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The Journal Editorial Team would like to thank the reviewers for their time and effort. The comments that we received were very constructive and detailed, and help us to continue to produce a consistently top-quality journal. Your participation is very important in the success of providing a distinguished outlet for original valuable articles. Again I would like to thank you all for your assistance in the review process.

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Application of Drum-Buffer-Rope (DBR) in a Computer Assembly Plant

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Abstract

This paper presents an application of the Drum-Buffer-Rope (DBR) in an assembly line of a local computer system manufacturer. DBR production-control and scheduling methodology is gaining increased attention due to its positive impact on rapid response and due-date performance. To conduct this study, a simulation model was developed using ARENA 14 Software. The results indicated that a batch size of 20 units will minimize work-in-process while achieving maximum capacity utilization.

1. Introduction

One of the most crucial indicators of any business is the due-date performance (DDP). In a job shop environment, the work-in-process (WIP) and dispatching play significant roles in the production schedule. Therefore, many studies propose methods for improving DDP. Examples include Baker and Bertrand (1981), Baker (1984), Lu and Kumar (1991), Grabot and Geneste (1994), and Subramaniam et al (2000). To prevent the excessive WIP, the release of materials must be directly synchronized to the rate of the capacity-constrained resource (CCR), which is the weakest link (machine/station) in the system. This mechanism requires a detailed scheduling for CCR supported by a time buffer in front to prevent the bottleneck from starvation. This concept is commonly known as Drum-Buffer-Rope (DBR), which is the application of the Theory of Constraints (TOC). DBR aims at increasing the throughput of the total system. However, any hour lost in the CCR is an hour lost for the entire system (Goldratt & Cox, 1992). According to Demmy and Petrini (1992) DBR has critically benefited the US Air Force for many different work sectors. They provided an example involving the Air Logistics Centers (ALCs) at Ogden where they applied DBR. The results indicated that the throughput increased by 38% and flow days decreased by 75%. Guide and Ghiselli (1995) implemented the DBR in military engine rework at the Alameda Naval Aviation Depot. They reduced the turnaround time (TAT) and WIP by 40% and 50% respectively. Corbett and Csillag (2001) reported significant reductions in inventory and lead time after implementing the DBR at seven companies in Brazil.

Since the 1970s, there have been many production planning and control techniques developed and implemented to help organizations meet market demands. These range from simple manual scheduling procedures to highly computerized systems. Stevenson et al (2005) provided a review of production planning and control systems in make-to-order (MTO) manufacturing environments including Material Requirements Planning, Kanban, and TOC. Gupta and Snyder (2009) provided an extensive comparison between manufacturing resource planning (MRP), just-in-time (JIT), and theory of constraints (TOC). They highlighted similarities and differences between these systems. Olhager

(2013) represented an excellent review of operations planning and control systems and their evolution over the past 50 years.

This study represents an application of the DBR production control and scheduling method at a local computer assembly plant. The paper is organized as follows: The next section (section 2) represents a review of literature pertaining to Drum-Buffer-Rope (DBR) and its buffer management (BM) techniques. Section 3 includes the case study and efforts made to simulate the production line. Section 4 represents the results and related discussion. Conclusions and final remarks are presented in Section 5.

2. Literature Review

Theory of Constraints (TOC) is a management science philosophy developed by Goldratt in the late 1970s that assumes there is always at least one constraint inherent in any system. However, this constraint is considered the weakest link in the process. Goldratt and his colleague Cox (1984) expressed the main steps of TOC in their book, The Goal. They wrote the novel in the context and manner of a day-to-day operational and manufacturing management in order to educate managers and workers about how to resolve industrial and manufacturing problems. Goldratt (1990) adopted five focusing steps to ensure the TOC's effectiveness. Those focusing steps enable managers to invent their own solutions for any problem in the plant. They are as follows:

1. Identify the system's constraints.
2. Decide how to exploit the system's constraints.
3. Subordinate everything else to the above decision.
4. Elevate the system's constraints.
5. If in the previous steps a constraint has been broken, go back to step one, but do not allow inertia to cause a system constraint.

TOC has evolved steadily since it was invented by Goldratt. For example, (Watson et al. 2007; Tulasi and Rao 2012; Rahman, 1998, Cox and Schleier, 2010) and many others articulated reviews and applications of TOC. Its application was also applied in service sectors such as health care and banking. (Motwani et al. 1996a; 1996b; Bramorski et al. 1997; Siha 1999; Demmy and Demmy 1994).

2.1. The Traditional Drum Buffer Rope (DBR)

DBR is an application of TOC known as a production scheduling and controlling technique. It determines the slowest operation of the plant's machines known as the capacity-constrained resource (CCR). After exploiting the CCR, the entire capacity should be subordinated to it. DBR is a Pull-Push system from CCR. The materials are pulled all the way to the CCR machine/station, and then pushed to the end (shipping dock). DBR always assumes a single CCR for the entire plant. In The Goal (1984) followed by The Race (1986), Goldratt introduced the notion of DBR by using the marching scout paradigm. DBR dictates the total system by regulating the most restricted resource to the system. This provides the resource with the least capacity authority to drag any needed materials at the right time to prevent starvation, while simultaneously restricting WIP. Consequently, any period of time lost in that resource significantly hurts the total flow of the entire system (Goldratt &Fox, 1986; Goldratt & Cox, 1992).

The traditional DBR consists of three main parts: (1) Drum; (2) Rope and (3) Buffer. According to Schragenheim and Dettmer (2000) the drum is the slowest machine, as shown in Figure 1 below (the one with 12 units per unit of time). Therefore, this workstation is considered the system's CCR labeled as drum, and it dictates the system's pace. The communication part between the drum and the raw materials release is called the rope. It pulls the materials according to the length of time necessary to pass the materials from the raw materials release spot to the CCR station. Moreover, rope prioritizes the release work and prevents any excessive WIP inventory between machines. The third part is called buffer, which is expressed in time rather than actual parts or products. This buffer is a protection for CCR to prevent assembly and shipping from being starved. The buffer should always be sized properly; otherwise it will lead to an increase in the lead time and operational costs.

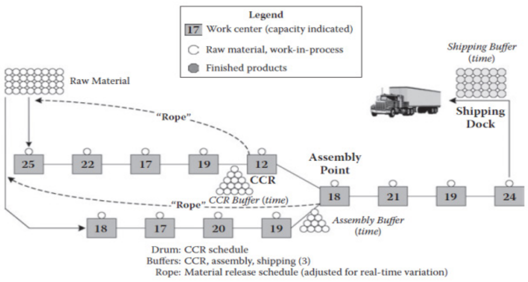

Figure 1. The Drum-Buffer-Rope (Schragenheim et al., 2009)

In order to implement DBR, there are three essential steps that must be utilized for optimal function. First of all, the implementer must determine the master production schedule (MPS) for scheduling the drum that has the weakest capacity in the entire system. Basically, MPS dictates the pace of the system. Second, the proper buffer size should be determined to prevent the CCR starvation. Finally, raw materials should be released according to the previous two steps (Schragenheim & Ronen, 1990).

Schragenheim and Dettmer (2000) mentioned some benefits of traditional DBR. These include fast response, reliable due date performance and effective exploitation of the system's constraint. Corbett and Csillag (2001) indicated some advantages drawn from a study of seven companies that implemented DBR in Brazil. The companies that implemented DBR claimed that the due-date performance (DDP) improved, inventories were decreased, and lead times were reduced. According to Wu and Liu (2008), DBR is finite detailed scheduling. The benefit of DBR is that it protects the (CCR) and improves the throughput of the entire system. Moreover, it prevents the inventory from getting increased, which would increase the lead time as well.

However, Cox and Schleier (2010) pointed out some limitations of DBR. These include the likelihood of changing the bottleneck with changes in the product mix. Early release of materials cause inventory buildup during processing, thereby disrupting the drum. Similarly, increasing the batch size to reduce setup can cause material buildup and may shift the bottleneck. In addition, underutilized capacity of the non-constraints represents waste.

2.2. Buffer Management (BM)

Once the order is released, the only control dominating the flow is the buffer. Buffer Management (BM) is a guiding tool for implementing the DBR. It also prioritizes orders based on its due dates. According to Rahman (1998), there are three types of time buffers in DBR; (1) Constraint buffers, (2) Assembly buffer and (3) Shipping buffer. The time buffer is divided into three different zones (green, yellow, and red), each representing one-third of the total length. The buffer size becomes an issue, and accordingly, many firms hesitate to implement DBR. Buffer is the execution part and considered an assessment tool for the production managers to monitor the system and intervene whenever the process is in danger (Schragenheim and Dettmer, 2000). Since uncertainty and variability are inevitable in any production process, estimating the right size of the time buffer is not an easy task. According to Radovilsky (1998), the majority of publications emphasize the time buffer as proportional to the lead time. Some estimate it as one-fourth, while others identify it as one-half of the total lead time. This estimate approach can be fixed (resized) and evaluated based on the experiences. Radovilsky (1998) developed the first mathematical model to estimate the time buffer of DBR. This model identifies the time buffer assuming a single product flow based on the queuing theory.

3. Case Study

This case study involves the application of DBR at a local computer assembly plant. At the request of the plant manager not to reveal the actual company's name, it will be referred to as X-PC. The company was established in 1997 and is best known for building and selling custom configured gaming systems. The company has since expanded its business to cover servers, personal computers and laptops.

The production line consists of five workstations; each workstation has a different capacity. The arrangement of these workstations is shown in Figure (2). The processing time for each workstation varies based on the unit configuration and order quantity. Production orders involve both standard and customized products. Customized products take longer depending on their configurations. Conversely, standard products are processed in batches of 40 units. Units are typically pushed through the production line in batches all the way to the end based on forecasted demand. Since the company receives orders that require immediate fulfillment, workers tend to accumulate stockpiles as WIP between stations in order to satisfy rushed orders. This study was only focused on standard products.

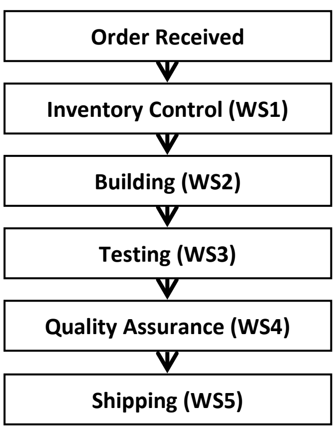

Figure 2. The production process sequence

3.1. Modeling Simulation

Estimates of the processing time in minutes at each workstation were obtained based on the company's records of the most recent 165 orders. As a first step, the data was analyzed for stability using control charts for individual measurements and moving ranges (MR). An example involving the Build Station (WS2) is shown in Figures 3 and 4. The vertical axis on the X-chart in Figure 3 represents recorded times in minutes. In Figure 4, the vertical axis represents values of the moving ranges in minutes based on the difference between two successive records. The charts were constructed using the Statgraphics software.

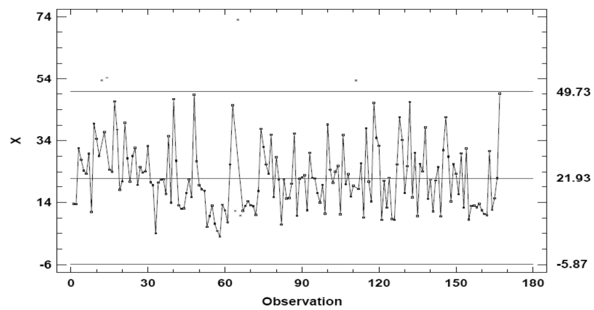

Figure 3. X-chart for build station processing times

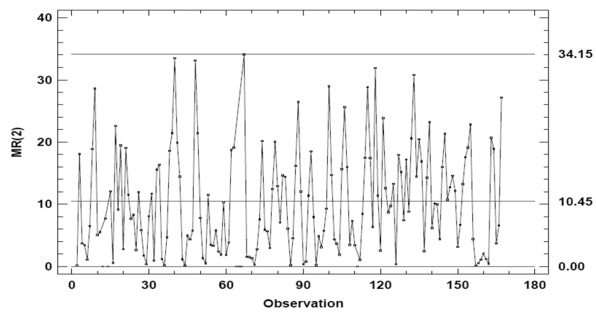

Figure 4. MR-chart for build station processing times with span of 2

With evidence of stability, estimates of the unit processing time (in minutes) were obtained as shown in Table 1. Utilizing the distribution fitting function in Statgraphics, the normal distribution was found to be appropriate for modeling the processing time at WS2 with a p-value of 0.807. Similar procedures were followed in identifying appropriate models and estimating parameters of the processing times (in minutes) for each station. These estimates indicated that the Build Station (WS2) has the longest processing time where most of the WIP was observed. Hence, the Build Station WS2 represents the system's bottleneck (CCR).

Table 1. Estimated parameters of the build station

Average per unit	21.928
Standard deviation	10.3777
Coefficient of variation	47.3264%
Range	46.19

Another indicator used to identify the bottleneck is the utilization ratio. This is the ratio between the actual work time and the total available time. A simulation model was developed using ARENA 14 Software to help estimate this ratio. Figure 6 is a screenshot of one of the validation runs with the Build Station (WS 2) shown to accumulate WIP. Estimated values of the utilization ratio at each work station are shown in Table 2. These represent averages of ten replicated runs. As shown, WS2 appears to have the highest estimated average value.

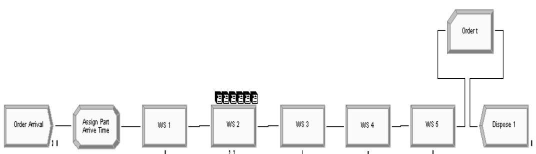

Figure 5. Screenshot of the simulation model

Table 2. Estimated utilizations from simulated runs

Workstation	Utilization
WS1	31.12%
WS2	69.48%
WS3	58.33%
WS4	51.21%
WS5	51.09%

The next step is to develop another simulation model that supports the DBR method with different batch sizes. This DBR simulated model exploited the constraint at the maximum possible utilization in all targeted batch-size scenarios. It made the CCR run at almost 100% in all different scenarios, regardless of the capacity of all non-constrained workstations. From this perspective, different batch sizes were proposed and tested in order to study the performance of the system. The four different batch sizes (scenarios) considered are depicted in Table 3. These four values were of special interest to the X-PC management.

The criterion for evaluating system performance is the lowest average number of products in the system on replicated runs. The simulation model takes into consideration the time buffer and the rope, as shown in Figure 6. To prevent the CCR from starvation, a time buffer was assigned in front of the CCR. This buffer is to hold incoming materials that the rope draws to the floor at the right time. A buffer of four hours (one quarter of the total lead time) was specified to allow sufficient time for materials to flow among workstations and accumulate no more than one unit at full capacity in the CCR.

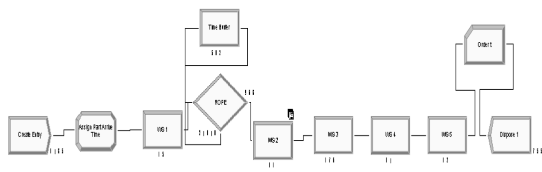

Figure 6. Screenshot of DBR simulated model

Table 3. List of four tested batch sizes

	Batch Size
Scenario 1	15
Scenario 2	20
Scenario 3	25
Scenario 4	40

4. Results and Discussion

Results of the simulated runs for all batch sizes are shown in Table 4. In terms of the estimated utilization at each workstation, it appears that the real constraint (CCR) of the system WS2 in all batches is exploited at its maximum capacity. In the case of batches of 40 units, the inventory control station (WS1) is fully loaded and it reaches the maximum utilization, which indicates development of a dummy bottleneck. This is the result of the hold function added to the simulated model representing the rope action. The entire production process is elevated by making all non-constrained workstations follow the CCR pace.

Table 4. List of the four scenario cases

	Batch Size 15	Batch Size 20	Batch Size 25	Batch Size 40
WS1	48.12%	63.39%	80.56%	100.00%
WS2	99.25%	99.65%	99.74%	99.74%
WS3	93.87%	94.06%	94.18%	94.34%
WS4	70.60%	70.80%	70.88%	70.95%
WS5	70.29%	70.48%	70.55%	70.62%

The results are based on eight replications, each representing one month of operating time. The scenario involving batch size of 40 units showed the highest number of WIP stacked among workstations resulting in system congestion. In addition, this batch size resulted in largest average lead time. Both 15 and 25 batch sizes accumulated moderate queue sizes with high average lead times. The results indicated that a batch size of 20 is the most efficient. It gives the lowest waiting queue size (WIP) in the system, as demonstrated in Figure 7. This allows the lowest queueing in the entire system compared to other batch sizes. Table 5 shows the estimated average WIP at each workstation and number of units in each in the system. The utilization of a batch size of 20 units was recommended to assure the best utilization at current capacity. The company is required to make detailed scheduling for WS2 (CCR) with an allocated buffer of 4 hours. Batches must be expedited by the end of the first two hours.

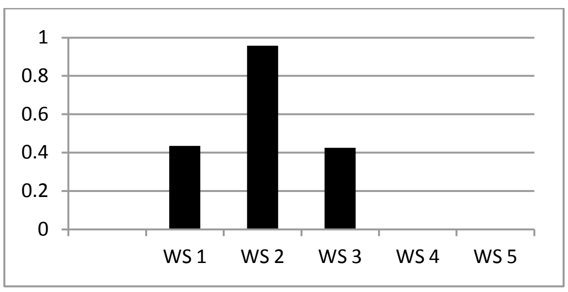

Figure 7. The proportion of maximum average number waiting for batch size of 20 units

Table 5. The average and number of queue in the system

Workstation	Ave. WIP	Queue Size No.
WS1	0.5412	32
WS2	0.9632	1
WS3	0.9291	14
WS4	0.0054	3
WS5	0.003	3

5. Conclusions

The DBR is an effective scheduling methodology to reduce total costs and improve the efficiency of the entire system. However, successful implementation requires a great deal of modeling. In this study, the appropriate batch size was identified based on a simulation experiment. Statistical techniques were utilized to model the system behavior, and compare the results. A batch size of 20 was found to be the most efficient scenario. These authors are in the process of collecting new performance data following the execution of this production control policy.

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Assessing Electric Energy Consumption in North Florida

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ABSTRACT

One of the most important issues facing all states and counties is the availability of reliable, affordable, and clean energy. To be prepared for the future accentuation of this topic, energy providers around the country have developed plans to reduce per capita electricity consumption. For example, Maryland has set a government goal to reduce its energy consumption by 15% by 2015 (Woolf, 2008). In Duval County in North-Eastern Florida, Company X (Co X) dedicates big parts of their PR to help consumers reduce their electricity bills. Reducing electricity consumption not only helps consumers, but also is strategically important for Co X. Avoidance of major investments into a new energy plant helps Co X to keep their energy prices low and remain competitive. In addition to the consumers and Co X, the environment benefits from savings in electrical energy.

