation using autonomous operators.

Keywords: Warehousing, logistics, quality, distribution, manpower

1. Introduction

Quality theories, methodologies, and techniques disseminated throughout the business community pledge to reduce or even eliminate non-value-added activities, reduce variability, lower operating costs, achieve gains in market share, increase customer satisfaction, and provide the path for economic success. Although there are some exceptions to this viewpoint [1, 2, 3], in general this perspective is supported by some prominent quality management and quality control authors and consultants [4–16].

Implementing quality programs requires top management's commitment and the investment of resources, such as capital, manpower, and technology. As these trends continue to unfold, the need for tools to calculate the financial limits for these investments becomes more meaningful. As suggested by Hawley [17], companies need to determine how much they are willing to spend for the positive effects sought from total quality management programs. The challenge is to determine how much capital and resources to invest in quality programs, while being mindful of the uncertainty of the resulting operational improvements prior to implementation of these quality programs.

It is important to recognize that although the cost of quality has been extensively defined and discussed in the literature, accurate estimates of the cost of quality are difficult to achieve. The stochastic nature of the work environment makes experimentation and measurement of the cost of quality a difficult prospect, yet one ideally suited for simulation analysis.

This study is focused on a warehouse/distribution operation. It includes analysis of both the receiving and shipping functions, including the material handling tasks and information support systems necessary to perform the receiving, put-away, picking, replenishment, loading, control, and dispatching of goods (Figure 1).

2. Background

Warehousing has been recognized as a component of the logistics process by several researchers [18–22]. Warehousing also has been acknowledged for its participation in providing the economic benefit of reducing the overall logistical costs [23], and allowing supply to be uncoupled from production.

The cost and necessity of warehousing make it a significant component of business operations. A perspective into just how significant a component is evident when realizing that over $55 billion a year is spent on warehousing and storage, that 2,500,000 workers are employed in the warehousing business, and that overall logistics costs comprise nearly 21% of GNP.

Despite the use of power-driven equipment to assist warehousing personnel in the completion of their material handling tasks, most warehouse functions still entail a high degree of manual labor. The impact of labor costs in warehousing is therefore also significant because the required functions in a conventional warehouse (receiving, put-away, replenishment, picking, and loading products) are labor-intensive tasks. The high level of manual effort in these tasks results in the possibility of a high level of errors. The costs associated with doing things wrong, manual or otherwise, have been identified as a component of the cost of quality by Crosby [5], Juran and Gryna [11], and Feigenbaum [8].

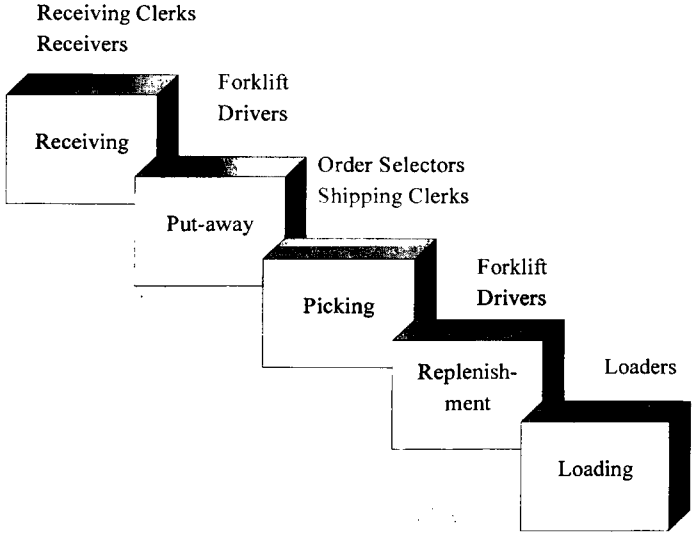

Figure 1. Primary activities and resources involved in the warehousing process

We propose, as has Gunneson [24], that the cost of quality is the difference between the actual operating costs of a company and the operating costs if there were no failures, no mistakes, and no possibility of failures or mistakes. However, defining the cost of quality in this manner does not imply that the business can be run perfectly; it merely emphasizes the potential for improvement that actually exists.

3. Research Objective

The purpose of this research is to create a tool capable of statistically estimating the cost of quality in a conventional (i.e., predominantly manual labor) food warehousing operation. After the previous discussion we propose that the cost of quality be defined as the cost differential between the actual operating costs and the "would-be" costs if non-value-added activities and ill-designed procedures are completely eliminated.

Conventional warehousing was selected for this study because of the labor intensive nature of the business and the fact that conventional distribution centers account for 98% of all food warehouses [25]. The technique we propose can be easily extended to a wide range of other labor-intensive operations (i.e., office environments, credit card processing centers, etc.), providing a quantitative method for determining the maximum expenditure limits to be devoted to quality improvement.