This paper examines main economic and environmental factors that drive electrical energy consumption by using Co X's data in a regression analysis. Specifically, unemployment rates and Heating-/Cooling Degrees-Days are identified as the key influential components. From this result, conclusions regarding counter measures to reduce energy consumption are derived. Furthermore, recommendations reaching beyond physical- and into psychological spheres may guide advanced research and activities in the electrical energy sector.

1. BACKGROUND

Modern life without electrical energy is virtually unthinkable. From household necessities (heating, cooling, refrigeration) to daily conveniences (phones, computers, Christmas decorations); everything runs on electric power. Electricity not only plays a significant role in households, but in all market sectors, including most government agencies, industries and agriculture. In addition, electricity generation is a major contributor in the nation's growth. U.S. government energy and job creation policies were also heavily dependent on jobs created in the energy sector to overcome the 2008 recession. By changing its energy policies, the U.S. government created a strong positive trend in job creation with an initial focus on oil and natural gas drilling activities Haggerty (2011). Despite the current plunge of oil prices, the U.S. energy boom will continue (Bastasch, 2014). However, as Figure 1 illustrates, the focus will shift towards renewable energy and economical ways of its consumption.

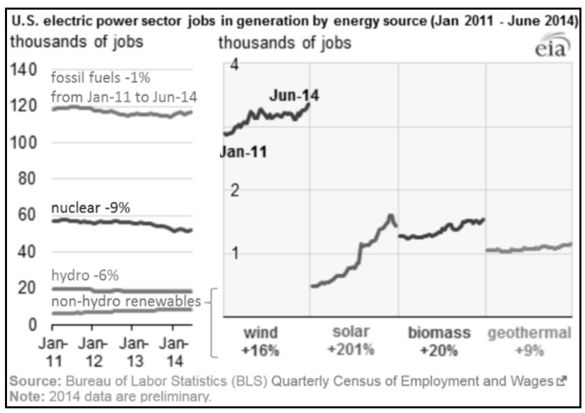

Figure 1: Employment in Energy Sector (McManmon, 2014)

Figure 2 shows that the majority of electrical power is still produced from non-renewable energy sources. The portion of renewable sources is expected to only slightly increase until 2040 and is therefore a cause for constant debate in the government's energy policy discussions

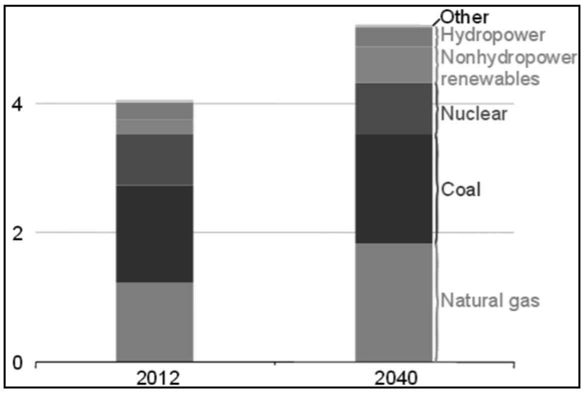

Figure 2: Total U.S. electricity generation by energy source, 2012 and 2040 (billion kW) (U.S. Energy Information Administration, 2014, [13])

Electrical energy is most often generated using turbines. The most common supply of energy to drive the turbines in the U.S. comes from burning coal, gas or oil. In 2013, only 13% of U.S. energy was produced from renewable sources (U.S. Energy Information Administration, 2014 [14]).

Another important factor in shaping energy policy is the government's responsibility for handling the challenges and threats posed by climate change. In a report released by the Yale Project on Climate Change Communication, the authors state that America's concern about global warming is now at its highest level since 2010. As illustrated in Figure 3, 70% (in 2012) of Americans expressed concern about global warming and increasingly perceive global warming as a threat to themselves, their families, and their communities. For the first time since 2008, more than half of Americans believe global warming is caused mostly by human activities (George Mason University, 2012).

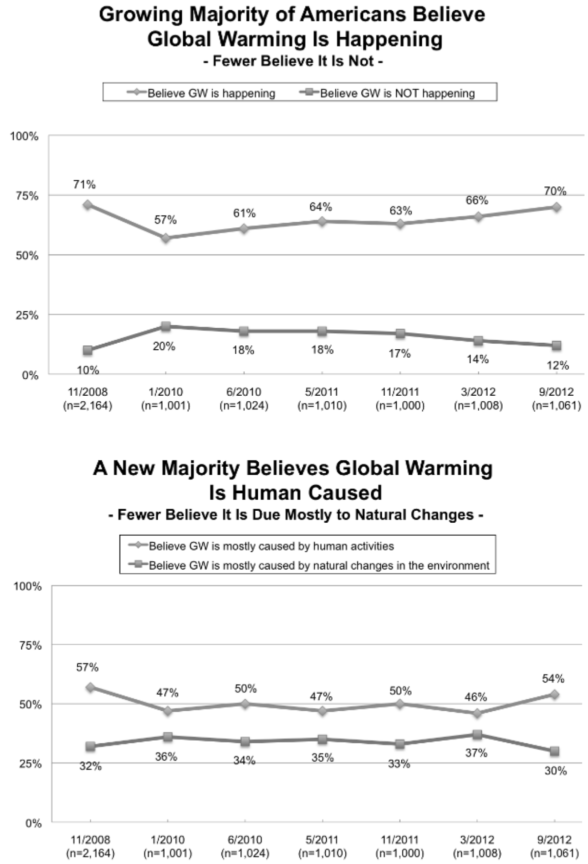

Figure 3: Global Warming Believes (George Mason University, 2012)

Whether U.S. energy sources are non-renewable or renewable, whether the dependency on foreign energy is decreasing (by creating more U.S. energy sector jobs) or increasing, and whether humans cause global warming or not; the U.S. population, as well as the rest of the world, is increasingly dependent on electrical energy. In order to counteract the continuously increasing energy usage (and therefore prices in the near future), ways need to be found to reduce per capita demand for energy in the future. Established methods supporting this goal in households include upgrades to energy efficient appliances and insulation techniques (U.S. Department of Energy, 2012). Additionally, any actions taken to affect simple reductions of consumption would contribute to this objective. Subsequently, energy consumption is analyzed using data from Co X, in order to derive suggestions for an effective future energy policy. Co X serves an estimated 420,000 electric, 305,000 water and 230,000 sewer customers. It owns and operates an electric system with six generating plants with extensive transmission and distribution facilities. Co X's total generating capacity is approximately 3,757 MW (Co X, Data 2004-2011 [4, 5]).

The foundation for the following analysis is a total of ninety-six data records for the period between January 2004 and December 2011.

2. PROBLEM STATEMENT

This research paper is seeking to establish the relationship between electrical energy consumption and various relevant economic and environmental factors. Knowing the most relevant drivers of electrical energy consumption will help Co X focusing on the 'right' energy-savings efforts.

After discussion with key technological personnel at Co X, it was determined that an initial set of potential independent variables should include the following:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \varepsilon$$

Where: Y = Electrical energy consumption (product)

X_1 = Electrical Energy Rate (cost of product)
X_2 = Unemployment Rate
X_3 = Heating Degree-Days (HDD base 65°F)
X_4 = Cooling Degree-Days (CDD base 65°F)
X_5 = Average Temperature
X_6 = Rain Precipitation
X_7 = Consumer Price Index
β_i = Coefficients
ε = Random error

The following paragraphs explain the details of the potential independent variables ($X_1 \dots X_7$), and discuss the expected relationship to electrical energy consumption.

X1 - Cost of Product

The economic law of demand states that, if all other factors remain equal, the higher the price of a good, the less buyers will demand that good.

X_2 - Unemployment Rate

One would expect that a high unemployment rate (Unemployment data, n.d.) would lower demand due to lack of household income. A contrary view states that energy usage may actually increase with a higher unemployment rate as people may be at home using more items that consume electricity.

X_3 and X_4 – HDD and CDD

Heating and cooling degree-days are used to relate how much more or less a consumer might spend on heating or air conditioning.

The concept of heating degree-days relates each day's temperatures to the demand for energy to heat houses and buildings. To calculate the heating degree-days for a particular day, the day's average temperature is determined using the day's high and low temperatures. If the number is above 65°F, there are no heating degrees-days that day. If the number is less than 65, subtract it from 65 to find the number of heating degree-days. For example, if the day's high temperature is 60°F and the low is 40°F, the average temperature is 50°F degrees giving 15 HDD.

Cooling degree-days are similarly calculated. The day's temperature relates to the energy demands of air conditioning. For example, if the day's high is 90°F and the day's low is 70°F, the day's average is 80°F giving 15 CDD (Williams, 2004).

X_5 – Average Temperature

Similarly to HDD and CDD, it is expected, that the average temperature (weather factors, n.d.) has an effect on energy consumption, especially in Florida. With everything else left constant, higher temperatures can cause increased air conditioning usage, resulting in higher electrical energy consumption. Similarly, very cold temperatures cause increased consumption due to heating efforts.

X_6 – Rain Precipitation

It is expected that rain precipitation has an effect on energy consumption. Everything else left constant, higher rain precipitation causes more humidity which leads to an increased use of air conditioning units to dehumidify. Additionally, rainy days cause people to stay inside using more electrical energy.

X_7 – Consumer Price Index

CPI is a measure that examines the weighted average of prices of a basket of consumer goods and services, such as transportation, food and medical costs of living. It is expected that CPI has an inverse relation to energy consumption; the higher the CPI, the lower consumption.

3. HYPOTHESES

The null hypothesis and the alternative hypothesis for the overall model are:

- **Null Hypothesis (H_0) -** There is no relationship between Co X's electric energy consumption and the independent variables identified as Cost of Product, Unemployment Rate, HDD, CDD, Average Temperature, Rain precipitation, or Consumer Price Index. i.e.:

  H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_5 = \beta_6 = \beta_7 = 0$

- **Alternative Hypothesis (H_1) –** A relationship exists between the electric energy consumption in Co X and at least one of the independent variables identified as Cost of Product, Unemployment rate, HDD, CDD, Average Temperature, Rain precipitation, or Consumer Price Index. i.e.:

  H_1: At least one $\beta_j \neq 0$, j = 1…7

4. RESEARCH DESIGN AND METHODOLOGY

Regression equation analysis is used to test the hypothesis. Therefore, data for each of the measures was required. Data was collected for CoX in the time periods of January 2004 to December 2011. The data measures include:

a. Electric consumption data from Jacksonville Electric Authority (Co X)

b. Monthly electric energy sales in kWh

c. Electric energy price in $/kWh

d. Weather factors (National Weather Service):

   - Heating Degree Days (HDD) base 65, against average daily temperature

   - Cooling Degree Days (CDD) base 65, against average daily temperature

   - Precipitation (in 0.1 mm increments)

   - Average temperature

e. Data from the US Bureau of Labor Statistics:

   - Unemployment Rate, Duval County

   - CPI for the U.S. South region

To determine the relationship between the seven independent variables and the dependent variable, a multiple regression analysis with a significance level of $\alpha = 0.05$ (5%) was conducted.

5. ANALYTIC MODEL

Stepwise regression was used to arrive at the best model. Initially, a model was employed that contained all *seven independent variables* and the dependent variable; energy consumption. This model contained all available candidates as predictors, and then was simplified by discarding candidates that do not contribute to explaining the variability in the dependent variable (Burrill, 1993).

A multicollinearity test indicated that *average temperature* in combination with *Heating and Cooling degree-days (HDD, CDD)* may be a problem (see Appendix A: Multicollinearity: Average Temperature). A correlation test was then conducted on all three suspicious variables. Based on these tests, it was concluded that *average temperature* was highly correlated to *HDD and CDD* (see Appendix B: Correlations: Average Temperature). Therefore, it was decided to remove *average temperature* from the set of independent variables.

A second multicollinearity test (see Appendix C: Multicollinearity: Consumer Price Index) was employed in conjunction with a correlation test (see Appendix D: Correlations: Consumer Price Index). This revealed a high correlation between *Consumer Price Index* and *Electricity Price*. Therefore, it was decided to remove *CPI* from the dataset of independent variables.

The next step was to examine the remaining five independent variables and their test statistics. For each of the variables, we defined the null and alternative hypothesis accordingly and, stated the significance level of 5% used earlier in the paper as well. The test statistics for our remaining independent variables from Minitab is shown below:

Regression Analysis: First Model

The resulting regression equation is:

Electricity Usage = 789872 + 1218 Electricity Price + 678 HDDBase65 + 1130 CDDBase65 - 198 Total Rainfall - 19018 UnempRate

Predict	Coeff	SE Coeff	T	P	VIF
Constant	789872	3715	21.3	0.0	
Elec Price	1218.0	382.7	3.18	0.002	3.17
HDD	678.1	49.58	13.68	0.0	2.55
CDD	1130.09	40.07	28.2	0.0	2.59
Rainfall	-197.9	188.8	-1.05	0.297	1.11
UnRate	-19018	2850	-6.67	0.0	3.42

S = 46447.8 R-Sq = 91.6% R-Sq(adj) = 91.2%

If the p value for a predictor variable is less than the stated level of significance (.05), the variable is significant causing a rejection of the null hypothesis. For the conducted regression, p-values were close to zero for most predictor variables. It was decided that the only variable that was not significant was *Rainfall*. It was then determined that *Rainfall* should be eliminated from the model. The final regression model now consists of following four remaining independent variables *Electricity Price*, *HDD, CDD*, and *Unemployment Rate* for the dependent variable electricity consumption.

Regression Analysis: Final Model

The modified regression equation is:

ElectricityUsage = 789580 + 1253 Electricity Price + 671 HDDBase65 + 1125 CDDBase65 - 19640 UnempRate

Predict	Coeff	SE Coeff	T	P	VIF
Constant	789580	37173	21.2	0.0	
Elec Price	1253.1	381.4	3.29	0.001	3.15
HDD	671.36	49.19	13.65	0.0	2.51
CDD	1125.28	39.83	28.25	0.0	2.55
UnRate	-19640	2789	-7.04	0.0	3.27

S = 46472.8 R-Sq = 91.5% R-Sq(adj) = 91.2%

Source	DF	SS	MS	F	P
Regress	4	2.12E+12	5.30E+11	246	0.0
Resid Err	91	1.97E+11	2.16E+9		
Total	95	2.32E+12			

Source	DF	Seq SS
Electricity Price	1	32523315124
HDD Base65	1	3.64143E+11
CDD Base 65	1	1.61845E+12
Unempl. Rate	1	1.07090E+11

6. RESULTS

Overall Model

The regression analysis above also shows the regression equation with all independent variables as being significant (p-values < 0.05) and not having correlation problems (VIF-value <5.0). Since all p-values are less than the stated level of significance (0.05), the null hypothesis for *Electricity Price, HDD, CDD*, and *Unemployment Rate* was rejected.

The following F-test bases on the previously stated hypothesis for the model:

H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_5 = \beta_6 = \beta_7 = 0$
H_1: At least one $\beta_j \neq 0$, j = 1…7

From Minitab, the following results are noted:

$F_{stat} = 245.66$ *and* $p = 0.0$

From the F-table, the following values are noted:

$F_{critial}\ (4; 91) = 2.45$
$|F_{stat}| > F_{critical}$ ➔ *model is acceptable*

Therefore, the null hypothesis is thereby rejected at the significance level α = 0.05, because 245.66 > 2.45 and the p-value = 0.000 < 0.05.

Additionally, the multiple R-Sq value needs to be highlighted. Ninety-one plus percent (91+%) is an extremely high result and shows that even though it consists of only four variables, the model is very thorough.

Interpreting the Coefficients

Electricity Price

If everything is kept constant, an increase of the Electricity Price of $1 appears to increase monthly electricity consumption by 1253kWh. This is a marginal effect which will need to be investigated further in the analysis.

Heating Degree Days (HDD)

If everything is kept constant, a one day HDD increase corresponds with a 671 kWh increase in electrical consumption. This is plausible and explains that people in the county will use their electric heating system more on colder days.

Cooling Degree Days (CDD)

If everything is kept constant, a one day CDD increase corresponds with a 1125kwh increase in electrical consumption. Similar to above, people in the county will use their air conditioners more on warmer days.

Unemployment Rate

If everything is kept constant, an increase of one percent in the unemployment rate will decrease the electricity consumption by 19640kWh. The more unemployed, the lower the electricity consumption is in the county. People will more stringently monitor their monetary expenses and some Floridians will spend the day outside instead of cooling their house.

7. DISCUSSION

Based on the statistical results, the main drivers for electricity consumption in Duval County appear to be *Heating Degree-Days, Cooling Degree-Days*, and *Unemployment.*

It should also be noted that the consumption for Cooling Degrees-Days was almost double as for Heating Degrees-Days which can be explained by the geographical location of Co X and source of the sample values. In general, heating and cooling account for about 56% of the energy use in a typical U.S. home, making it the largest energy expense for most (U.S. Department of Energy, 2013). With this fact and the results of this research, it seems likely that the reason for the strong correlation between energy consumption and especially Cooling Degree-Days is the use of air conditioners and other cooling devices. Of secondary importance for Co X and Duval County appears to be

Heating Degree-Days and therefore heating devices in the fall and winter months.

As shown, unemployment plays a big role for the energy market. However, this aspect can hardly be influenced directly, neither by energy companies, nor by energy consumers.

It was noted earlier that the effect of *Electricity Prices* needs to be analyzed further. In this research, the effect of increased electricity prices did not translate into decreased usage by consumers. In fact the price for electricity continuously increased during the study period along with consumption. The relationship between electricity prices and consumption may be mostly shaped by supplier power within an oligopoly. Additionally, industrial and economic factors exert strong influence besides private household consumption. In general, the low influence of price changes on consumption might also indicate that energy prices in Florida (and the U.S.) are still on such a low level that consumers do not consider exceptional saving efforts.

It is evident, that the energy efficiency of households (and also industries) and possibly more the consumption behavior of users offer a large potential to decrease electricity demand. More efficient heating and cooling appears to be a prerequisite to future savings for individuals and to reduce electricity supply by providers. In order to determine how much credence can be put into this positive relationship between electricity price and consumption requires further investigation. Appendix E illustrates the results in form of scatter point graphs for each independent variable separately. It should be noted that the scatter plot between electricity price and consumption appears to be the weakest of the four explanatory variables. This needs to be factored into the conclusions that follow.

8. CONCLUSIONS

It is concluded that the four independent variables in the model are strongly related to electricity consumption. Using *Heating Degree-Days, Cooling Degree-Days*, *Unemployment,* and *Electricity Prices* this model allows predicting electricity consumption for Co X and Duval County. Only 8.5% are of the variation in electricity consumption are unexplained by this model or unknown.

The discussion above concerning the main drivers in the model points to the fact that the weakest of the explanatory variables is electricity price. Thus, the main drivers of electricity consumption appear to be the three explanatory variables other than electricity price, namely unemployment, Heating Degree-Days and Cooling Degree-Days.