4. Research Methodology

The methods utilized in this research estimate quality costs as being comprised of two components: the hidden costs and the identifiable cost. The hidden costs are appraised by calculating the difference between the "ideal" number of warehousing personnel and the actual number of warehousing personnel being employed. The "ideal" number of resources is determined by estimating the current utilization of warehousing personnel as if non-value-added activities or poorly designed procedures have completely been eliminated from the warehousing operations. The identifiable component is appraised by determining the number and cost of the supplemental personnel being used. Supplemental resources (i.e., those workers performing job functions directly related to correcting identifiable errors) are identified during the data gathering and analysis phase.

In summary, to calculate the total cost of quality, the actual number of resources must be known; the "ideal" number of resources must be estimated; the supplemental personnel must be identified; and the cost of each resource must be available. Simulation is the only tool that will permit us to economically generate the

estimates for the "ideal" number of resources in this stochastic environment.

5. The Simulation Model

This study is based on the development of a simulation model capable of determining the level of manpower required to support warehouse movement. Movement throughput levels change subject to fluctuating percentages of movement error and are therefore ideally suited to simulation analysis. Over 38 conventional warehousing operations were visited and studied so as to determine a representative example operation to be modeled [26].

5.1 System Description—The Warehouse

The dry grocery department of a large conventional distribution center was selected as the experimental setting to develop estimates of the total cost of quality through an appraisal of its two components. The dry grocery department has many inherent advantages: the feasibility of isolating it for analysis, its manageable size, the large quantities of performance data already available, knowledgeable supervisors, flexibility to capture additional data when needed, warehousing personnel's understanding of errors, and a clear, definable process flow.

The simulation was constructed by combining flowcharts of material movement, job requirements, and process flow. Each job profile consists of a brief description of the tasks performed, the names of the resources employed, the equipment used to accomplish the required tasks, some typical performance measures, and a list of errors that could occur during the performance of the warehousing tasks. Identifying warehousing errors is not a very difficult task; however, calculating accurate measures of error frequencies, identifying their effects on operational efficiencies, and eliminating the root cause of errors are complicated tasks.

A sample job profile for forklift drivers assigned to the receiving process is illustrated in Table 1. The job profile illustrates that the drivers are capable of inputting errors into the process by incorrectly locating material or not reporting when material has been damaged. The behavior of the forklift drivers was captured as a resource in the model. A resource attribute contains the information on the likelihood and frequency of error occurrence.

5.1.1 The Receiving Process

The boundaries of the receiving process include all functions directly related to the scheduling and processing of inbound loads. The process flow for the receiving operations is presented in Figures 2 and 3, which illustrate the steps followed during the execution of the administrative and materials handling tasks. We have also included on these figures the distributions used to model these steps. The techniques used for data gathering and distribution fitting are discussed in Section 5.2.

5.1.2 The Shipping Process

The shipping process represents the last contact with the customer prior to the delivery of goods. The process flow for the shipping operation is presented in Figure 4. The functional boundaries of the shipping process include the generation of picking labels and invoices, the replenishment of picking slots to maintain continuity in order selection, the staging of completed orders, the loading of orders into outbound trailers, and the logging of completed trips.

Figure 4 also describes the operational units of measurement for each shipping function, the probability distributions expected to represent the actual tasks and the resources engaged in performing the required functions (i.e., shipping clerks, order selectors, forklift drivers, and loaders).

Supervisors and foremen perform some additional administrative functions essential to the success of the shipping operation. These tasks include the dynamic reallocation of warehousing personnel as needed to meet outbound schedules, invoice and inventory adjustments required when cases are billed but not found, and assignment of warehouse personnel to search for product when the system generates picking labels but the order selectors or the letdown drivers do not find the product.

Table 1. Overview of the receiving process—forklift drivers

Resource	Forklift Driver
Tasks	Puts away incoming pallets on either receiving or picking slots as specified on the pallet labels, performs letdowns as required
Equipment	Power-driven forklift
Performance Measures	Minutes per pallet
Types of Errors	Setting incoming pallet in the wrong location (reserve or pick slot), not reporting damaged merchandise

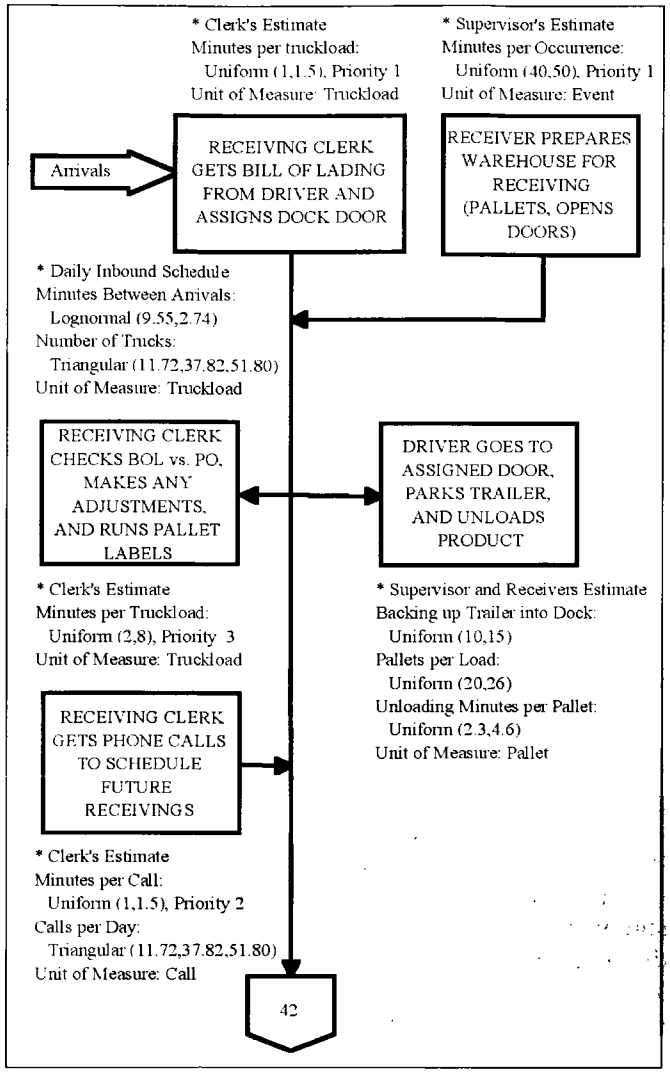

Figure 2. Receiving process flow—Part 1

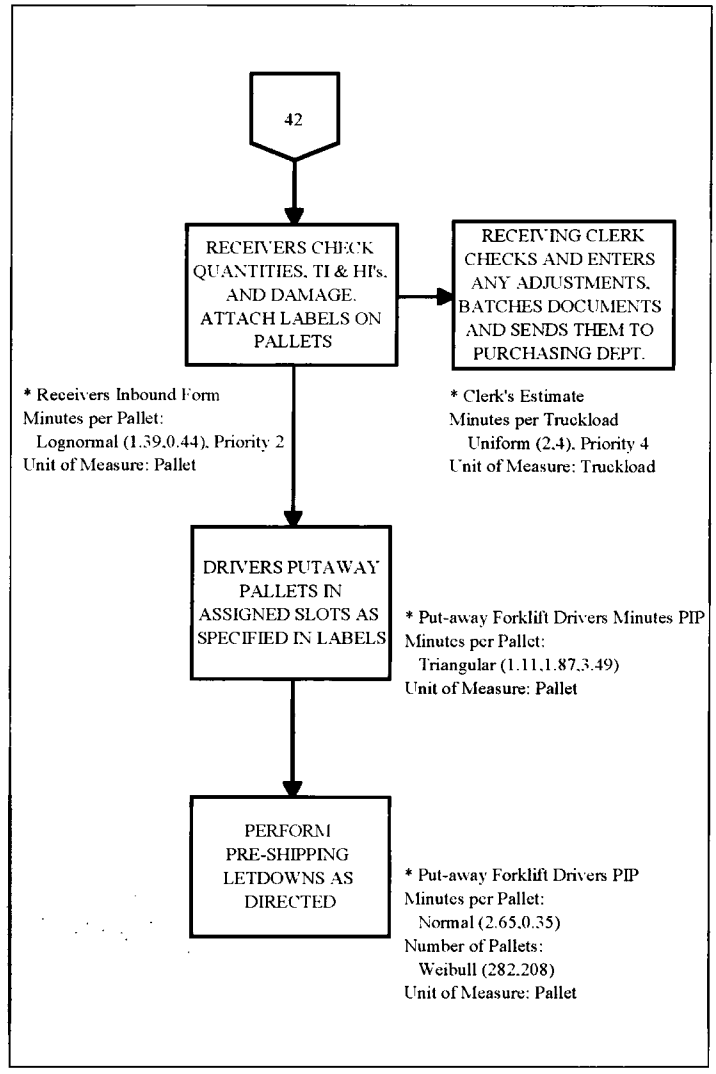

Figure 3. Receiving process flow—Part 2

The model is constructed to replicate actual system operation including errors in pallet placement, recording errors, and data entry errors. Failures are implicitly modeled by creating an abstraction that includes their movement and/or search requirements. In reality, the placement or retrieval of a pallet in error requires a sample from the same time distribution as the one that was performed correctly. The current system does not track errors as they occur, since if this were possible the error would obviously not be made. Instead the errors are modeled as part of the standard movement requirements by increasing the standard workload required of an operator. Historical data records were used to determine the long-term error rates of the operators. These rates were imposed on the model movement requirements and later reduced to determine the impact of a reduction in errors. A facility running at a lower level of error rate will require fewer resources and therefore be used to determine "ideal" resource requirements.