9. RECOMMENDATIONS

Recommendations derived from this research mainly focus on electric efficiency of households, assuming that most industries already follow a more serious approach on saving energy. With Cooling and Heating Degree-Days as the major drivers for electricity consumption, more attention needs to be directed toward ways to increase the efficiency of cooling or heating devices and also decrease their use. Especially in Florida, air conditioners are used extensively. House and office owners should increase the use of intelligent thermostats and get away from cooling whole buildings instead of specific rooms that are in more immediate need. Furthermore, insulation techniques and alternative energy sources, such as solar panels to help supply air conditioners, need to be considered to reduce energy consumption.

In order for Co X to help consumers reduce their consumption and therefore avoid having to build another power plant, Co X is in the progress of introducing new technologies, such as Smart Meter and Smart Grid Technology. These will help consumers to identify major electricity consuming habits and usage patterns, as well as any cooling devices that must be replaced with newer EnergyStar equipment.

However, while large businesses of the industry have CSR ratings and customer perception as incentives to reduce waste, private households often have dated attitudes toward energy savings. Starting in school, people need to be taught that turning lights and fans off and running the dishwasher only when fully loaded is not just being overly "green", it is a business case. As a foundation for sustainable energy consciousness, many habits of consumers should be changed. Furthermore, society must understand their role in this revolution.

Recommendations for future research in this field correlate to an improvement of the used regression model. The addition of more data points and potential variables could help drawing further conclusions. Suggestions are to include:

- Overall population in the county to help explain consumption in relation to electricity prices
- Energy prices of primary fuel like oil and coal prices that influence the price of electricity
- GDP and buying power indicators as evidence for growth and wealth
- Psychological determinants to consider consumer habits

Especially, the field of consumer behavior, which had not been included in the current research model, should gain attention for future analysis. This factor entails enormous potential for changes in energy consumption.

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11. APPENDICES

APPENDIX A:

Multicollinearity: Average temperature

Minitab lets you display the ‘Variance inflation factor’ (VIF) as part of the regression analysis. A VIF tolerance of 5 or 10 and above indicates a multicollinearity problem (Belsley, Kuh, Welsch, 1980; Greene, 1993).

Regression Analysis: Electricity Usage

The regression equation is:
Electricity Usage = - 2156519 + 840 ElecPrice
+ 43764 AvgTemp + 2123 HDDBase65
- 306 CDDBase65 - 28 TotalRainfall
- 19338 UnempRate + 741 PriceIndex

Predict	Coeff	SE Coeff	T	P	VIF
Constant	-2156519	1083141	-1.99	0.05	
ElecP	840.3	745.8	1.13	0.263	12.785
AvgTemp	43764	16541	2.65	0.01	1443.76
HDD	2123.1	546.6	3.88	0.0	328.613
CDD	-306.0	543.1	-0.56	0.575	504.436
Rainfall	-27.9	193.8	-0.14	0.886	1.242
UnRate	-19338	2779	-6.96	0.0	3.447
PriceIndex	741	1226	0.6	0.547	10.017

S = 45095.3 R-Sq = 92.3% R-Sq(adj) = 91.7%

APPENDIX B:

Correlations: Average Temperature (AvgTemp)

As a second step after the multicollinearity test the correlation test on the identified independent variables AvgTemp, HDDBase65, CDDBase65, follows. In this test 0 means that here is no correlation whereas modulus 1.0 indicates identical data.

Table 1: Correlations: Electricity Price, AvgTemp, HDDBase65, CDDBase65

	Electricity Price	AvgTemp	HDD Base 65°F
AvgTemp	-0.021 0.84		
HDD Base 65°F	0.039 0.703	-0.923 0.000	
CDD Base 65°F	-0.003 0.974	0.950 0.000	-0.759 0.000

The correlation test shows that AvgTemp is highly correlated to HDD and CDD.

APPENDIX C:

Multicollinearity: Consumer Price Index

Similar as to in the test above, CPI and Electricity Price, that both are above the VIF tolerance, were analyzed. A VIF tolerance of 5 or 10 and above indicates a multicollinearity problem.

The regression equation is:
Electricity Usage = 672114 + 771 ElecPrice
+ 683 HDDBase65 + 1127 CDDBase65
- 193 TotalRainfall - 18885 UnempRate
+ 848 PriceIndex

Predict	Coeff	SE Coeff	T	P	VIF
Constant	672114	179625	3.74	0.0	
ElecP	770.6	770.0	1.0	0.32	12.769
HDD	682.63	50.19	13.6	0.0	2.596
CDD	1127.13	40.43	27.88	0.0	2.62
Rainfall	-192.9	189.6	-1.02	0.312	1.113
UnRate	-18885	2866	-6.59	0.0	3.434
PriceIndex	848	1265	0.67	0.504	10.006

APPENDIX D:

Correlations: Consumer Price Index

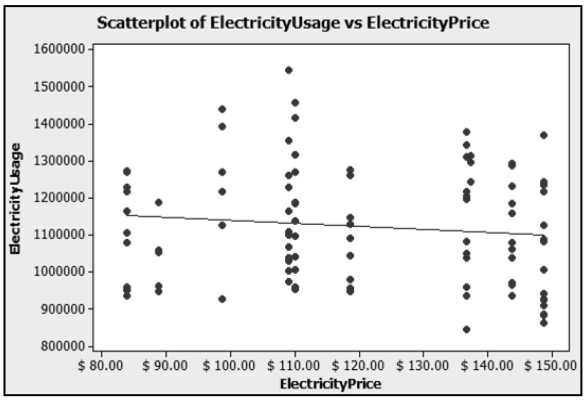
The correlation test between CPI and Electricity Price revealed strong correlation (0.941). Therefore one of the independent variables needed to be dropped.

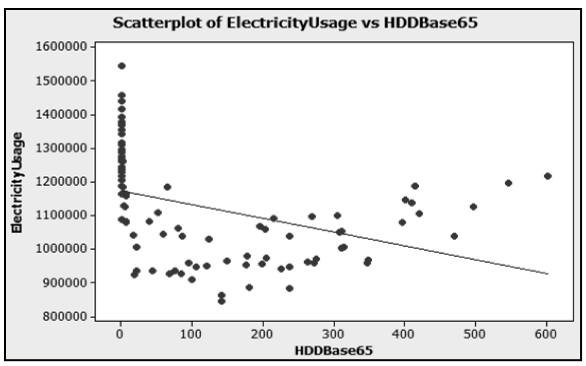
Correlations: Electricity Price, Price Index

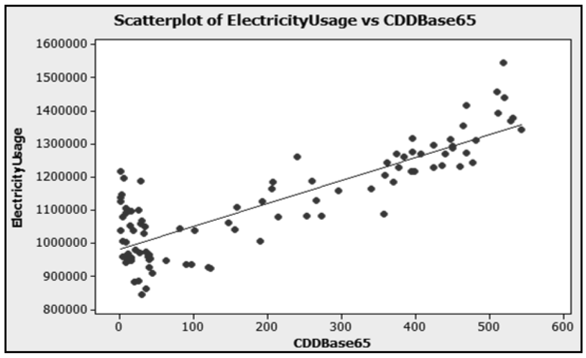
Pearson correlation of Electricity Price and
PriceIndex = 0.941
P-Value = 0.000

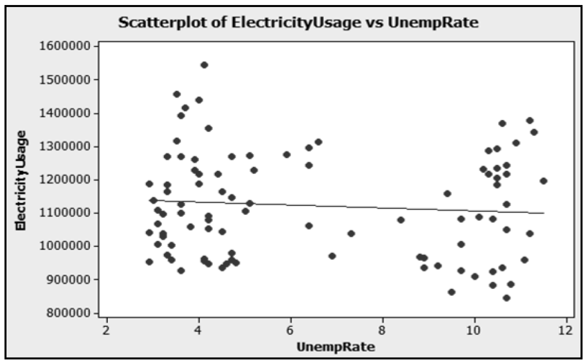
APPENDIX E:

Scatterplots









Performance Evaluation of Technique Introducing Crossing Detection Method for the Traveling Salesman Problem

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Abstract

As presented in this paper, we describe performance evaluation of the following five methods for solving the Traveling Salesman Problem (TSP) based on Self-Organizing Maps (SOM) and an Ant System (AS). The first method is the basic SOM. The second is SOM combined with the Crossing Detection (CD) method. The third is the basic AS. The fourth is applying the CD method to the best solution obtained in AS, designated as "AS + CD (I) method." The fifth is applying the CD method to each artificial ant during the AS search process, designated as "AS + CD (II) method." We conducted numerical experiments using several TSP benchmark problems involving 51–532 cities. Subsequently, we clarified the following: As the number of cities increases, the SOM method exhibits superior performance to that of the AS method. The combination of the CD method with the SOM method and AS method improves the solution accuracy. Regarding the CPU time, the SOM method is faster than the AS method. This trend is distinct in large-scale problems.

1. Introduction

The Traveling Salesman Problem (TSP) [Fischer and Merz, 2005; Lawler, Lenstra, Rinnooy Kan, and Shmoys, 1985; Lin and Kernighan, 1973], an example of a combinatorial optimization problem, is in fact an NP-hard problem that is studied widely as the basic index for comparison of approximate performances of optimization algorithms. Actually, TSP is closely related to problems in many research fields such as vehicle routing problems, scheduling, circuit board design, IC board design, and VLSI design. Development of an algorithm that solves TSP efficiently can make an important contribution to cost reduction and shortening of CPU time in the fields described above.

In this problem, a combinatorial number of routes increases explosively as the number of cities increases. The CPU time eventually increases exponentially. Therefore, probably for a large-scale problem, quality solutions are only slightly obtainable using a simple searching method. In recent years, heuristics such as Genetic Algorithms (GAs) and Simulated Annealing (SA) [Aarts and Korst, 1989; Munakata, 2008] are used frequently for TSP. However, these methods present such disadvantages that it takes a longer time before an optimal solution or suboptimal solution is obtainable. Moreover, the setting of various parameters is extremely difficult.

Self-Organizing Map (SOM) [Kohonen, 2001; Angeniol, Vaubois, and Texier, 1988; Fujimura, Tokutaka, Tanaka, Maeno, and Kishida, 1997], a type of neural network proposed by T. Kohonen [2001], is a two-layer type (without intermediate layer) unsupervised competitive learning model. With SOM for TSP, much simpler algorithms are used than those of other procedures. Consequently, savings of CPU time are expected. Salient features of this procedure are that setting of parameters is easy and that convergence is assured empirically. Nevertheless, we regard prior investigations of the method as insufficient for the optimality of the solution obtained. Moreover, the optimality of the obtained solution is regarded as poor in investigations. We have proposed a hybrid method [Takano, Shirai, and Matsumoto, 2011] that combines a method of improved SOM and an annealing method to demonstrate its effectiveness for a large-scale TSP.

Ant Colony Optimization (ACO) simulates the actions of ants. An Ant System (AS) [Dorigo and Stutzle, 2004; Wang, Zhou, Zhao, and Xia, 2012] is the ACO developed for TSP. In AS, searching is performed while artificial ants move to colonies and thereby generate a circuit of routes. For routes connecting colonies, pheromone intensity values are assigned. Each artificial ant selects a route having a stochastically larger pheromone intensity from the colony of origin, thereby generating a circuit route. The pheromone intensity on each route is enhanced according to the total distance of the generated circuit routes.

The route accuracy obtained by SOM and AS for TSP worsens locally by the intersection of routes. In this paper, we propose a method to improve the accuracy of the solution for TSP introducing the Crossing Detection method (CD method), thereby resolving the problem of intersection. Furthermore, we carry out numerical experiments using this proposed method for the benchmark problems of TSP in an earlier report [TSPLIB] including 51–532 cities to evaluate our methods.

2. Traveling Salesman Problem (TSP)

2.1. Formulation of TSP

Optimization in the TSP is a challenge for a salesperson, who must find a route having the shortest possible distance. The person must start from a certain city, visit each city once, and ultimately return to the city of origin. As a basic index for comparison of various optimization methods, TSP is widely studied. It is formulated as presented below [Fischer and Merz, 2005; Lawler, et al., 1985; Lin and Kernighan, 1973].

$$\min. \quad Z = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij} x_{ij} \qquad (1)$$

$$\text{Subject to} \quad \sum_{j=1}^{n} x_{ij} = 1 \qquad \forall i \in N \qquad (2)$$

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad \forall j \in N \qquad (3)$$

$$\sum_{i \in S}\sum_{j \in N \setminus S} x_{ij} \geq 1 \quad \forall S \subset N \left(S \neq \phi, \quad S \neq N\right) \qquad (4)$$

$$x_{ij} \in \{0,\ 1\} \quad \forall i, \quad j \in N \qquad (5)$$

In these equations, the following variables are used.

n: number of cities
Z: total travel distance
d_{ij}: distance between city i and city j
x_{ij}: 1; passing the route from city i to city j
0; other cases
N: set of quantities of cities = {1, 2, 3, ..., n}
S: subset of N (not empty set and not equivalent to N)

Equation (2) shows that only one route is available from city *i* to other cities. Equation (3) shows that only one route is available to come to city *j*. Equation (4) shows a traveling route to visit all cities only once. Symbol [\] in Equation (4) represents subtraction of the set.

2.2. Conventional Studies of TSP

The geometric TSP posits the existence of a polynomial time approximation scheme for obtaining a solution with accuracy of a factor $1+\varepsilon$ of the optimal solution [Arora, 1998]. Approximation algorithms of TSP fall into the following categories:

(1) Algorithm proposed by Arora [1998]: Solution by Dynamic Programming (DP) based on the recursive division of a plane.
(2) Algorithm proposed by Lin–Kernighan [Lin and Kernighan, 1973]: This is widely regarded as the best heuristic for solving TSP.
(3) The approximate procedure by heuristics such as greedy method, nearest neighbor method, 2-opt [Clarke and Wright, 1964].
(4) Numerous studies using meta-heuristics such as GA and SA [Aarts and Korst, 1989; Munakata, 2008; Wang et al., 2012].
(5) TSP solvers by SOM [Angeniol et al., 1988; Fujimura et al., 1997; Kohonen, 2001; Matsumoto et al., 2011].
(6) TSP solvers using *Elastic Net* [Yi, Yang, Zhang, and Tang, 2009]
(7) TSP solvers using an *artificial immune system* [Zhu, Tang, Dai, and Gao, 2008]

There is no decisive method for TSP in terms of optimality of solution and machine time. We examine here SOM and AS, which are considered recently as effective for solving TST.

3. Solutions used in This Study

3.1. Self-Organizing Map (SOM)

A type of neural network proposed by T. Kohonen [Kohonen, 2001], SOM is a two-layer type (without an intermediate layer) competitive learning model without a teacher. The learning algorithm of SOM learns features of the input data through competitive neighborhood learning without a teacher. Then SOM forms a map in which data having similar features are arranged nearby and other data are arranged at a distant location. This process enables SOM to exhibit high-dimensional information.

Angeniol et al. [1988] applied T. Kohonen's SOM [2001] to TSP for the first time. Angeniol's algorithm is such that starting from one initial node, a node is subsequently added or deleted as necessary so that the node ultimately approaches a city in one-to-one fashion. Figure 1 presents a conceptual diagram of the motion of nodes. Its algorithm is shown as follows.

[Step 1] Locate an initial node (one) at the origin.
[Step 2] Determine the order of presentation of cities randomly.
[Step 3] Obtain the Euclidean distance V_{ij} between city *i* and node *j* from the following equation to determine the most adaptive node *jc* having the smallest V_{ij}.

$$V_{ij} = \sqrt{\left(y_1^i - c_1^j\right)^2 + \left(y_2^i - c_2^j\right)^2} \qquad (6)$$

$$V_{ijc} = \min V_{ij} \qquad (7)$$

(y_1^i, y_2^i): coordinates of city *i*
(c_1^j, c_2^j): coordinates of node *j* on the ring

[Step 4] Bring the node to the city according to the following equation.

$$c_k^j \leftarrow c_k^j + f(G,m)\cdot\left(y_k^i - c_k^j\right) \qquad (8)$$

$$f(G,m) = \frac{1}{\sqrt{2}}\exp\left(-\frac{m^2}{G^2}\right) \qquad (9)$$

m: distance scale in ring-shape (refer to Figure 1)

G: gain parameter

[Step 5] Generate nodes.

[Step 6] Go to [Step 7] when investigation is concluded for all the cities; otherwise go to [Step 2].

[Step 7] Delete nodes.

[Step 8] Update gain parameter G according to equation as follows.

$$G \leftarrow \gamma \cdot G \tag{10}$$

The range of update coefficients γ is $0<\gamma<1$, being given a value close to 1 in general.

[Step 9] When all cities have acquired one node, the investigation is concluded. Otherwise, go to [Step 2].

When a node in [Step 4] is brought to a city, all nodes are moved with the most adaptive node as a standard. The CPU time can be expected to be reduced by moving only δ % of all the nodes with the most adaptive node as a standard.

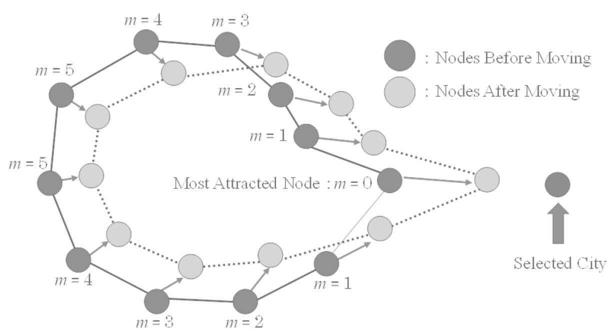


Figure 1. Concept of nodes moving for a selected city in SOM

3.2. Ant System (AS)

Ant Colony Optimization (ACO) is a method of simulating the actions of ants. The Ant System (AS) [Dorigo and Stutzle, 2004] is the mode of ACO developed for the TSP. Searching is performed while artificial ants move among cities to generate circuit routes. For each route connecting two cities, the pheromone intensity value is given, respectively. Each artificial ant selects a route having a stochastically greater pheromone intensity from the city in which the ant stays to move into the next city. They take a round of all cities to generate a circuit route and enhance the pheromone intensity of each route according to the total distance of generated circuit routes. Therein, although pheromones leading to a shorter circuit route are enhanced, pheromones in the circuit route are not as enhanced.

A circuit route to be generated depends on the probability. Because a circuit route generated among numerous candidates cannot be estimated easily, the pheromone intensity provided by a single artificial ant is regarded as including a considerable degree of uncertainty. However, the pheromone intensity generated when multiple artificial ants search multiple circuit routes is likely to be used as a high-quality information source for searching in this problem. In fact, AS constructs algorithms such that collective searching is conducted through interactions among artificial ants while effectively using the pheromone intensity formed by numerous artificial ants. Figure 2 presents a conceptual diagram of search of an artificial ant in AS. As shown in this figure, when an artificial ant goes to the prey field from the nest, the artificial ant tends to select a shorter route in distance as the search progresses. Consequently, the pheromone intensity of a shorter route is enhanced. Such shorter routes are likely to be selected.