Flowcharts such as these were developed for all of the process steps. They were then used as the basis for the model creation and simulation development.

5.2 *Data Analysis*

Most warehousing operations keep extensive historical records on incoming and outgoing transactions. This information was used when applicable to generate model input. In general, 225-350 days of historical data were condensed into a usable input distribution. Many of the operations were not recorded in historical data records and were therefore gathered using work sampling, time study, and/or survey methods. All of the data gathered using sampling approaches consisted of a minimum of 40 days of observation.

A major difficulty in modeling a large system is the distillation of collected data into usable data. The immense volume of data collected for this research would have made this task nearly impossible without a computerized distribution fitting software package (Bestfit, from Palisade Software). This software converts the input data into density distributions, and provides a first guess of parameters for each of 26 probability distribution types using maximum-likelihood estimators. Next, it performs an optimization process using the Levenberg-Marquardt iterative method.

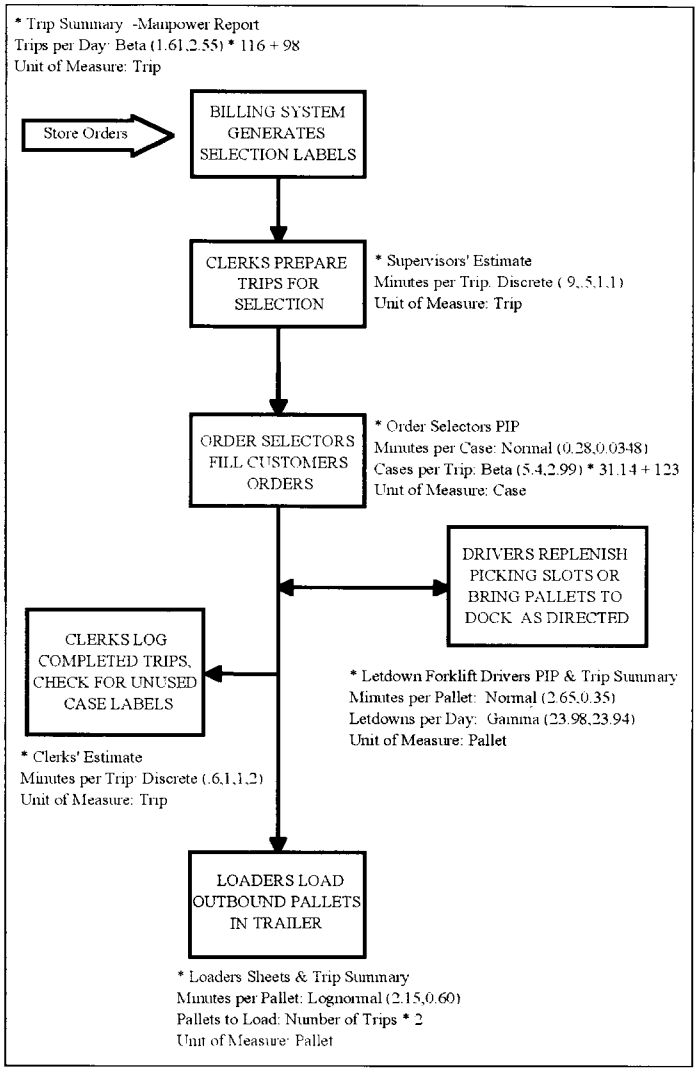

Figure 4. Shipping process flow

As an example of this data fitting process we present the analysis for the dry grocery inbound loads. Data representing 251 receiving days for a total of 8,503 dry grocery loads is represented in Figure 5. As illustrated, the Triangular distribution is a reasonable fit. A graphical presentation of the theoretical probability distribution fit in relation to the input data (inbound loads) is shown in Figure 6.

This process was repeated for all of the process steps defined in the flowcharts. It is estimated that the data analysis step consumed over half of the total modeling effort.

5.3 *Building the Model*

The flowcharts, job profiles, and data gathered allowed for initial model creation. The intent of the simulation model is to provide a means for predicting manpower performance of an existing warehouse system and to then determine changes in manpower requirements as a function of error rate. The assessment of the hidden quality costs in the warehousing process are determined as a function of this error rate.

The programming of the models was accomplished using the SIMAN simulation language from Systems Modeling Corporation [27]. SIMAN's modeling framework as well as its ease of material handling system modeling were major advantages and aided in its selection.

5.4 *Validation/Verification*

The framework utilized to develop, verify, and validate the simulation models follows the simulation method first described by Schlesinger [28]. The three major elements of this framework are to define reality, to abstract to concepts, and to create a computer representation. The reality step is represented by the warehousing process in the grocery department, while the conceptual model is depicted by the receiving and shipping process flows presented in Figures 2, 3, and 4. The computerized model has essentially been constructed from two simulation models—a receiving module and a shipping module, both programmed in the SIMAN simulation language.

The system definition process, including the determination of the domain of intended application, was

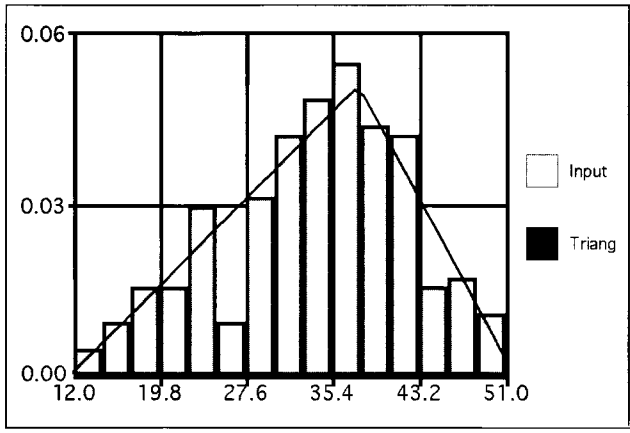

Figure 5. Comparison between the daily inbound dry grocery loads (input data) and the Triangular (11.72, 37.82, 51.80) generated from the fitting process

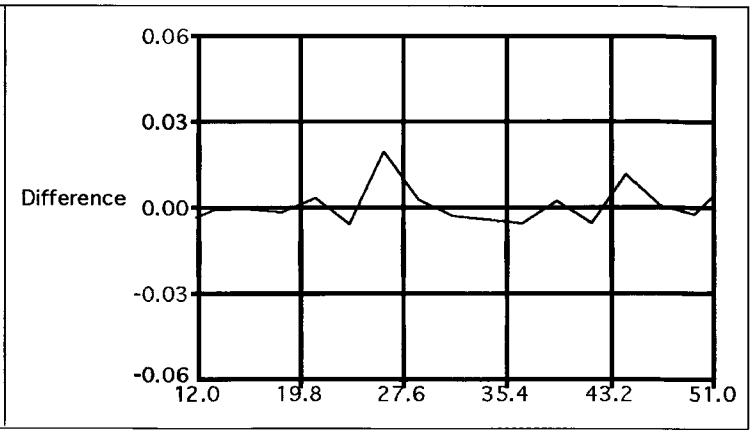

Figure 6. Difference between the inbound loads and the Triangular (11.72, 37.82, 51.80) probability distribution function

completed after close operational analysis of an integrated distribution center, and multiple interviews with distribution center management and systems support personnel. The building of the conceptual model and the data gathering phase were accomplished based upon experience gained through the review of the 38 distribution centers. Model translation and verification were achieved with the assistance of experts in the SIMAN simulation language, the SIMAN's syntax errors and message subsystem, and the use of SIMAN's Interactive Debugger.

The validation of the models was achieved by presenting the simulation results to the warehouse systems coordinators, grocery supervisors, the dry warehouse manager, and warehouse hourly personnel. After short explanations of the format of the simulation results, the simulation-produced numbers were not distinguishable from those obtained via daily operation. Since the result of this modeling effort was the production of a model that closely resembled reality, the staff's inability to distinguish from actual data validated the accuracy of the model's abstraction. This model could now be "improved" by eliminating failure activities and thus used to determine "ideal" staffing requirements.

6. Results

As stated earlier, the cost of quality has two major components—the hidden costs and the identifiable costs. The hidden costs of quality were assessed with the simulation model. The simulation run lengths were fixed at 360 independent replications, or approximately one year of warehousing operations. This number of observations generated a relative precision on resource utilization half-width of less than 2%. Table 2 presents summary simulation results for each resource.

The identifiable costs of quality were obtained during the data gathering process. As analyses were carried out to identify the types and numbers of personnel, it was noted that two resources, classified as stock controllers, were allocated exclusively to "fixing" errors. Their tasks entailed counting and adjusting inventory levels, identifying unreported damage, creating slot locations for misplaced pallets, searching for pallets not found in the assigned slots, and correcting wrongfully measured case dimensions. These resources can therefore be defined as identifiable costs of quality.