An algorithm that applies AS to TSP is shown as follows.

[Step 1] Initialize pheromone τ_{ij} between cities *i* and *j*.

[Step 2] Locate each artificial ant in a starting city.

[Step 3] Repeat selection of cities using the following equation until the circuit route is completed for each artificial ant.

$$P_{ij}^{k}(t)=\begin{cases}\left([\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}]^{\beta}\right)\Big/\left(\sum\limits_{i\in J_i^k}[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}]^{\beta}\right) & \text{if } j\in J_i^k\\ 0 & \text{otherwise}\end{cases} \tag{11}$$

J_i^k is a set of un-visited cities at the time when an artificial ant k is in a city i, η_{ij} is the inverse of the distance between cities i and j, and α and β are parameters that control the influence rate of the pheromone and distance.

[Step 4] Update the pheromone information among cities based on the circuit route and the total travel distance of each artificial ant.

$$\tau_{ij}(t)\leftarrow(1-\rho)\cdot\tau_{ij}(t)+\Delta\tau_{ij}(t) \tag{12}$$

$$\Delta\tau_{ij}(t)=\sum_{k=1}^{h}\begin{cases}1/L^{k}(t) & \text{if } (i,j)\in T^{k}(t)\\ 0 & \text{otherwise}\end{cases} \tag{13}$$

ρ signifies an evaporation coefficient, $\Delta\tau_{ij}$ denotes an increase amount of pheromone between cities i and j, h represents the number of artificial ants, and T^k and L_k respectively stand for the circuit route and the total travel distance of the artificial ant k.

[Step 5] Return to [Step 2] if the maximum repetition number has not been achieved.

[Step 6] Output the best circuit route obtained to conclude.

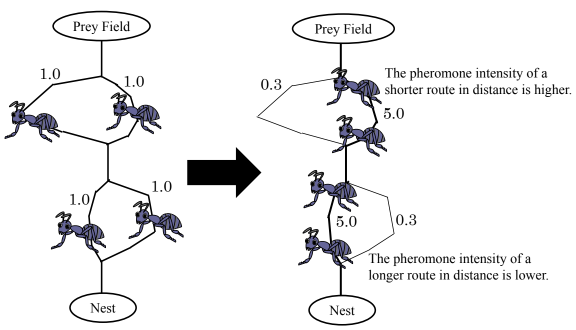


Figure 2. Conceptual diagram of artificial ant search in AS (numbers in figure shows pheromone intensity)

3.3. Introduction of Crossing Detection Method

Accuracy of traveling route determined by SOM and AS, introduced into sections 3.1 and 3.2, for TSP might worsen locally by the intersection of routes. Based on results of this study, we wish to improve the accuracy of solution for TSP incorporating CD and thereby for resolving intersections, if any, by exchange of routes.

In the exchange of routes, one first selects two routes intersecting each other and tries to exchange them. Then one compares the distances of traveling routes before and after the exchange. If one achieves route improvement (distance of traveling route reduced), then one selects the exchanged route as a new traveling route. Figure 3 presents an example of improvement attained by the exchange of routes. Trade of routes (*l, j*) and (*k, l*) for those (*i, k*) and (*j, l*) must shorten the traveling route distance.

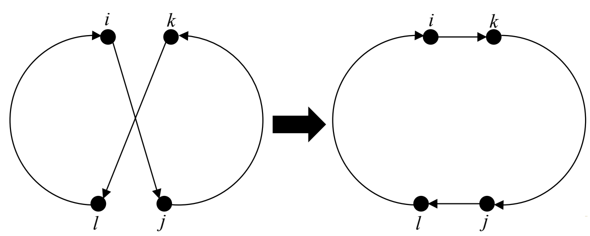


Figure 3. Improvement example of the circuit route by exchange of the route

3.4. Proposed Method

We propose five solution methods and then evaluate their performance using a benchmark test.

(1) SOM Method

This method finds traveling route using SOM introduced in section 3.1.

(2) SOM+CD Method

In this method, one first finds a traveling route by SOM and applies CD to find any intersection. Then one resolves any intersections found to improve the solution accuracy. The algorithm of this method is presented below.

[Step 1] One finds a traveling route by SOM.
[Step 2] Then one applies CD for the route found in [Step 1] to resolve intersections.

(3) AS Method

This method finds the traveling route by AS introduced in section 3.2.

(4) AS+CD (I) Method

In this method, one first finds a best traveling route using AS, similarly with the method explained above and applies CD for that route resolving intersections to improve accuracy of solution. We designate this method as the "AS+CD (I) method." The algorithm of this method is presented below.

[Step 1] One finds a best traveling route by AS.
[Step 2] Then one applies CD for the route found in [Step 1] to resolve intersections.

(5) AS+CD (II) Method

In this method, one applies CD to each traveling route found by artificial ants, [Step 2] to [Step 5] in section 3.2, and resolves the intersections. Then one selects the best traveling route between those of each ant as the final solution. In the AS+CD (I) method, CD is applied only to the final traveling route; although in this AS+CD (II) method, CD is applied to each route of artificial ants before the final route is selected. We designate this method as the "AS+CD (II) method." The algorithm of this method is presented below.

[Step 1] One applies the CD method to each traveling route found by artificial ants, [Step 2] to [Step 5] in section 3.2, and resolves the resultant intersections.
[Step 2] Then one selects the best traveling route between those of each ant found in [Step 1] as the final solution.

4. Numerical Experiments

We conducted parametric numerical experiments of SOM and AS methods for the benchmark problems of TSP in reference [TSPLIB] including 51–532 cities to evaluate our methods described in section 3.4. The PC used for the experiment was equipped with Intel Core i7-2670QM 2.20 GHz and 8 GB memory. We performed 100 trials for each condition.

4.1. Parameter Experiment of the SOM Method

SOM parameters were G=1, 10, 15, 20, 25, and 30, γ=0.9, 0.99, and 0.999 and δ=5%. The average CPU time (s) and percentage error between the average and optimum values (%) are shown in Figures 4, 5, and 6.

Figure 4 presents a comparison of CPU time (s) against γ for G=20. The CPU time seems to increase by around one-order when γ is increased from 0.9 to 0.99 and from 0.99 to 0.999.

Figure 5 depicts a comparison of the accuracy of solution (averages) against γ for G=20. The accuracy seems poor for γ of 0.9; those for γ of 0.99 and 0.999 do not mutually differ very much.

Figure 6 presents a comparison of accuracy of solution (averages) against G for γ=0.99. With increasing G, the CPU time increases slightly, moreover, the accuracy is improved. Accuracies for G of 20, 25, and 30 do not differ greatly.

We applied the approach of two-way analysis of variance done in the design of experiments for SOM parameters. Results revealed some mutual interaction among the parameters.

Although some few dispersion is apparent in the favorable set of parameters, those of *G*=2 and *γ*=0.99 seem better than others in view of the optimality of solutions and the CPU time.

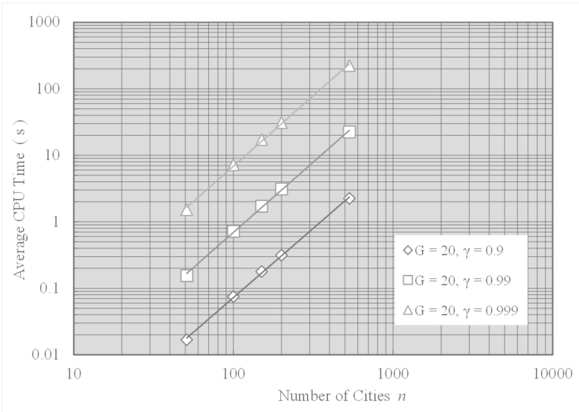


Figure 4. Comparison of the average CPU time for *γ*

Figure 5. Comparison of the solution accuracy (average) for *γ*

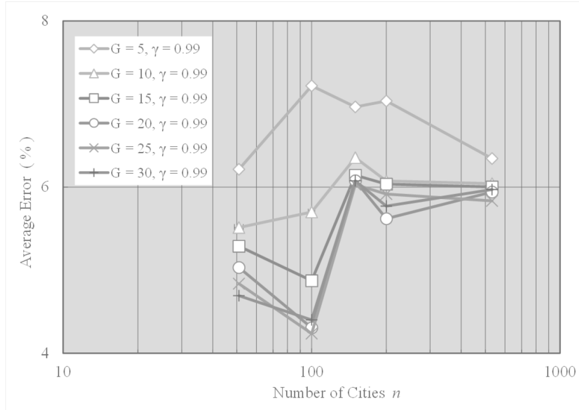


Figure 6. Comparison of the solution accuracy (average) for *G*

4.2. Parameter Experiment of the AS Method

We tested the AS parameters of *α*=1, 3, 5, 7, and 10, *β*=1, 3, 5, 7 and 10, *ρ*=0.1, 0.25 and 0.5, the number of artificial ants =50, τ_{ij}=1 and the number of repetitions =1000. Percentage errors between average and optimum values (%) are presented in Figures 7 and 8.

Figure 7 depicts a comparison of the accuracy of solution (averages) against *β* for *ρ*=0.25 and *α*=1. Although *β*=3 seems good for small-scale problems, larger *β* is preferred with increasing problem scale.

Figure 8 presents a comparison of the solution accuracy (averages) against *α* for *ρ*=0.25 and *β*=3. All in all, *α*=1 is recognized as a good selection.

We also found good performance of *ρ*=0.25 through preliminary experiments. We conducted two-way analysis of variance done in the design of experiments for AS parameters. Results revealed some mutual interaction among them.

Although few dispersions exist in favorable sets of parameters, those of *α*=1, *β*=3, and *ρ*=0.25 are recognized as working well overall. Increasing the solution accuracy for large-scale problems such as 532 cities, demands increased for the numbers of artificial ants and repetition of calculations, although it would require more CPU time.

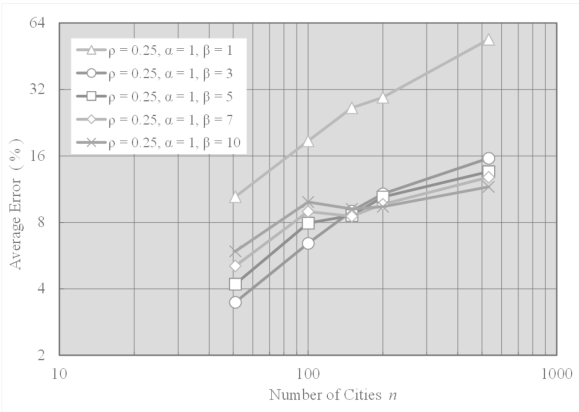


Figure 7. Comparison of the solution accuracy (average) for *β*

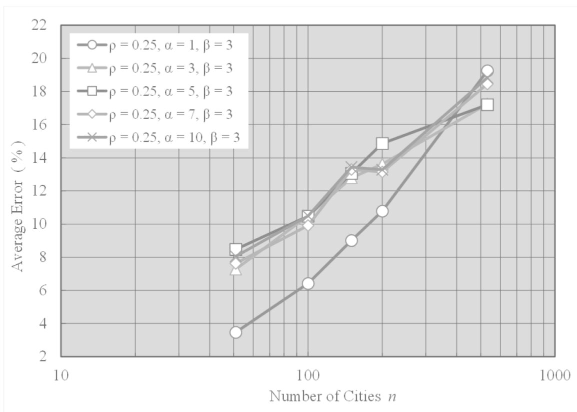


Figure 8. Comparison of the solution accuracy (average) for *α*

4.3. Performance Evaluation of Five Methods

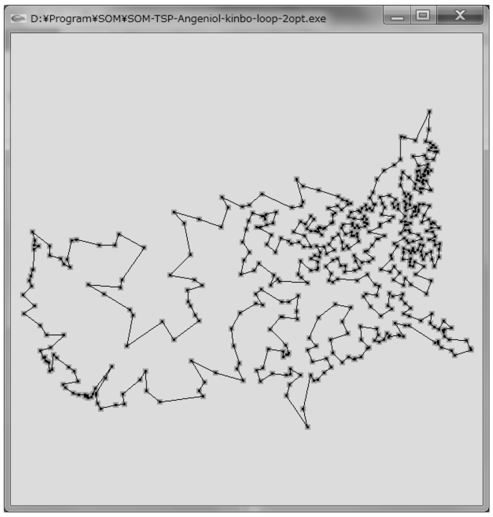
Table 1 presents the best solution, average, standard deviation and CPU time for five methods obtained by experiments described in the preceding section with SOM parameters of (G=20, γ=0.99, and δ=5%) and AS parameters of (number of artificial ants=50, τ_{ij}=1, α=1, β=3, and ρ=0.25). In addition, the AS repetitions were 1000; those in AS+CD(I) and AS+CD(II) were 100. "Best Solution" shows the solution of the best value in 100 trials. "Average" shows the mean of the solution for 100 trials. Ratio between optimum values are presented in Table 1.

Comparison of lone methods (SOM and AS) with methods connected with CD (SOM+CD, AS+CD (I) and AS+CD (II)) shows that methods incorporating CD improve the accuracy of solution without inviting a significant increase of CPU time. CD incorporated into AS reduces the number of repetitions, greatly improves the solution accuracy and cuts down the CPU time.

Among SOM+CD, AS+CD (I) and AS+CD (II) the last provides the best accuracy but requires the most CPU time. For large-scale problems (532 cities or more), SOM+CD apparently provides better performance than AS+CD (I) does. With respect to CPU time, SOM is much better than AS and is suitable for large-scale problems.

Table 1. Result of comparison of five methods

Number of Cities		SOM	SOM+CD	AS	AS+CD (I)	AS+CD (II)
51	Best Solution	1.009	1.007	1.012	1.009	1.000
	Average	1.050	1.036	1.035	1.023	1.001
	Standard Deviation	0.017	0.012	0.012	0.009	0.003
	CPU Time (s)	0.156	0.166	8.741	0.888	1.259
100	Best Solution	1.004	1.003	1.055	1.011	1.000
	Average	1.043	1.028	1.064	1.032	1.000
	Standard Deviation	0.022	0.017	0.008	0.013	0.000
	CPU Time (s)	0.724	0.763	33.320	3.357	7.393
150	Best Solution	1.020	1.013	1.072	1.033	1.008
	Average	1.061	1.049	1.090	1.046	1.011
	Standard Deviation	0.019	0.017	0.009	0.012	0.002
	CPU Time (s)	1.722	1.770	77.748	7.502	23.859
200	Best Solution	1.015	1.014	1.092	1.046	1.017
	Average	1.056	1.046	1.108	1.063	1.022
	Standard Deviation	0.017	0.014	0.010	0.014	0.003
	CPU Time (s)	3.116	3.211	140.321	13.196	54.795
532	Best Solution	1.033	1.026	1.179	1.040	1.024
	Average	1.059	1.047	1.193	1.051	1.028
	Standard Deviation	0.009	0.008	0.005	0.007	0.003
	CPU Time (s)	22.361	23.116	951.915	86.663	1160.926



(Total Circuit Route, 28352:
Optimum Solution, 27686)
Figure 9. Best Round Route of 532 Cities Obtained by Experimentation (AS+CD (II) Method)

Moreover, SOM is a method of improving one solution, and AS is improved holding several solutions. Therefore, for standard deviation, it is understood that the dispersion of AS is fewer than the dispersion of SOM.

Results show that in addition that AS+CD (II) using CD on the mode of search by each artificial ant brought about good accuracy for every benchmark problem. However, the CPU time of AS+CD (II) increased rapidly. Therefore, in view of the optimality of solution and CPU time SOM+CD seems advantageous. Furthermore, it is necessary to improve solution accuracy and CPU time for large-scale problems.

Figure 9 depicts the best route found by AS+CD (II) for 532 cities.

5. Conclusions

We evaluated the performance of SOM, SOM+CD, AS, AS+CD (I), and AS+CD (II) for benchmark problems with 51–532 cities using parametric experiments to ascertain the following.

(1) We found proper parameter settings for SOM and AS.
(2) Incorporated CD improves the accuracy of solution without markedly increasing the CPU time.
(3) AS+CD (I) or AS+CD (II) is preferred if one assigns little value to CPU time. However, in view of optimality of solution and CPU time SOM+CD seems advantageous.
(4) For small-scale problems, AS works better, but requires a long CPU time. With increasing scale of the problem, SOM exhibits increasingly better performance.
(5) Regarding CPU time, SOM is much faster than AS. It is particularly advantageous for large-scale problems.

Our future challenges include improvement of the solution accuracy using advanced algorithms, reducing CPU time, and facilitating these methods' application to delivery planning.

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Supply Chain Milk-run Delivery Optimization

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Abstract

This study presents different approaches to deal with milk-run issue in Lean Supply Chain (LSC) management, which was introduced by Zhou and Kelin (2011). At first, these authors built up a theoretical total cost model for LSC using milk-run logistics. Afterwards, the model was applied in a LSC case study in automobile industry and then solved by improved Ant Colony Optimization (ACO) combining with classic optimal technique. Although the obtained result was acceptable, it did not achieve an optimal value. To optimize the solution, Mixed Integer Programming (MIP) and hybrid ACO and Tabu Search (HAT) approaches are proposed to resolve this issue in general. In the small-scale LSC, MIP is qualified through data from the case study while HAT is tested with random data in large size LSC. The solutions show that MIP can attain optimal outcome and HAT outperforms ACO regarding LSC total cost.

1. Introduction

In order to survive and develop in the fierce pressures of globalization, enterprises relentlessly seek measures to enhance the performance of their supply chain (SC). By improving SC performance, enterprises can cut down inventories, improving service levels (Panneerselvam, 2007) and gain a competitive advantage (Angerhofer & Angelides, 2006). Among several SC models that have been studied and applied, LSC is evaluated as an "ideal SC" (Srinivasan, 2012) owing to the ability of supplying final products/ services to consumers promptly, and economically in a seamless manner. Paschal et al. (2012) state that when Lean Manufacturing (LM) concepts are implemented across the entire SC, the SC is considered as LSC. Anand & Kodali (2008) summarize 59 LM tools/ techniques used to transform fat SC into LSC, in which milk-run delivery is one prevalent technique.

In SC management, Milk-run is one of the most efficient and regular transportation models (Kitamura & Okamoto, 2012). It is defined as "*A route on which a truck either delivers product from a single supplier to multiple retailers or goes from multiple suppliers to a single buyer location*" (Sunil & Peter, 2013). This network maximizes the capacity of vehicles by conveying items in small quantities with high frequency among all members instead of large stuff from individual company. To balance with milk-run pace, companies keep production at the level that their output at a time window fits with the amount of products received/ picked up by each milk-run. As a result, waste relating to inventory in LSC is eliminated and total cost (TC) is reduced. Meanwhile, it speeds up the circulation of materials through facilities, which improves responsiveness of the whole chain (Du et al., 2007). Other advantages of milk-run are analyzed in detail by exhausted review of Sadjadi (2009). With such striking advantages, milk-run is widely applied in both inbound and outbound logistics (Kilic & Durmusoglu, 2013) or even in plants among assembly lines or workstations (Pesce et al., 2000). In reality, Toyota and Seven-Eleven are the worldwide successful cases of the milk-run application.

To identify a solution for milk-run logistics, numerous approaches are used from specific software (Thanatorn, 2013) to Heuristic (Kilic & Durmusoglu). Nowadays, general Meta-Heuristics have been employed in order to define the best milk-run path. Some effective ones are ACO (Zhou & Kelin, 2011; Yang et al., 2013), Tabu Search (Jiang, 2010) or the Genetic Algorithm (Sadjadi, 2009; Wang, 2013). After reviewing the application of Meta-heuristics in SC and logistics, Stanley et al. (2012) conclude that although the results found from Meta-Heuristics are acceptable, hardly do they obtain optimal values. Thus, this article proposes MIP and HAT approaches to achieve better results.

The next section analyzes the problems of the milk-run delivery in LSC then re-addresses its modeling proposed by Zhou and Kelin. The following section particularly details the proposed methodology of MIP and HAT before presenting the results of the testing stage from a case study and random data. Finally, the two last sections discuss obtained solutions as well as express essential conclusions and further suggestions.

2. Problem define

2.1 Milk-run problematic

Although considered as a more effective model than direct shipment in minimizing SC TC (Gurinder & Gagan, 2011), milk-run can only have an advantage when applied in proximity distance. Regarding shipping cost, Sunil and Peter point out two cost components that a shipper incurs: *Transportation Cost* (based on route distance - *dr*), and *Delivery Cost* (stemmed from delivery frequency - *n*). When applying milk-run, its shipment planning must be carefully scheduled to ensure the synchronized coordination in LSC and make sure total volumes/ weights of all items conveyed less than a truck load. Thus, optimizing milk-run issues turns out finding the best compromise of *dr* and *n* which contributes to the lowest *TC* while satisfying vehicle capacity restrictions. Yet, solving this issue is monumentally difficult due to the complexity nature of SC. Thus, researchers as well as managerial cadre usually need the support of modeling and simulation.

2.2 Modeling the milk-run network

There are numerous studies formulating a mathematical model of SC through TC. Depending on research objectives, variables in these models can be defined differently, but at the strategic level, SC TC model includes some basic elements. According to Tim (2003), SC TC comes from Production, Distribution, Storages and Marketability Costs while Sadrnia et al. (2013) believe these components are Transportation, Operation and Initial Facility Cost. In the case of available structure and stable market, Zhou and Kelin assume that SC TC is made up from three elements (in which Delivery Cost includes Transportation Cost):

TC = Cost(Production + Delivery + Inventory) (1)

In this model, sharing analogous points of view with Sunil and Peter, Zhou and Kelin consider *dr* and *n* as variables while other parameters are designed. As these authors, the theoretical objective function *TC* (1) in one-core-business LSC, is generally formulated at the operational level as shown:

$$\text{Min TC} = \sum_{i=1}^{N}\{(UIC_s)^i(SI_s)^i + (UIC_m)^i(SI_m)^i + \frac{(UIC_d)^i P_m d_r}{VT} + P_m(UPC_s)^i\} + \sum_{j=1}^{K}\{UIC'_m \times SI'_m + UIC'_c)^j(SI'_c)^j + \frac{UIC'_d)^j(D_c)^j dr}{VT} + (D_c)^j\ UPC_m\} + (\sum_{i=1}^{N}\{(USC_s)^i + (FOc)^i\} + \sum_{j=1}^{K}\{USC_m + (FOC')^j\} + FDC + UDC * dr*)n + \{(UIC_s)^i\ P_m\ (1- \frac{P_m}{2(P_s)^i}) + \frac{(UIC_m)^i}{2}P_m\} + (\sum_{j=1}^{K}\{UIC'_m((D_c)^j - \frac{((D_c)^j)^2}{2P_m}) + \frac{(UIC'_c)^j(D_c)^j}{2}\})/n \quad (2)$$

Constraints:

i. Each supplier/customer visits once only;
ii. Each supplier/ customer is included in one path of 1 milk-run;
iii. Delivery frequency of each supplier/ customer in the same path is equal
iv. $n \in$ integer and $n>0$, $dr>0$;
v. Delivery capacity constraint (weight restrictions):

$$\sum_j \frac{(D_c)^j w'}{n} + \sum_i \frac{(P_m)^i}{n} \le W \quad (3)$$

Where:

N, K, m: number of suppliers, customers and all members of SC respectively;

$UPC_{s/m}$: unit production cost of suppliers and core business;

$USC_{s/m}$: production start-up cost/batch of suppliers and core business;

P_m, P_s, D_c: productivity/ demand rate from core business; suppliers; customers;

FOC/FOC': order fixed cost of parts/ finished products;

FDC: delivery start-up cost;

UDC: unit delivery cost;

$UIC_{s/m/d}$: parts unit inventory cost of suppliers, core business and in-transit;

$UIC'_{m/c/d}$: finished product unit inventory cost of core business, customers and in-transit;

$SI_{s/m}$: part safety stock quantity of suppliers and core business;

$SI'_{m/c}$: finished safety stock quantity of core business and customers;

T: core business production cycle;

V: average rate of delivery vehicle;

W: capacity of delivery vehicles;

w, w': weight of part/ finished product (kg);

It is noted that (2) can be written in shortened form:

$$TC= A*dr + B*n + C*n*dr + D/n + E \quad (4)$$

Where:

$A=\sum_{i=1}^{N}(\frac{(UIC_d)^i P_m}{VT}) + \sum_{j=1}^{K}(\frac{UIC'_d)^j (D_c)^j}{VT})$

$B=\sum_{i=1}^{N}\{(USC_s)^i + (FO_c)^i\} + \sum_{j=1}^{K}\{USC_m + (FOC')^j\} + FDC$

$C=UDC$

$D=\sum_{i=1}^{N}\{(UIC_s)^i P_m (1- \frac{P_m}{2(P_s)^i}) + \frac{(UIC_m)^i}{2} P_m\} + \sum_{j=1}^{K}\{UIC'_m((D_c)^j - \frac{((D_c)^j)^2}{2P_m}) + \frac{UIC'_c)^j (D_c)^j}{2}\}$

$E=\sum_{i=1}^{N}\{(UIC_s)^i(SI_s)^i + (UIC_m)^i(SI_m)^i + P_m(UPC_s)^i\} + \sum_{j=1}^{K}\{(UIC'_m) SI'_m + (UIC'_c)^j(SI'_c)^j + (D_c)^j UPC_m\}$

A, B, C, D and E > 0.

Mathematically, *n* and *dr* can be found by:

$$\begin{cases} \partial(TC)/\partial n = 0 & (5) \\ \partial(TC)/\partial(dr) = 0 & (6) \end{cases}$$

$$\Leftrightarrow \begin{cases} (B+C*dr) - D/n^2 = 0 & (7) \\ A + C*n = 0 & (8) \end{cases}$$

$$\Leftrightarrow \begin{cases} n = -C/A & (9) \\ dr= D*A^2/C^3 - B/C & (10) \end{cases}$$

Particularly,

$$\partial^2(TC)/\partial n^2 = 2C/n^3 \quad (11)$$

The compromise of *n* and *dr* found from (9) and (10) is unacceptable owing to the violation with constraint (iv). However, when $n>0$, $dr>0$, value $\partial^2(TC)/\partial n^2 > 0$ from (11) indicates that *TC* can obtain a local minimum when *(7)=0* with one pre-determined *shortest dr.* From (7) *optimal n* can be defined as:

$$\text{optimal } n= \sqrt{\frac{B+D*(\text{shortest dr})}{C}} \quad (12)$$

So, the milk-run issue becomes solvable if the *shortest dr* can be defined. At each *m*, the *shortest dr* is unique while *B, C* and *D* are constant, so value *optimal n* counted by (12) is exclusive. As *dr* is linear with *TC*, when *dr* changes, *TC* has lineal motion along with *dr* and *optimal TC* attains at the same value of *optimal n.* These arguments are exemplified in the case study. Based on these characteristics, two new approaches (programed by MATLAB 2013b) are proposed to identify the *optimal dr*. In small-scale SC, both MIP and HAT can be used. Yet, when *m* is sufficiently large, the computer processing time is too long, which makes MIP unsolvable. In this case, HAT shows useful in overcoming the timing trouble. In both methods, when the *best dr* defined, the *optimal TC* and *n* are calculated by programming.

3. Proposed Methodology

The size of a SC is defined by the number of members m (or nodes) of SC including the plants, suppliers and customers. In the context of this paper, the SC is considered “small” or “large” depending on the application limit of the two proposed approaches.

3.1 MIP approach for small-scale LSC

As Srinivasan (2012), the structure of fat SC is quite complicated due to many redundant members. To make it lean, managers tend to use supplier reduction or a sole sourcing policy through strategic alliances. When SC is leaned with limited members, *optimal dr* in milk-run can be identified by MIP by checking and comparing all possible *dr* to determine the best value of it. In small LSC, *dr* is the distance of the route that connects all delivery nodes in one path (departure and arrival at core business). So, distance matrix (*D*) among all delivery nodes in the milk-run is used as MIP input. From *D*, MIP creates a loop of assignment *i* to find *optimal dr*. Other initial values of MIP parameters are set in Table 1.

Table 1. Initial values of parameters

Name	Initial value	Note
Mindr	Infinitive	
Mini	23…(m-1)m	(m-1)-element increasing integer
maxi	m(m-1)…2	(m-1)-element decreasing integer
maxn		Max loading capacity > 50%

Figure 1 illustrates a flowchart of MIP approach, which proceeds as follows:

i. Setting assignment i = mini as a minimum increasing integer containing the number of all different nodes.
ii. Transferring value *i* to one-array *route*. *route* is the path of milk-run.
iii. Checking the validity of *route* (no sub-route and all elements ≠ 0)

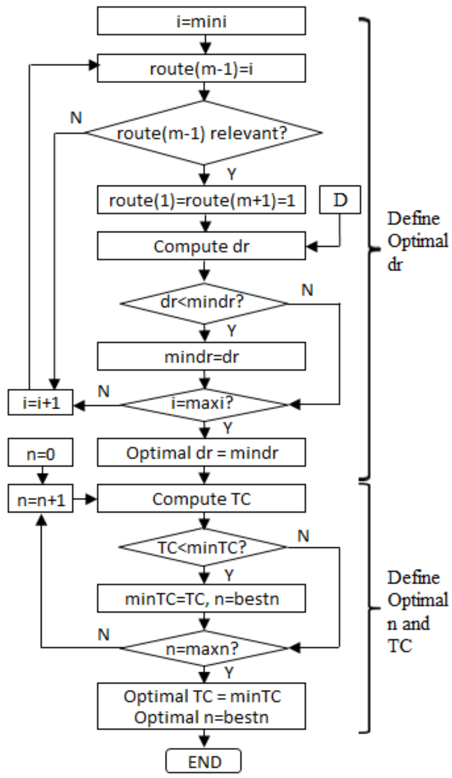


Figure 1: MIP flowchart

iv. Creating full *route* by assigning the departure and arrival nodes as node 1.
v. Computing *dr* though the geographical coordinate matrix *D* of LSC.
vi. Comparing *dr* with *mindr*, the smaller value is assigned to *mindr.*
vii. Continuing to check other possible values of *route* by increasing *i*
viii. When *i=maxi*, *optimal dr* defined=*mindr*
ix. With *optimal dr* found from (viii), creating a loop of *n* and compute *TC* through (2).
x. Comparing *TC* with *minTC*, the smaller value is assigned to *minTC.*
xi. Stopping when *n* reaches *maxn*. *optimal TC* found is *minTC*. *optimal n* identified= *bestn* which contributes to *optimal TC*.

In short, MIP checks all potential *dr* to identify *optimal dr*. Then, combinations of *optimal dr* and all possible *n* are computed and compared for *optimal TC* eventually.

3.2 HAT for large-scale LSC

In large-scale SC, HAT is proposed to figure out the best solution for milk-run in complicated logistics network. HAT is developed based on the hybridization of ACO and Tabu Search (TS) through input distance matrix *D*. ACO is a well-known Meta-Heuristics that mimics the tracking method of ant colony (Dorigo & Stützle, 2004) while TS is powerful algorithm developed by Glover (1986). Defining *optimal dr* in milk-run has the identical characteristic with seeking the shortest path for the famous Travelling Saleman Problem (TSP). Solving TSP by TS, the acceptable initial solution can be obtained quickly by Greedy Search or other heuristics before being refined following temporary memory or Tabu list (Sumanta, 2012). Incontrovertibly, ACO proves better performance in solving TSP than other heuristics. Hence, HAT replaces Greedy Search by ACO in TS to improve the initial results which leads to near optimal final solution (Figure 2). The procedure of TS in solving TSP was systematically summarized by Sumanta (2012), so it is not repeated here. When possible *optimal dr* is found by HAT, the following stages are similar to MIP in identifying *optimal n* and *TC* (step ix-xi).

To qualify MIP and HAT, a case study and random data are used in testing stage.

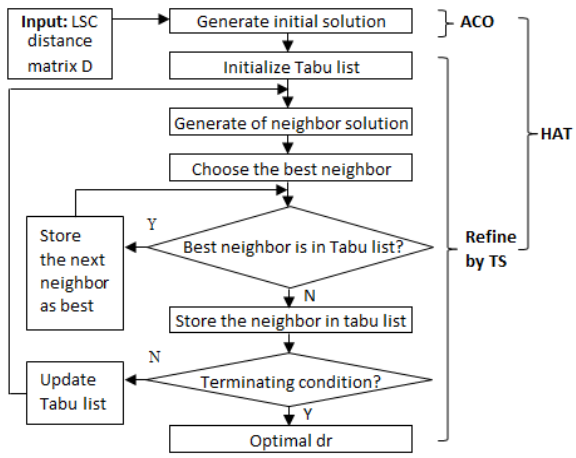


Figure 2: HAT flowchart

4. Results

4.1 Case study and MIP testing

In the original case study, the 9-member automobile LSC (m=9) having one plant, 3 (*N*) suppliers, 5 (*K*) customers was used to illustrate milk-run mathematical model (2). The information of the LSC in case study is enumerated in Table 2 and 3. The distance matrix *D* among all LSC members is computed from Table 4. Other values of the chain are:

T= 30 days; V=50km/h; W=20 tons.

Table 2. Data of the LSC case study

	UPC_s	$USC_{s/m}$	FOC	UIC_s	UIC_d	SI_s	w(kg)	P_s
S1	10	1000	100	10	12	4000	2	134000
S2	12	1500	100	12	14	5000	1.5	135000
S3	15	2000	100	15	18	8000	1.5	138000
	UPC_m	USC_m	-	UIC_m/UIC'_m	-	SI_m/SI'_m	w'(kg)	P_m
R0	50	5000	-	12/12/15/50	-	4000/16000	5	126000

	-	-	FOC'	UIC'_c	UIC'_d	SI'_d	-	D_c
C1	-	-	200	50	60	2200	-	22000
C2	-	-	200	50	60	2000	-	20000
C3	-	-	200	50	60	1800	-	18000
C4	-	-	200	50	60	2000	-	20000
C5	-	-	200	50	60	1800	-	18000

Table 3. The businesses geographical coordinate in LSC case study

Business code	R0	S1	S2	S3	C1	C2	C3	C4	C5
X coordinate	50	26	62	52	40	73	38	86	21
Y coordinate	70	95	49	15	80	12	66	97	82

Table 4. Distance matrix *D* of LSC

$$D=\begin{vmatrix} 0.00 & 34.66 & 24.19 & 55.04 & 14.14 & 62.39 & 12.65 & 45.00 & 31.38 \\ 34.66 & 0.00 & 58.41 & 84.12 & 20.52 & 95.38 & 31.38 & 60.03 & 13.93 \\ 24.19 & 58.41 & 0.00 & 35.44 & 38.01 & 38.60 & 29.41 & 53.67 & 52.63 \\ 55.04 & 84.12 & 35.44 & 0.00 & 66.10 & 21.21 & 52.89 & 88.77 & 73.82 \\ 14.14 & 20.52 & 38.01 & 66.10 & 0.00 & 75.58 & 14.14 & 49.04 & 19.10 \\ 62.39 & 95.38 & 38.60 & 21.21 & 75.58 & 0.00 & 64.35 & 85.99 & 87.20 \\ 12.65 & 31.38 & 29.41 & 52.89 & 14.14 & 64.35 & 0.00 & 57.14 & 23.35 \\ 45.00 & 60.03 & 53.67 & 88.77 & 49.04 & 85.99 & 57.14 & 0.00 & 66.71 \\ 31.38 & 13.93 & 52.63 & 73.82 & 19.10 & 87.20 & 23.35 & 66.71 & 0.00 \end{vmatrix}$$

Substituting these values to (2), *TC* yields:

$$\text{Min TC} = 10^3 * (11220 + 7.616dr + 11.8n + 11798.853/n) + 5dr*n \quad (13)$$

And, (5), (6) become:

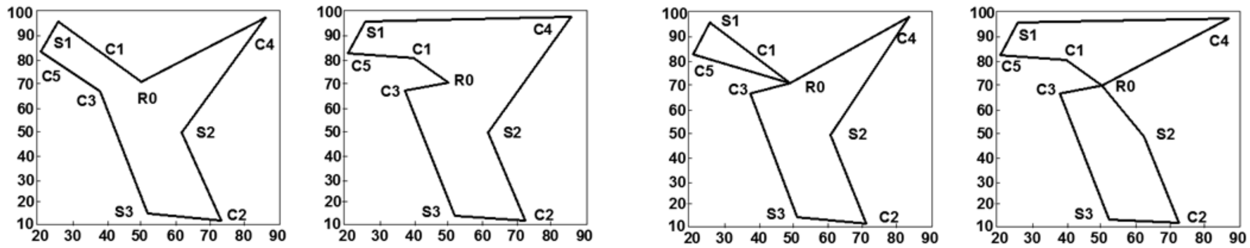
$$\Leftrightarrow \begin{cases} 10^3*(11.8-11798.853*n^{-2})+5*dr=0 & (14) \\ 7616+5n=0 & (15) \end{cases}$$

Solving (14) and (15), n=-1323.20 and dr=-2358.65. Obviously, both *n* and *dr* violate constraint (iv). The authors used improved ACO (2-Opt) to find *acceptably shortest dr* before substituting this value to (14) and then (13) for *n* and *Min TC* respectively.