6.1 Total Cost of Quality Calculations

The cost of quality (COQ) for the grocery department of the distribution center under study is presented using two different views. One view displays the COQ as a set of estimates (i.e., pessimistic, average, and optimistic); the other view shows COQ as a probabilistic confidence interval. The foundation of the cost of quality calculations is based on the following formula.

$$COQ = \sum_{i=1}^{n} (AR_i - IR_i) * CR_i + \sum_{i=1}^{m} SR_i * CR_i$$

where:

- AR_i = Actual number of resource i used,
- IR_i = deal number of resource i that should be used,
- CR_i = Annual cost of resource i,
- $i \rightarrow n$ = Different resources being analyzed,
- SR_i = Supplemental resources outside the model,
- $i \rightarrow m$ = Different supplemental resources being analyzed.

The actual resources allocated to the grocery department (AR_i) and the supplemental resources (SR_i) were obtained by a combination of research methods, including sampling and detailed observation of the warehouse operations. The hourly cost per resource type (CR_i) was acquired from the payroll records of the distribution center under study. The ideal number of resources (IR_i) for each resource type was derived from the percent resource utilizations generated by the simulation models and presented in Table 2.

The cost of quality estimates (i.e., pessimistic, average, and optimistic) obtained by applying the above COQ mathematical formula are presented in Table 3,

Table 2. Confidence interval estimates of average resource utilization

Identifier	Average Utilization	Standard Deviation	Half-Width	Minimum	Maximum	Number of Observations
Clerks	37.6	8.72	1.19	16.6	56.7	360
Receivers	86.5	2.34	.32	80.3	92.7	360
Forklift (Receiving)	82.9	7.58	1.03	62.3	94.0	360
Shipping Clerks	23.5	.95	.14	20.8	25.7	360
Selectors	96.3	1.03	.14	91.7	98.4	360
Forklift (Shipping)	63.1	12.20	1.66	31.7	84.5	360
Loaders	56.7	4.53	.62	47.8	66.9	360

Table 3. Cost of quality estimates: optimistic, average and pessimistic

Resource Type	Resource Requirements in Hours Per Year				Cost of Quality Differential in Dollars Per Year		
	Actual Resources	Ideal Resources					
		Optimistic	Average	Pessimistic	Optimistic	Average	Pessimistic
Receiving Process:							
Clerks	4,160	1,780	1,839	1,897	$ 28,322	$ 27,620	$ 26,930
Receivers	6,240	5,379	5,398	5,416	17,013	16,638	16,282
Forklift Drivers	16,640	13,628	13,795	13,961	59,517	56,217	52,937
Subtotal	27,040	20,787	21,032	21,274	104,852	100,475	96,149
Shipping Process:							
Clerks	4,160	2,018	2,026	2,034	25,490	25,395	25,299
Selectors	24,960	24,011	24,036	24,086	15,943	15,523	14,683
Forklift Drivers	8,320	5,108	5,250	5,383	63,469	60,663	58,035
Loaders	4,160	2,334	2,359	2,388	36,082	35,588	35,015
Subtotal	41,600	33,471	33,671	33,891	140,984	137,169	133,032
Support Process:							
Stock Controllers	4,160	0	0	0	49,504	49,504	49,504
Totals	72,800	54,258	54,703	55,165	$295,340	$287,148	$278,685
(Hours and Dollars)							

which shows the cost of quality differential in both hours and dollars. This COQ differential is the result of carrying additional resources in the warehouse operation due to the existence of non-value-added activities (i.e., correcting errors, unnecessary delays, excessive material handling).

The creation of probabilistic confidence intervals for the cost of quality in the grocery warehouse operation first began with the calculation of the correlation coefficient matrices for the receiving and shipping processes. This step was necessary to determine the strength of the relationship between the percent resource utilizations within each process. The resulting correlation coefficient matrices calculated for the receiving and shipping processes using the 360 replications generated by the simulation models for each resource are illustrated in Tables 4 and 5.

It can be observed in Tables 4 and 5 that the resource percent utilizations have relatively high correlation coefficients. These results were expected at the outset because of the many interdependent functions that these resources perform within each process.

In order to develop a probabilistic confidence interval for the overall cost of quality (i.e., both receiving and shipping processes combined), the interactions between resources within each process had to be taken into account; consequently the following formula was adopted to calculate the variance for each process.