With m=9, the LSC is classified as small-scale, thus it is taken into the test for MIP efficiency. The primary results of MIP in comparison with original's are presented in Table 5 and Figure 3.

Table 5. Primary results of MIP, HAT and Original

Approach	dr (km)	Best Route	n	TC ($)	Note
MIP	283.30	R0-C1-S1-C5-C3-S3-C2-S2-C4-R0	30	14,167,402.90	Optimal TC
HAT	286.22	R0-C1-C5-S1-C4-S2-C2-S3-C3-R0	30	14,190,079.62	
ACO (Original)	286.22	R0-C1-C5-S1-C4-S2-C2-S3-C3-R0	19	14,272,234.68	



Primary dr_{MIP}=283.30 km Primary $dr_{HAT,\ Original}$=286.22 km Final dr_{MIP} =295.94 km Final $dr_{HAT,\ Original}$=301.75 m

Figure 3. Primary and final *dr* found from MIP and HAT/Original

As can be seen from the Table 5, *dr* obtained from HAT and approved ACO stay identical at 286.22 km while the one from MIP achieves optimal value at 283.30 km. However, this promising milk-run is inapplicable because vehicle following the route violates the strict condition of capacity (3). Since the sole milk-run causes delivery truck overweight, it must be divided into two sub-routes. Consequently, the new delivery distance becomes longer in total while value *n* keeps unchanged. The values of sub-routes and final *Min TC* after splitting primary milk-run path are summarized in Table 6 and figured out in Figure 3.

Table 6. Final results of MIP, HAT and Original after divided primary milk-run route dr

Approach	dr (km)	Best sub-route	n	TC ($)	TC improvement	Note
MIP	295.94	dr1: R0-C4-S2-C2-S3-C3-R0	30	14,265,636.58	9.52%	Optimal TC
		dr2: R0-C5-S1-C1-R0	30			
HAT	301.75	dr1: R0-C3-C1-C5-S1-R0	30	14,310,647.55	9.23%	
		dr2: R0-C4-C2-S3-S2-R0	30			
ACO (Original)	301.75	dr1: R0-C1-C5-S1-C4-R0	19	15,766,546.00		
		dr2: R0-C3-S3-C2-S2-R0	19			

After splitting, MIP still remains optimal regarding *final dr* and *TC*, while HAT provides the same *dr* and better *TC* in comparison with the original. Besides, o*ptimal n* given from both MIP and HAT are identical at 30. Notably, they are far different with *n* provided from original (19). To re-define *optimal n* as well as to clarify the modeling arguments, *TC* is figured out with a range of all possible *dr* from *min dr* to *max dr*. In the case study, through MIP, *min dr* is equal to *final optimal dr* (295.94km) while *max dr* defined = 542.72 km. (Figure 4).

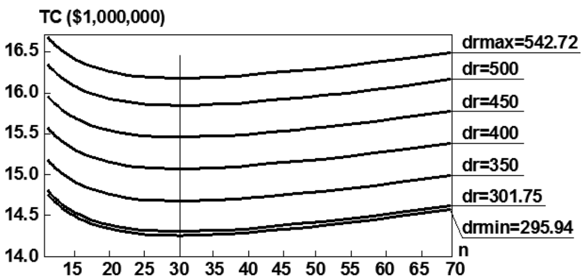


Figure 4. ***TC*** **obtained within** ***dr*** **range and various** ***n***

The result demonstrates that *TC* reaches globally optimal point at *optimal dr* = 295.94 km and *optimal n* = 30. Besides, with different *dr*, *TC* only gains minimal values with the same *optimal n*. This *n* is then combined with the range of *dr* to test the linearity of *Min TC*. Figure 5 shows that *Min TC* is linear within the range of *dr* as the aforementioned arguments. In this case, *max dr* makes *min TC* rise to maximum value at $16,182,058.62.

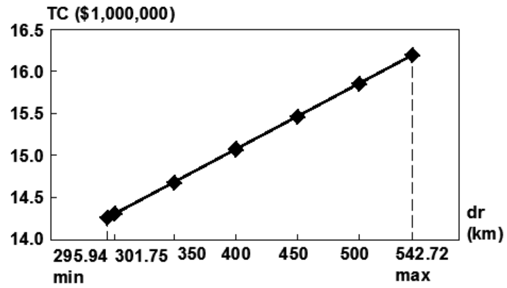


Figure 5. ***Min TC*** **obtained within** ***dr*** **range and** ***n*****=30**

4.2 Results from HAT

HAT performance is evaluated in large scale LSC, where MIP is inapplicable. As with each *m*, the shorter *dr* obtained, the smaller *TC* incurred, HAT is qualified through the ability of generating better *dr* in comparison with ACO. To implement the test, distance matrices *D* of large size LSC (m=20-100) are created randomly (In MATLAB, command *rand(m,m)* returns a random square matrix *D* size m and *D = 0.5(D+D')* makes *D* symmetric, then all values on diagonal are assigned to 0). These matrices simulate the geographical locations of delivery nodes of milk-run in LSC. The values of elements in matrix *D* are set from 0 to 300 km as acceptable distances for milk-run. With each *m*, *dr* is repeatedly calculated 100 times. Table 7 demonstrates *dr* given by the first 10 tests, where Table 8 and Figure 6 present the average *dr* found from 100 iterations. Particularly, ACO-HAT variation is counted and shown in Figure 7.

Table 7. The first 10 ***dr*** **attained from ACO and HAT corresponding with different value** ***m***

	m=20		m=30		m=40		m=50		m=60		m=70		m=80		m=90		m=100	
No.	ACO	HAT	ACO	HAT	ACO	HAT	ACO	HAT	ACO	HAT	ACO	HAT	ACO	HAT	ACO	HAT	ACO	HAT
1	1610	1429	1740	1634	1953	1844	2266	2262	2399	2372	2681	2666	2814	2806	3118	3118	3361	3304
2	1498	1494	1612	1612	2015	1996	2324	2285	1979	1979	2817	2723	2816	2791	2935	2927	3020	3006
3	1063	1063	1788	1750	1815	1815	2358	2358	2794	2631	2741	2702	2613	2613	3122	3006	3087	2983
4	1429	1424	1547	1524	2118	2024	2103	2049	2458	2404	2764	2757	2738	2733	2901	2802	3137	3076
5	1342	1290	1658	1646	1661	1661	2209	2176	2364	2320	2940	2827	3048	2990	3278	3267	2998	2936
6	1386	1265	1560	1471	1778	1771	2245	2193	2245	2211	2851	2820	3412	3191	3022	3022	3546	3323
7	1528	1498	1754	1741	1747	1736	2581	2455	2708	2564	2714	2714	3087	3065	2934	2877	3535	3426
8	1262	1321	1792	1769	1828	1768	2204	2196	2285	2271	2703	2680	2498	2413	3300	3300	3269	3254
9	1364	1364	1800	1725	1919	1853	2160	2109	2699	2554	2562	2513	2609	2562	3359	3255	3239	3210
10	1275	1176	1629	1612	1928	1928	2143	2140	2731	2624	2719	2717	2880	2853	3309	3309	3546	3474

...

Table 8. Average *dr* attained from ACO and HAT and its variation

m	ACO	HAT	Variation
20	1416.7	1354.6	62.1
30	1758.2	1701.6	56.6
40	2038.1	1955.6	82.5
50	2263.9	2231.7	32.3
60	2500.9	2456.7	44.2
70	2767.3	2704.8	62.4
80	2914.0	2866.6	47.4
90	3072.3	3037.5	34.9
100	3258.9	3213.7	45.1

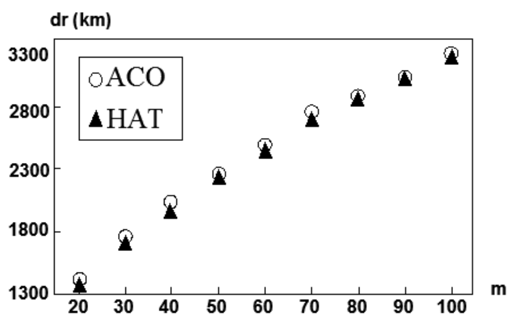


Figure 6. Average *dr* obtained from ACO and HAT

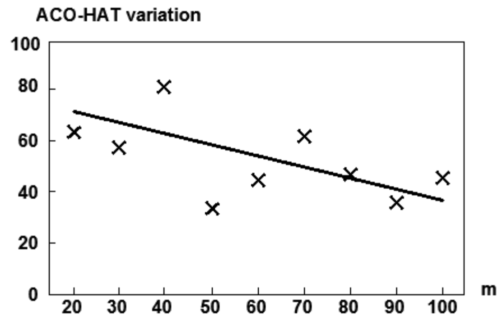


Figure 7. ACO-HAT variation

5. Discussion

The final *TC* offered by MIP achieves globally optimal value. Comparing with original, the LSC can save *TC* up to $1,500,909.42 and shorten the delivery path by 5.81 km/ milk run. The *optimal dr* and greater *n* obtained from MIP contribute to the reduction of TC globally (9.52%) thanks to the decrease of inventory holding cost of all members in chain. The result matches with the conclusion of Gurinder and Gagan (2011) which emphasizes the importance of cost improvement though high delivery frequency in short distances of milk-run. However, MIP confronts monumental trouble with large *m* since there are total *(m-1)!* feasible values of *dr* need to be checked for optimal *dr*. When m reaches to 15, the processing time of CPU (with processor can solve 2 million procedures per second) exceeds a week. When *m* larger than 15 (large-scale SC), the vast time spending in finding *optimal dr* makes MIP's meaningless in industrial application. In this case, the transition from the MIP to the HAT is necessary.

Regarding factor "short distance" *dr*, results from HAT with different LSC sizes in Table 7, and Figure 6 indicate that HAT provides smaller value *optimal dr* than the ACO average. In the test, with 100 iterations, *optimal dr* from the hybrid approach is superior to ACO in most of cases. Yet, while *m* increases, the linear regression model of ACO-HAT variation appears a gradual downward trend (Table 8 and Figure 7) or with very large-sized LSC, the difference between the two methods becomes small. However, in the practical size of milk-run as shown, HAT proves worthy applying. By providing shorter *dr*, HAT can offer better solution for milk-run delivery than ACO at each certain *m*. What is more, other advantage of HAT is emphasized regarding processing time. When *m* reaches 100, finding *optimal dr* from HAT costs only 163.65s in average while it is completely impractical for MIP.

6. Conclusion

To conclude, MIP can reach exact *optimal TC* which is proved in the case study. In industry, this approach is valuable in small-size LSC applications. Due to the MIP problem with processing time in a large network, HAT is proposed to obtain acceptably good solution. The results from random data show that HAT outperforms ACO regarding *TC* thanks to shorter milk-run distance

The meanings of these approaches are also highlighted due to the knock-on effects such as higher responsiveness, lower risks when milk-run model optimized, which contribute new intangible values to the chain. Finally, the HAT should be expanded inspection to other application areas for extensive assessment of its promising effectiveness.

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Cost of Software Quality: A Literature Review

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Abstract

Today, companies invest significant time and capital in the implementation of complex software systems to manage their daily operations. In order to remain competitive, software developers must provide high-quality software products. This paper presents a review of the cost of quality, and the associated applications of software cost models. This is followed by a technical discussion highlighting the advantages and limitations of each. Efforts are made to indicate the research gap in the area of estimating the Cost of Software Quality after release.

1. Introduction

Quality is one of the most vital factors in achieving success and perhaps gaining market share. The competition to provide higher quality in the manufacturing industry has increased in recent years. Quality is a function of design features and conformance to users' requirements. Deviations from the users' requirements and expectations will result in losses. These losses are typically estimated by using cost of quality models, which have been successfully applied in the manufacturing industry.

Numerous research has been performed in the area of estimating the cost of software quality, however efforts are limited to the development stage of the lifecycle. This paper provides a review of the literature pertaining to traditional cost of quality models and their applications in the software industry.

The following section represents a review of software quality models. Section 3 represents a review of the traditional models used to estimate the cost of quality. Section 4 represents a review of applications of cited models for estimating the cost of software quality. A comparison between software quality models and cost models is represented in Section 5. This is followed by final conclusions with indications of directions for future research.

2. Software Quality Models

Software quality is a term that encompasses both functional and non-functional features of a software system. In general software quality can reflect users' expectations and experiences of the system. This means that different users may have different perceptions of software quality depending on their back grounds. According to IEEE STD 1061, (1992) software quality is "The degree to which software possesses a desired combination of attributes". IEEE STD 729 (1983) defined software quality as "The composite characteristics of software that determine the degree to which the software in use will meet the expectations of the customer." Whereas, ISO/IEC IS 9126 (1991) defines software quality as "The totality of features and characteristics of a software product that bear on its ability to satisfy given needs". Models have been proposed to measure software quality and determine its attributes from different perspectives.

McCall et al. (1977) presented a model that is known as the General Electric Model. This model defines software quality through three different perspectives: product operation, product revision, and product transition. The model consists of eleven quality factors (from the users' view) and twenty three quality criteria (from the developer's view).

Boehm (1978) developed a model for evaluating software quality. His model is based on a hierarchical composition of characteristics the same as McCall's model. The model defines software quality as a set of attributes and metrics. It starts with a general utility as being the higher level that is broken into a set of factors and each factor is made up of several criteria.

Dromey (1995) proposed a framework using a different approach than the two previously presented. The framework consists of three models: a requirement model, design model, and implementation model.

The functionality, usability, reliability, performance, and supportability (FURPS) model was developed by Grady (1992). The model is basically structured in two layers. One layer defines the quality characteristics and the other defines their associated attributes. The main concept behind this model is that it decomposes characteristics into two categories of requirements, functional and non-functional. These categories are used to specify product requirements as well as to evaluate the software quality.

In 2004, the International Organization for Standardization published the ISO/IEC TR 9126 document for software product evaluation. The evaluation method is based on McCall and Boehm models and structured in a similar manner. The document is divided into four parts. These include a quality model, internal metrics, external metrics, and quality in use metrics.

Unterkalmsteiner, et al (2012) conducted a literature review on the evaluation and measurement of Software Process Improvement (SPI). They identified evaluation strategies and measures that can be used to determine the impact of different (SPI) advantages. They concluded that quality was the most measured attribute, followed by cost, and finally schedule.

3. Cost of Quality Models

The cost of quality offers a way to evaluate continuous improvement projects and help resolve the conflicting objectives of minimizing cost while maximizing product quality. Over the years, the definition of the cost of quality changed from one industry to another and even from one researcher to another. These changes included adding new elements of the cost to account for the nature of the product and industry. In general, the costs related to quality are divided into two main categories. One represents the cost of conformance, while the other represents the cost of nonconformance or poor quality (COPQ). According to Slaughter, et al. (1998) the total cost of quality (COQ) is calculated by adding both categories.

The first definition of the cost of poor quality appears to have been introduced by Juran in 1951. He stated that COPQ should disappear and vanish when no defects are produced.

Feigenbaum (1956) defined four quality cost categories. These four categories were identified as prevention, appraisal, internal failure, and external failure costs. Prevention costs (P) are those associated with efforts to reduce or eliminate the chances of producing defective units. Appraisal costs (A) are the costs associated with activities designed to ensure product conformance. Internal and external failure costs (F) are those incurred due to poor quality. The model is known as the PAF model, and estimates the total cost of quality as the sum of all four categories. It can be expressed mathematically as:

COQ = P + A + F

Hwang and Aspinwall, (1996) pointed out that prevention costs may be extended to include other costs related to employee training and quality engineering activities. They also noted that the PAF model is the most commonly used model in manufacturing and service industries. Wang, et al. (2010) indicated that the model supports a tradeoff between the cost of conformance (prevention and appraisal) and the cost of failure (internal and external).

Crosby (1979) appears to be the first to define quality costs in terms of conformance and non-conformance. In his book Quality is Free, he argued that quality does not cost money. He defined the cost of quality in terms of the costs incurred when things are not done right the first time. According to Crosby, the COPQ is the price paid for producing non-conforming products or services. His process cost model defines the total cost of quality (COQ) as the sum of the price of conformance (POC) and the price of non-conformance (PONC). He indicated that the model supports continuous improvement efforts within the organization and relates to the plan-do-check-act cycle. The model is represented as:

COQ = POC + PONC

Porter and Rayner (1992) suggested that this model is an ideal model to be used when it comes to tracking a specific process. In addition, the model can be used to analyze data related to direct and indirect costs and support the economics of process improvement. Hwang and Aspinwall (1996) concluded that this model is more dynamic than the PAF model and can be used to solve more quality problems.

The activity-based cost (ABC) model was developed by Cooper and Kaplan in (1988). This model was developed to trace the various cost elements to their resources and activities. It can be utilized to identify non-value added activities which can be excluded to reduce the total cost. Turney (1991) characterized the (ABC) model by using two dimensions. The first is from a cost standpoint while the other is based on a process standpoint. The first dimension reflects the organization's need to trace or allocate resources to activities or cost objects. This point of view is used to analyze critical decisions about such things as pricing, product mix, sourcing, and distribution channel management. The second dimension reflects the organization's need for information about events that affect activities and their performance measures. It reflects what causes work and how well it is done. Tsia (1998) outlined a framework structure for measuring quality costs under the ABC model. He identified three weaknesses of most cost of quality (COQ) systems. First, the models do not account for the indirect time spent by workers on different activities. Second, the models do not have the ability to trace quality costs to activities. Third, there is no agreement on methods for allocating overhead costs to the COQ elements. He explained that the two-dimensional ABC model overcomes these deficiencies, identifies quality improvement opportunities and helps control the total cost. Ittner (1999) proposed a simplified version of the ABC model that was used by a wide variety of service and manufacturing firms. This model categorizes activities into four types: essential work, prevention activities, appraisal activities, and rework or failure activities.

Porter and Rayner (1992) developed a cost-benefit model to account for the costs and benefits of quality improvement. The improvement cost comes from the investment in prevention activities, while the benefit comes from the reduction in failure and appraisal costs due to such improvements. These benefits can be defined in terms of increased market share as well as customer satisfaction and profit. They noted that both the PAF and the process cost model did not recognize these benefits. In addition, Wang et al. (2010) also emphasized the importance of incorporating opportunity cost into the cost models. Another model was proposed by Sandoval-Chaves and Beruvides (1998) which incorporates opportunity costs into the PAF model.

Bakota, et al (2011) proposed a probabilistic model for estimating the cost and risk of software changes. This model defined software quality attributes based on ISO/IEC 9126 standard. In addition, they developed an approach for computing high-level quality characteristics, which integrate expert knowledge, and deal with ambiguity at the same time.

4. Applications in Software Industry

Mandeville (1990) utilized the PAF model by dividing the cost of software quality into two categories: the cost of conformance and the cost of non-conformance. The first represents all costs related to activities aimed at meeting the specifications. These costs include expenditures to prevent and find defects. Whereas, the second accounts for all costs associated with failure (internal and external), including the costs of fixing errors in the software and the rework after the software is released to the end user or customer.

Knox, (1993) applied the same PAF model to calculate the total cost of software quality. The model recognizes the five levels of capability maturity for software development. The model is based on two data-driven assumptions. First, it is assumed that the total cost of quality at level 1 is about 60 percent of the total development cost. The second assumption is that the total cost of quality will decrease by about 67 percent as the company reaches level 5.

Krasner (1998) emphasized the importance of key dimensions such as level of satisfaction, product value, key attributes, defectiveness, and process quality. He also concluded that the cost of software quality is a framework indicating how much good software quality and poor software quality cost. He claimed that the PAF model is the most appropriate to implement in terms of conformance and non-conformance.

Whittaker and Voas (2002) pointed out that users of software have been suffering from poor quality. In applying the PAF model to the software quality, they defined the prevention costs in terms of development, training, and quality audits. Appraisal costs were defined in terms of the costs associated with testing and reviewing. Non-conformance costs were associated with both internal failure and external failures.

Radziwill, (2006) presented a case study involving a telescope operation software. He proposed an accounting method to capture the various cost elements of the PAF model. He assigned a five-digit accounting code to each cost category and utilized a time keeping system to capture the time spent on each element. Special metrics were used to extract cost figures from the accounting system.

Karg and Beckhaus (2007) noted that there have been limited research efforts made to calculate and model the cost of software quality. In general, most of the efforts were aimed at applying common manufacturing models and adjusting them to the characteristics of the software. They pointed out that the most commonly used models are the PAF model, the process costing model, and the activity-base model.

Osteen, et al (2013) presented an

application of the PAF model and defined transformation models that align the cost of quality based on maturity and quality rigor within the business.

Wagner and Seifert (2005) proposed a model based on defect-detection techniques. They stated that "The basis for the analysis of the quality costs is the net present value of the cash flows (NPVCF), i.e. the revenues and costs during the lifecycle of the software that are related to quality." This model was represented as follows:

$$\mathbf{NPVCF = r - C_{direct} - C_{\mathit{fut}}}$$

Where, r is the discounted savings generated by using defect-detection techniques, C_{direct} is the sum of execution, fault removal, and setup costs, discounted to net present value, and C_{fut} is the present value of failure costs based on estimated costs per severity class. The model uses software reliability functions to predict future failures, and incorporates effectiveness metrics and severity indicators in allocating failure costs. However, the model does not account for all types of maintenance costs, which are important and can fluctuate widely. The model also ignores opportunity costs due to external failures such as lost sales.

Table 1. Comparison Between Five Software Quality Models (Al-Qutaish, 2010)

Factors/Attributes	McCall	Boehm	Dromey	FURPS	ISO 9126
Correctness	X				
Efficiency	X	X	X		X
Flexibility	X				
Functionality			X	X	X
Human		X			
Integrity	X				
Interoperability	X				
Maintainability	X		X		X
Modifiability		X			
Performance				X	
Portability	X	X	X		X
Reliability	X	X	X	X	X
Reusability	X		X		
Supportability				X	
Testability	X	X			
Understandability		X			
Usability	X		X	X	X
Total	11	7	7	5	6

Nolan, et al (2011) presented an effort to integrate key quality attributes into the cost estimation model. They presented a set of prioritized quality attributes and a scenario based on two specific quality attributes (maturity and variability) to analyze the importance of considering quality attributes when performing cost-benefit analysis.

5. Discussions

The literature reflects two trends in addressing software quality. One trend, led by software engineering, is aimed at identifying a set of characteristics and factors that derive software quality. Efforts have been made to map these factors to different stages of the lifecycle of the product. However, over the last two decades, the software industry has shifted its focus from providing more functionality to improving users' perceptions of its product quality. These improvements, for example, may target characteristics such as ease-of-use, stability, reliability and security. Software failure is, for the most part, predictable and avoidable. The attributes and factors shared between the models cited in Section 2 are summarized in Table 1. As shown, McCall's model appears to identify the largest number of attributes that can be used in evaluating software quality. The ISO 9126, on the other hand defines six high-level, user oriented attributes that are shared among the cited models. These have been divided into eighteen sub-attributes to minimize overlap in evaluating software quality. ISO 9126 attempts to eliminate any misunderstanding between users and suppliers. The key point is that these six attributes are the top level of a hierarchical structure of sub-attributes. At the bottom of the hierarchy are appropriate metrics that can be used to measure the value of each.

The other trend in the literature, led by quality engineering, is aimed at estimating the cost of software quality using traditional models. These models have been successfully adopted to manufacturing and service industries. As was noted by Porter and Rayner (1992), the PAF is the most widely used model especially in large companies. The model relates the various cost categories to each other, and shows that an increase in prevention and appraisal costs can lead to reduction in failure costs. However, applications of the PAF model in the software industry appear to have a number of difficulties. For example it is difficult to characterize the costs into the three known categories. In addition, the interest usually is limited to calculating the cost of quality during the development phase. As reported by Zelkowitz et al. (1979), the development portion of the software represents only 33% of the lifecycle cost. The remaining 67% are costs incurred after release (during operation and maintenance) while in the hands of the users. The majority of these costs represent external failure costs and cannot be ignored.

6. Conclusions

A review of the literature indicated that applications of traditional cost of quality models diverge from current trends in the software industry. There are no models that can help evaluate the cost of software quality based on its performance after release. New research efforts are needed to estimate these costs from the users' perspective. These authors are in the process of developing a cost model that accounts for deviations from performance targets established by the ISO 9126-4. The model will utilize the results of a survey instrument specially designed to assess users' perceptions of the software quality. Differences between standard performance targets and users' perceptions will represent the cost of poor quality. As such, the model will address the cost from the users' viewpoint and help evaluate the return on investment when making decisions to replace, upgrade, or continue to use the same software.

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Cycle Time Reduction in Course Scheduling: A Lean Six Sigma Project

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Abstract

Every semester, course scheduling for Electronic Systems Engineering Technology (ESET) can take a program coordinator several days to complete. Due to the increasing enrollment in the ESET program, there are more potential conflicts in course scheduling within the ESET program and with other programs. Sometimes, a course schedule has to be revised multiple times before it can be finalized. Each round of revision requires a long period of time. Even with the best efforts of the program coordinator, there have been many complaints from students and faculty members about the conflicting times and locations assigned to the courses and laboratories. A student team in the Applied Statistics and Six Sigma course worked on this problem as their Lean Six Sigma project. They followed the DMAIC process to define the problem, measure the current performance, analyze the cause of the problem, come up with a solution to satisfy the customers, and ensure the improved process will be followed. This paper presents the detailed work of this Lean Six Sigma project.

1. Introduction

Six Sigma is a popular tool used in industries for process improvement (Harry and Schroeder, 2000; Pande and Holpp, 2002). Lean manufacturing was introduced by Toyota to eliminate waste in a process (Womack *et al*, 1990). The combination of Lean and Six Sigma proposed by George (2002) brought tremendously successful applications to industries, health care, and service sectors.

Due to its importance, a large amount of literature in the area of Lean Six Sigma exists (Nonthaleerak and Hendry, 2006; Snee, 2004). Many higher educational institutions started to look into the possibility of incorporating Lean Six Sigma into their curricula (Coowar *et al*, 2006; Furterer, 2007; Gore, 2004; Ho *et al*, 2006; Rao and Rao, 2007; Scachitti *et al*, 2008; Zhan *et al*, 2010; Zhan and Porter, 2010; Zhan *et al*, 2009).

In 2012, based on the feedback from its industrial advisory board, the Electronic Systems Engineering Technology (ESET) program in the Department of Engineering Technology and Industrial Distribution (ETID) at Texas A&M University shifted its focus to product and system development (Porter *et al*, 2012). A new course ENTC 329, Six Sigma and Applied Statistics, was created as a part of the curricular revamp effort. It is a required course for ESET students. Students are required to complete a course project as their Six Sigma Greenbelt project. One of the teams chose to improve the ESET course scheduling process.

Every semester, the ESET program coordinator spends many days working on the schedule for ESET courses and laboratories. There are many factors that have an impact on course scheduling, including

- new courses offered
- existing courses eliminated
- new faculty members
- faculty members on leave (sabbatical)
- increasing student enrollments
- expanding lab sections
- larger classrooms required.

Courses typically taken by the same student group, let's say sophomores, are not scheduled at the same time. Many classrooms are shared among various departments and colleges, therefore, the availabilities of these classrooms are not guaranteed. It is not enough to create a schedule that works for ESET students and faculty. The draft schedule must be submitted to the department for approval and then to the university registrar's office for approval. Conflicts are often found during these approvals. The program coordinator usually needs to revise the schedule several times before it is finalized. The entire process can take months.

The student team spent eight weeks working on a project to improve the efficiency of course scheduling. This article presents the detailed execution of the Lean Six Sigma project. The student team followed the DMAIC process (Pyzdek, 2003; Wortman *et al*, 2001). Each step of the DMAIC process is presented in a separate section (sections 2-6). Conclusions and future work are discussed in section 7.

2. Define

Define is the first step of the Lean Six Sigma process. In this step, it is important to define the project scope, establish the business case, understand the current process, determine a performance metric, set a goal for the project, and assess the potential risks of the project.

Business case: Improving scheduling efficiency will allow more students to be educated with the given resources. The workload of the program coordinator will be reduced to allow him to focus on other important tasks.

Scope: Scheduling all ESET courses and laboratories without conflicts (Even though it can be extended to all ETID courses and laboratories later on as a follow up project)

Process Owner: ESET program coordinator

Stakeholders: ESET faculty, ESET students, ETID, and TAMU

Resources: Four students, eight weeks

Performance metric: time for creating a course schedule or making revisions to the schedule

Goal: Reduce the time for creating a course schedule by 50%

Risks: Lack of course scheduling experience by the team

To define the current process of making the ESET schedule, a meeting was held between the student team and the ESET program coordinator. A set of questions were prepared before the meeting in order to get a clear understanding of how the schedule was made each semester. After the meeting, the team had a good understanding of the current scheduling process. Based on the information collected by the team, the SIPOC diagram was created as illustrated in Fig. 1.

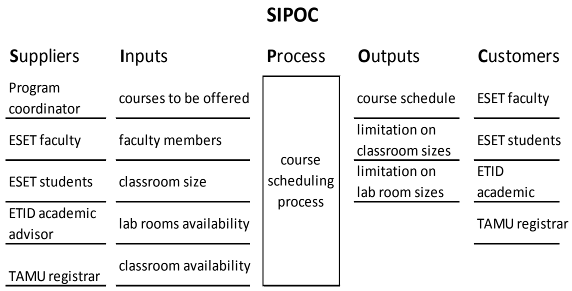

Figure 1. SIPOC diagram

The current course scheduling process was captured in Fig. 2 to provide a high level understanding of the current process.

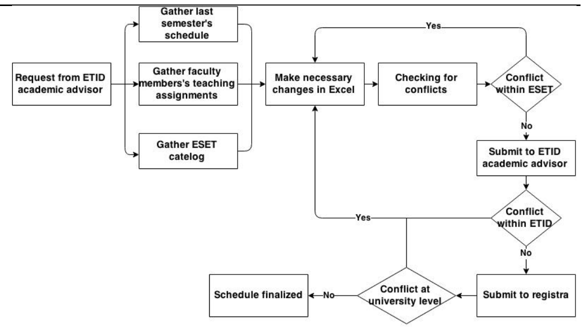

Figure 2. Current course scheduling process

Upon request from the departmental academic advisor, the program coordinator started to collect the information needed for course scheduling. Usually, the new schedule is based on the previous year's schedule and modified according to the changes in the curriculum, the faculty members, and the estimated student enrollment numbers.

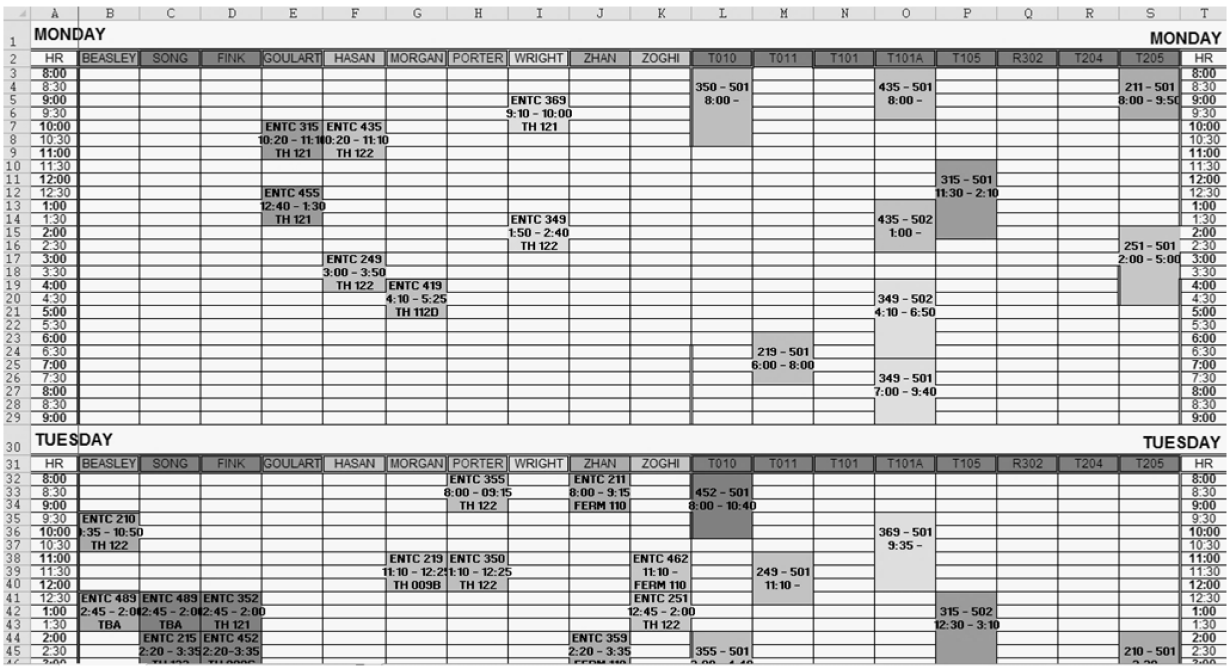

Figure 3. Excel program used in the current scheduling process

The software tool used to create the course schedule was Excel. All items were entered or revised manually. As illustrated in Fig. 3, the faculty members and lab rooms were listed as separate columns. The rows were days and time slots. Each item was color coded to help identify the courses taught by different faculty members or held in different laboratory rooms.

The constraints to the schedule consisted of the following factors:

- Every laboratory must use a designated room because it requires special equipment.
- Courses taken by certain groups of students must use different time slots for both lectures and laboratories so that they can take these courses at the same time.
- If the student enrollment exceeded certain limitations for a specific laboratory, extra laboratory sections must be created.
- It is imperative that a faculty member cannot be teaching more than one lecture or lab section at any given time. Many faculty members have preferences to teach at certain time slots and certain days of the week if the schedule permits.
- At least 20 minutes between classes must be reserved for students to walk from one class to the next.

Currently, there are 11 faculty members, eight laboratory rooms, and 22 courses offered by ESET. In addition, two technical electives may be offered. Each laboratory has a limit of 10-18 students per section. Therefore, the laboratory sections may vary depending on the student enrollment in each semester. In general, certain labs and courses cannot overlap in order for students to take a group of courses in the same semester. However, sometimes this restriction can be relaxed slightly, because most laboratories have multiple sections. One lab section having a conflict with another course may not be a problem. The process for making a new ESET schedule was a long and painstaking process. By the estimations of the program coordinator, creating one extra lab section sometimes could take upwards of three hours to complete. Typically, it was necessary to repeat the process several times due to conflicts at the department and university levels. Usually, large classrooms were not available at preferred times because they had already been requested by different programs either within the department or from a different department.

In order to understand the customer needs and what the team should do to improve the process, a CTQ tree was created, as shown in Fig. 4.

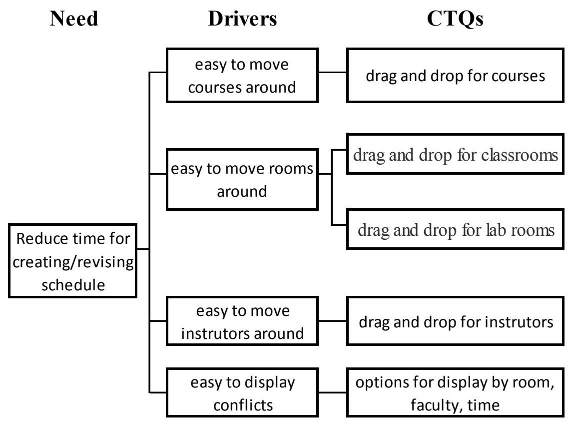

Figure 4. CTQ tree

The conclusions from the CTQ were:

- The software used for scheduling should have drag-and-drop capabilities for various operations such as moving courses around, moving classrooms, and moving instructors.
- There should be options for separately displaying rooms and faculty.

3. Measure

To establish the performance metric for the current scheduling process, the team decided to use four simple cases to test how much time it would take to finish revising the schedule. A copy of the Excel program used for ESET course scheduling was acquired from the program coordinator. After fully understanding the functionality of the Excel program, four tasks were selected for creating an extra lab section taught by graduate teaching assistants for various courses. The same tasks would be performed after an improved process was created. These tasks had fewer constraints than others and were easier to complete. Four members of the team completed the tasks, with the times each member took to complete the tasks recorded, as shown in Table 1. The average time for completing the tasks was calculated as 309 seconds and the standard deviation was calculated to be 86 seconds. This was used as the baseline performance of the current course scheduling process.

Table 1. Baseline process performance

	student					
	1	2	3	4	avg	std
time (sec)	197	402	302	336	309	86

4. Analyze

A brainstorming session was held to identify the potential causes of the lengthy scheduling time. The team used the Affinity Diagram method to come up with the Cause-and-Effect diagram shown in Figure 5.

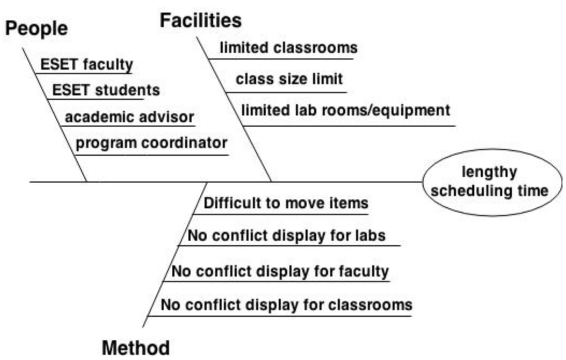

Figure 5. The Cause-and-Effect diagram

While changing people and facilities could make the process easier to complete, the resources required did not justify these to be the focus of the project. The focus was decided to be on the method, i.e., the software capabilities.