Table 4. Receiving process: correlation coefficient matrix

	Clerks	Forkdrivers	Receivers
Clerks	1		
Forkdrivers	–0.610	1	
Receivers	–0.690	0.823	1

Table 5. Shipping process: correlation coefficient matrix

	Clerks	Forkdrivers	Order Selectors	Loaders
Clerks	1			
Forkdrivers	–0.467	1		
Order Selectors	0.615	–0.261	1	
Loaders	–0.399	0.289	–0.227	1

$$Var\left(\sum_{i=1}^{n} y_i\right) = \sum_{i=1}^{n} Var\,(y_i) + \sum_{i=1}^{n}\sum_{j=1}^{n} Cov(y_i, y_j)$$

$$i \neq j$$

The formula above was simplified as follows:

$$Var\left(\sum_{i=1}^{n} y_i\right) = \sum_{i=1}^{n} Var\,(y_i) + 2\sum_{i=1}^{n}\sum_{j=1}^{n} Cov(y_i, y_j)$$

$$i \prec j$$

As specified in the mathematical formula, it was necessary to calculate the covariance matrices for each process. The same data sets of 360 replications used to calculate the correlation coefficients were also used to determinate the covariance matrices, as shown in Tables 6 and 7.

The figures presented in the diagonal positions of the covariance matrices are the variances for each percent resource utilization. These variances represent the y_i's presented in the mathematical formula above.

Upon substituting into the formula the variances and covariances, the following variances and standard deviations were obtained, as illustrated in Table 8.

6.2 Total Cost of Quality Confidence Level

Since it was previously ascertained that the receiving and shipping processes were independent, a confidence interval for the cost of quality was estimated by calculating the variance and the standard deviation of both processes combined. The following formula was used to achieve this objective.

$$Var(y_i + y_j) = Var\,(y_i) + Var\,(y_j)$$

The application of the process variances displayed in Table 8 to the previous mathematical formula results in a combined process variance of 297.79, and a standard deviation of 17.25. Since the calculated standard deviation was for the percent resource utilizations, which in turn were directly related to the annual ideal hours required to perform the receiving and shipping functions, the confidence interval developed was for the ideal annual average hours required. The confidence level was selected at 99% or $\alpha = 0.01$. The resulting interval on the ideal annual hours was 54,703 ± 52 hours. The narrow dispersion between the lower and upper limits of the confidence interval is due to the relatively small standard deviation obtained for the combined processes.

Utilizing the ideal average annual hours figures, a weighted average hourly cost for the grocery department under study ($17,904), and the actual operating costs ($1,266,554), a total cost of quality confidence interval was calculated. In this study the COQ interval was $287,148 ± $931.

Table 6. Receiving process: covariance matrix

	Clerks	Forkdrivers	Receivers
Clerks	75.873		
Forkdrivers	–40.255	57.332	
Receivers	–14.032	14.543	5.448

Table 8. Receiving and shipping processes: variance and standard deviation results

	Variance	Standard Deviations
Receiving Process	59.165	7.69
Shipping Process	238.62	15.45

7. Concluding Remarks

Acquiring estimates for the cost of quality in warehousing and other functional business areas is of key importance to management because it provides the opportunity to evaluate the return on investment in quality programs prior to incurring the expense. In view of the fact that this research was conducted in an actual conventional dry grocery warehouse, using operating data from the receiving and shipping processes proved it was feasible to estimate a confidence level for the cost of quality using a simulation approach. The total cost of quality upper confidence interval can be used as an upper limit guideline for management decisions regarding investments to reduce non-value-added activities. It must be recognized that the results obtained from this approach are only estimates of the cost differential between the actual operating costs and an "ideal" warehouse where all non-value-added activities have been eliminated.

The methodology used in this study is not limited to dry grocery warehousing; it also has the potential

Table 7. Shipping process: covariance matrix

	Clerks	Forkdrivers	Order Selectors	Loaders
Clerks	0.986			
Forkdrivers	–5.629	147.477		
Order Selectors	0.629	–3.263	1.061	
Loaders	–1.790	15.863	–1.055	20.420

to be applied to other types of warehousing operating environments. A major benefit of this approach is that during the mapping and flowcharting of the processes, and the data gathering and probability distribution fitting phases of the study, operational problems were revealed and potential solutions were identified. Another potential benefit was the overall increased awareness of the existence of non-value-added activities, the number of errors occurring during the performance of the warehousing functions, and the added personnel resources being dedicated to correcting errors.

It is important to note that the data gathering phase is complex, primarily when attempting to isolate the tasks for only one departmental unit, because of the inherent functional interdependencies and dynamic nature of distribution center operations. Warehousing functions in conventional operations are labor-intensive, relying on cross-trained personnel who are continuously on the move, performing duties wherever they are assigned. The warehouse workers' mobility is high because the motorized pallet jacks and forklifts they work with are fast and reliable.

The simulation approach applied in this study could potentially be carried out to estimate the total cost of quality in other logistics areas, and could also be expanded to measure the total cost of quality for the entire supply chain, given the time and resources necessary for the data gathering process.

8. References

[1] Fisher, T.J. "The Impact of Quality Management of Productivity." *International Journal of Quality and Reliability Management*, Vol. 9, No. 3, pp 44-52, 1992.

[2] Ghosh, A. *Redefining Excellence: The Financial Performance of America's "Best Run" Companies*. Praeger Publishers, New York, 1989.

[3] Howe, R.J., Gaeddert, D., and Howe, M.A. "Does Quality Pay? The Jury Is Out." *Quality On Trial*, pg 155, McGraw-Hill, Bershire, 1993.

[4] Bothe, K.R. *World Class Quality*. AMA Publications Division, New York, 1988.

[5] Crosby, P.B. *Quality Is Free: The Art Of Making Quality Certain*. McGraw-Hill, New York, 1979.

[6] Deming, W.E. "Improvement of Quality and Productivity Through Action by Management." *National Productivity Review*, Vol. 1, No. 1, pp 12-22, 1982.

[7] Deming, W.E. *Out of the Crisis*. MIT Center for Advanced Engineering Study, Cambridge, MA, 1986.

[8] Feigenbaum, A.V. *Total Quality Control*, Third Edition. McGraw-Hill, New York, 1983.

[9] Ishikawa, K. *What Is Total Quality Control?* Prentice-Hall, Englewood Cliffs, NJ, 1985.

[10] Johnson, R.D. and Kleiner, B.H. "Does Higher Quality Mean Higher Cost?" *International Journal of Quality and Reliability Management*, Vol. 10, No. 4, pp 64-80, 1993.

[11] Juran, J.M. and Gryna, F.M., Jr. "Quality Costs." *Quality Planning and Analysis*, Second Edition, pp 12-34, McGraw-Hill, New York, 1980.

[12] Juran, J.M. *Juran on Planning for Quality*. Free Press, New York, 1988.

[13] Kume, H. *Statistical Methods For Quality Improvement*. The Association for Overseas Technical Scholarship, Tokyo, 1985.

[14] Leonard, F.S. and Sasser, W.E. "The Incline of Quality." *Harvard Business Review*, Vol. 60, No. 5, pp 163-171, 1982.

[15] Taguchi, G., Elsayed, E.A. and Hsiang, T.C. *Quality Engineering in Production Systems*. McGraw-Hill, New York, 1989.

[16] Townsend, P.L. and Gebhardt, J.E. *Commit To Quality*. Wiley, New York, 1990.

[17] Hawley, J.K. "Where's the Q in TQM?" *Quality Progress*, Vol. 28, No. 10, pp 63-64, 1995.

[18] Cleveland Consulting Associates. "The State of Quality in Logistics" (survey). Computer Science Corporation, Cleveland, 1991.

[19] Gattorna, J. "What Is Logistics?" *Elective Logistics Management*, Vol. 18, No. 2, pp 4-6, 1988.

[20] Inglis, P.F. "Quality Logistics: A Key Competitive Advantage." *Canadian Business Review*, pp 29-32, Summer 1992.

[21] Stock J.R. and Lambert, D.M. *Strategic Logistics Management*. Irwin, Homewood, 1987.

[23] Bowersox, D.J., Closs, D.J., and Helferich, O.K. "Warehousing and Packaging." *Logistical Management*, Third Edition, pg. 586. Macmillan Publishing, New York, 1986.

[24] Gunneson, A.O. "How to Effectively Implement a Quality Cost System." In *Quality Costs: Ideas and Applications*, 2nd Edition, A.F. Grimm (Ed.), Vol. 1, pg 592, ASQC Quality Press, Milwaukee, WI, 1987.

[25] Lesser, W. and Roller, V. "Explaining Productivity Differences In Grocery Warehouses." In *Productivity and Efficiency in Distributions Systems*, D.A. Gautschi (Ed.), pg 234, North-Holland, New York, 1983.

[26] Mendez, E. "Measuring the Cost of Quality in Food Conventional Warehousing: A Simulation Approach." Doctoral Dissertation, College of Business, Arizona State University, 1996.

[22] Sussams, J.E. "The Impact of Logistics on Retailing and Physical Distribution." *International Journal of Retail and Distribution Management*, Vol. 19, No. 7, pp 4-9, 1991.

[27] Systems Modeling. *The SIMAN IV Reference Guide*. Systems Modeling Corporation, Sewickley, PA, 1989.

[28] Schlesinger, S. "Terminology for Model Credibility." *SIMULATION*, Vol. 32, No. 3, pp 103-104, March 1979.

9. Additional Reading

LaLonde, B.J., Grabner, J.R., Jr., and Robeson, J.F. "Integrated Distribution Systems: Past, Present, and Future." In *The Distribution Handbook*, J.F. Robeson and R. G. House (Eds.), pp 15-27, Free Press, New York, 1985.