The team evaluated several commercial products and free software, including Google Calendar. Considering the cost, features available, and the learning required to use the software, Google Calendar was selected as the potential software tool that could be used to improve the scheduling process.

5. Improve

Google Calendar allows the user to only display selected items such as individual professor’s schedule (lectures and labs), laboratory schedule, and course schedule.

Without the selected display, the overall course schedule using Google Calendar, as shown in Fig. 6, seemed to be just as messy as the Excel program in Fig. 3.

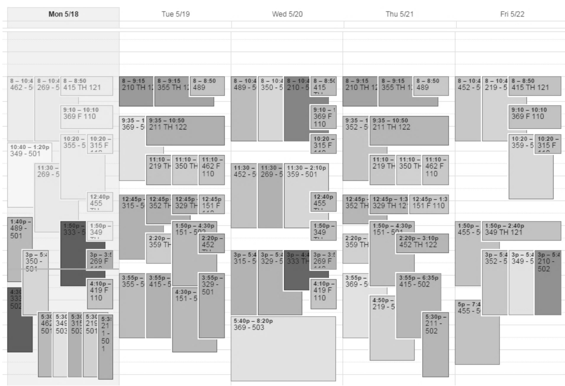

Figure 6. Course schedule using Google Calendar

With the selected display feature, one can easily find any conflicts among classes, laboratory room uses, and faculty time. By selecting a particular faculty member, his/her schedule can be display for checking any potential conflicts (Fig. 7). In this particular case, there was no conflict among the lectures and laboratories taught by this faculty member.

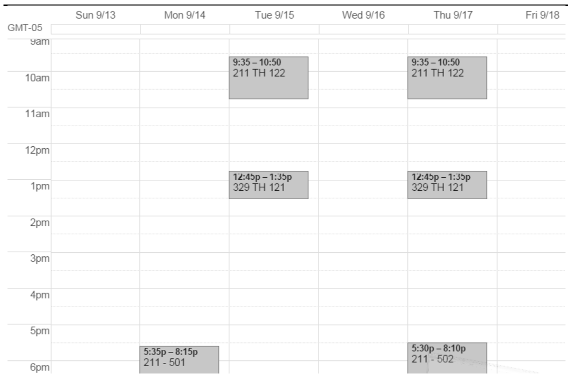

Figure 7. Schedule for a faculty member

Similarly, one can display a specific laboratory room to check for conflicts, as shown in Fig. 8. In this case, a conflict was identified.

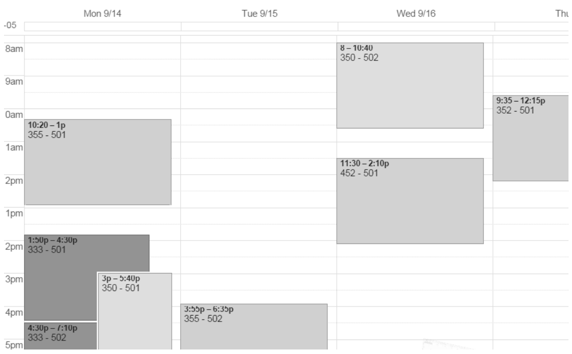

Figure 8. Schedule for a laboratory room

To eliminate a conflict, the user can simply drag the item to a new day and time slot. This process can be repeated until a satisfactory schedule is created. Color coding can be used to indicate different courses, different faculty members, and different laboratory rooms.

Using Google Calendar still requires manual entry of items. This can be time consuming for the first time or when there are significant amount of changes to be made to the course schedule. But compared to the Excel program, Google Calendar is significantly more efficient for course schedule revisions.

Google Calendar has many features that the Excel program does not have. Google calendar is easy to share among the faculty members. They can easily port their parts of the schedule to their own private calendar. Updating is also easy to accomplish. If additional features are desired, one can use the Google Application Program Interface (API) functionality for future improvements (see the following link for more detail) https://developers.google.com/google-apps/calendar/

6. Control

The course schedule for the current semester was fully implemented in Google Calendar. The same tasks tested in the Measure step to establish the baseline performance were tested in Google Calendar. The results are shown in Table 2.

Table 2. New process performance

	student					
	1	2	3	4	avg	std
time (sec)	78	53	102	90	78	25

The before-and-after performance metrics were compared in Fig. 9.

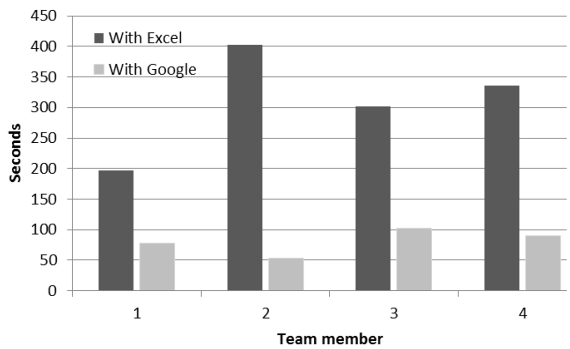

Figure 9. Before-and-after comparison

The average time and the standard deviation were reduced by 74% and 76%, respectively. The improvement exceeds the project goal of 50% reduction.

Due to the eight week time constraint of the project and the fact that course scheduling happens only twice a year, the team was not able to use Statistical Process Control (SPC) to monitor the performance of the new process.

7. Conclusions and future work

A Texas A&M University student team used Lean Six Sigma to reduce the course scheduling time for the ESET program.

Following the DMAIC process, the student team focused on the improvement of the software tool used for adding and changing classes for the ESET schedule. Google Calendar was identified as a better tool than the current Excel program.

With all the known constraints, one could probably develop a software tool that would automatically generate a schedule with no conflicts. However, the cost associated with the software tool makes Google Calendar a preferred solution.

Before-and-after analysis shows more than 74% reduction in time needed for scheduling courses. The improvement was much larger than the project goal of 50% improvement. A user guide was created so that the new process can be easily used by the program coordinator, other faculty members, and any potential user who would like to use Google Calendar for scheduling.

Future work includes implementation at the department and university levels after validation within ESET. SPC should be used to monitor the improvement each semester. Specific process performance metrics that can be used in SPC include time to create a new schedule, time to add a class, and time to add a laboratory section. The X bar-R charts can be used to monitor the process improvement and variation. Google API can be used for adding desired features to the Google Calendar for scheduling purpose. Using a third party app, such as GTimeReport or WinCalendar, the course schedule created in Google can be exported onto an Excel sheet. This allows seamless integration of the ESET schedule with other schedules at the department and university levels, where Excel is currently still being used as the software tool for scheduling.

In addition to the improvement made to the ESET scheduling process, this real-world project helped the Six Sigma team understand how the DMAIC process could be utilized to improve business efficiency.

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Dynamic Validation of Customer Satisfaction Surveys

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Abstract

Surveys are efficient tools for measuring customer satisfaction. Indeed, customer feedback analysis is a challenging task and few guidelines have been provided on the dynamic validation of the survey design used. This study is aimed at the development of a framework that can be used to update the survey items based on customer response to open ended questions. An illustration of the proposed framework is provided through a case study involving applications of several qualitative and quantitative data analysis techniques. The results supported the need for dynamic validation to help identify new requirements and emerging patterns of customers' expectations.

1. Introduction

Customer feedback analysis has been given great attention in recent years since customer satisfaction plays a major role in organization's success. There are several qualitative and quantitative data analysis techniques that have been used to obtain better understanding of customer requirements, measure customers satisfaction, and assess the quality of products and services offered. According to Juran and Godfrey [11], techniques that can be used to capture customer requirements include surveys, interviews, and focus groups. Surveys are considered as one of the most effective methods for measuring the level of customer satisfaction.

A survey or questionnaire consists of closed-ended questions and open-ended questions. Responses to closed-ended questions are limited to pre-specified ratings without further explanations. On the other hand, Open-ended questions allow respondents to express their perceptions, state their needs or wishes and comment on the quality of product used or service provided.

In fact, closed-ended questions reflect requirements as they have been perceived by the providers and not the actual requirements. Including open-ended questions in a survey provides an opportunity to discover new customer requirements and update the survey design.

The purpose of this paper is to develop a framework that can be used to update the survey items based on customer response to open-ended questions.

The following section provides a review of the literature pertaining to surveys and relevant analysis techniques. Section 3 represents a description of the proposed framework. A case study with the steps taken to update the design of an old survey based on responses to open-ended questions is presented in Section 4. This is followed by a discussion of the results and final conclusions.

2. Literature Review

A comprehensive review of previous studies conducted in the area of quality and customer satisfaction indicated that several qualitative and quantitative techniques have been used to analyze customer feedback. Each technique has different features, characteristics, advantages, and disadvantages. According to Grigoroudis and Siskos [8], qualitative survey methods are used when the aim of the survey is to investigate the behavior of customers whereas quantitative survey methods are used when the aim of the survey is to examine the attributes and performance of the product or service as well as to determine specific quantitative indices. Both qualitative and quantitative research methods can be used to analyze customer's feedback.

Customer satisfaction measurement is a main concern for all companies since it provides an indication about the quality of the service provided or product offered from the customers' viewpoints. According to Fornell [6], customer satisfaction results in increasing customer loyalty and saving money in the long term. Moreover, customer satisfaction is considered as the standard of excellence for an organization. Cengiz [6] stated that measuring customer satisfaction yields long term success in the market, better understanding of customers' needs, improved services and products. According to Gerson [7], measuring customer satisfaction is an effective way to understand customer expectation.

Pinsonneault and Kraemer [17] categorized surveys into three different types. Exploratory, descriptive, and explanatory. An exploratory survey is used to understand the subjects and main concepts. A descriptive survey is conducted to study different cases and events, explore human opinions and attitudes. In contrast, an explanatory survey is used to test a theory and the relationships among factors. Another categorization of surveys include cross-sectional surveys and longitudinal surveys. Cross-sectional surveys are used to analyze customer feedback in a single time whereas longitudinal surveys are used to analyze data over several periods of time. Reliability and validity are the most important issues when conducting a customer satisfaction survey. The survey results include two kinds of errors. These are systematic and random errors, which are related to validity and reliability of the results [8]. Hayes [9] demonstrated the importance of survey reliability and illustrated methods of reliability measures, which include test-retest, parallel form, spilt half, and Cronbach's alpha.

According to Cohen, Manion and Morrison [5], a typical questionnaire survey includes closed-ended questions and open-ended questions. Closed-ended questions are questions with multiple choices in a scale format, whereas open-ended questions are statements with specific information, and respondents are allowed to express opinions in their own words. Closed-ended questions provide simple data, are faster to code and easier to analyze. However, the respondents cannot add further explanations to support their answers. Sproull [18] and Cohen et al [5] stated that open-ended questions help to capture customer satisfaction but require more time from the respondents to answer. Numerous research has been conducted in the area of customer feedback analyses and several techniques are found to be useful in analyzing open-ended questions.

Computer-aided text analysis (CATA)

There are several qualitative data analyses, which can be used to analyze written comments of customers utilizing text mining and themes identification functions [17]. Qualitative data analysis techniques can be facilitated by using computer-aided text analysis (CATA) software programs. Utilizing different types of qualitative data analysis techniques to analyze customers' feedback results to provide deeper understanding of their perceptions toward the products consumed and services received.

Leech and Onwuegbuzie [12] demonstrated 18 qualitative data analysis techniques and categorized them based on the source of data. This included talks, observations, photographs, videos, and documents.

Most studies in the area of qualitative research have only focused on a single data analysis technique. Indeed, there are several CATA with different features, functions, and tasks. Using CATA facilitates data analysis, records conversations, stores respondents' data, organizes and codes qualitative data [14].

According to Bazeley [1], CATA facilitates categorization and coding of data as well as helps to reduce the time required to analyze qualitative data. Leech and Onwuegbuzie [13] stated that adopting qualitative data analysis procedures yields rigorous results and there are seven types of qualitative data analysis techniques, which can be applied in qualitative research by utilizing CATA such as NVivo [16] software. However, there are limited explanations of the different qualitative data analysis techniques embedded within commercial computer software programs.

Concept Mapping (CM)

Concept mapping (CM) has been successfully utilized to analyze open-ended questions through two techniques: code-based and word-based. Both can be used to develop research questions and analyze survey results. The main feature of CM is that it involves the respondents in the coding of the text and uses original statements as units of analysis.

Additionally, data structures are allowed to emerge using Multi Dimension Scaling (MDS).

Jackson and Trochim [10] outlined five steps of CM: creating units of analysis, performing MDS analysis of the pile-sorted data, deciding on the final cluster solution, and labeling the clusters.

There are several ways for interpreting CM results. As the units of analysis represent structured conceptualization of the data, evaluation of the map for regions of meanings is possible. A region on the map, which forms a cluster, is grouped together with other regional groups to form clusters. Decisions about regional distinctions are conducted by theoretical preconceptions or through group discussion.

Jackson and Trochim [10] demonstrated some advantages of the CM technique. These include creating items and defining dimensions in the process of scale development, showing how different groups of people might generate different solutions depending on their experience, identifying the similarity between concepts and clusters of respondent experience, and saving time. However, coding decisions which are typically made by researchers can impact the reliably and validity of the results. These represent different challenges when applying "word-based" and "code-based" methods.

The following section represents a framework, which utilizes computer-aided text analysis (CATA) and Concept Mapping (CM).

3. Proposed Framework

The proposed five steps framework is shown schematically in Figure 1. The first step involves data collection. This step is typically taken by the researcher following the administration of a survey including some open-ended questions. Customers' responses and comments are gathered and typed representing units for analysis. Lengthy statements are divided into simple units and ambiguous comments like "not sure", "do not know", and "nothing" are removed. Accordingly, units are classified under requirements already targeted in the original survey design. This will provide further validation of these requirements and their relative importance from the customer's point of view. All remaining units are compiled in a single document and saved in a portable document format (PDF) for further consideration.

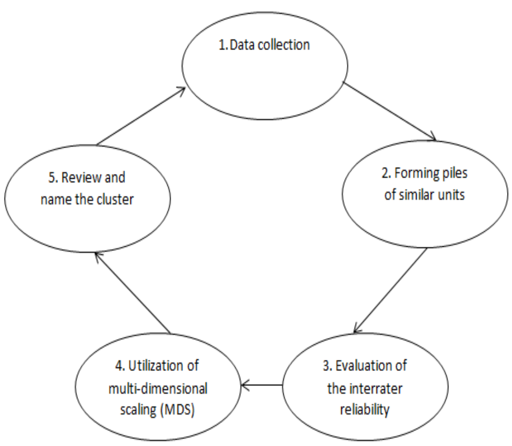

Figure 1: Proposed framework

The second step involves forming piles of similar units by a minimum of two sorters preferably selected from the target population or the design team. This is aided by text analysis software where similar units are grouped into different nodes. Depending on the units included, sorters are supposed to propose a name for each node.

These results are used to prepare a binary matrix for each sorter. The matrix cells are filled with 1 for the units grouped together and with 0 otherwise. These matrices are combined to form a similarity matrix. This typically consumes most of the researcher's time.

The third step involves an evaluation of the interrater reliability following the procedures recommended by Nunnally [15]. Statistical analysis programs (e.g., SPSS) support these calculations and help eliminate errors. Acceptable levels of reliability are required to justify aggregation of binary matrices. According to Nunnally [15], a basic research reliability of about 0.70 or better is acceptable and indicates methods for calculating the number of sorters to be added to increase reliability to an acceptable level.

The fourth step involves an application of multi-dimensional scaling, based on the similarity matrix. Again, SPSS [19] is one of a number of software packages with a built in MDS function.

The MDS constructs a two-dimensional map based on Euclidean distances computed from the similarity matrix. Clusters indicate units (statements) that were piled together most often by the sorters. The optimum number of clusters can be identified following the procedures recommended by Burn and Burn [3]. This involves a two-stage sequence of analysis. In the first stage, a hierarchical cluster analysis utilizing Ward's method based on the squared Euclidean distance.

In the second stage, cluster analysis is performed to help assign each unit of analysis to a specific cluster.

During the final step, the resulting clusters are reviewed and named by the sorters. This can help identify new requirements to be considered in updating the survey design. The following section represents an application of the proposed framework and the results obtained.

4. Case Study

Begum and Weheba [2] represented a comparison between the concept mapping and critical incident techniques with respect to their ability to identify customer requirements. They included a case study involving the design of a survey that can be used to measure students' perceptions of in-class presentations. As a result, six requirements were identified: organization and content of slides used, clarity of speech, use of examples to explain the concepts, appropriate use of figures and graphs, ability of the presenters to work together and answer questions. Following the identification of these key requirements, the survey shown in Figure 2 was designed. As shown, the survey includes a total of 10 questions of which three are open-ended questions. This study represents the steps taken to analyze the students' feedback in an effort to validate the survey design.

Data collection

The survey was administrated 23 times during the fall semester of 2013 and 2014 following in-class presentations. Students' responses to the three open-ended questions were collected resulting in a total of 1190 written comments. A list of all the comments was prepared and used to create units of analysis. In order to reduce the time required to analyze the large number of students' comments and achieve high reliability, NVivo 10 software was utilized for data analysis.

Did you read this paper before class? ☐ Yes ☐ No

#	Question	Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree
1	The presentation (organization and content of slides) was well-prepared	☐	☐	☐	☐	☐
2	The manner of presentation (voice level, clarity of speech, etc.) was satisfactory	☐	☐	☐	☐	☐
3	The group included appropriate examples to explain the concepts of the paper	☐	☐	☐	☐	☐
4	Figures and tables were properly utilized and explained	☐	☐	☐	☐	☐
5	Members of the group had equal chance to participate in the presentation	☐	☐	☐	☐	☐
6	The group successfully answered all questions	☐	☐	☐	☐	☐
7	Overall, I am satisfied with the presentation	☐	☐	☐	☐	☐
8	What did you like most about the presentation?					
9	What did you like least about the presentation?					
10	In what ways would you like to see this presentation improved?					

Figure 2: Survey questions

As shown in Figure 3, six nodes were created on Nvivo each representing one of the original six key requirements reported by Begum and Weheba [2]. An additional node termed "others" was created to include comments that do not pertain to any of the six key requirements. Each unit of analysis was placed in one of seven nodes by the researcher. The results are summarized in Figure 4. As shown, efforts to prepare the presentation (Q1), and the use of appropriate examples to explain the concept (Q3) appear to represent the most important requirements.

In addition, a total of 30 units were classified under the others node for further analysis.

Data analysis

The concept mapping (CM) procedure was applied to analyze the 30 units identified from the students' comments. Five students volunteered to sort and label these units utilizing NVivo. The sorters were provided instructions on the use of NVivo and the steps needed to create nodes, sort statements and save the results. Each sorter was asked to group similar units into one node and propose a name for each node. This resulted in a total of 18 nodes as shown in Figure 5.

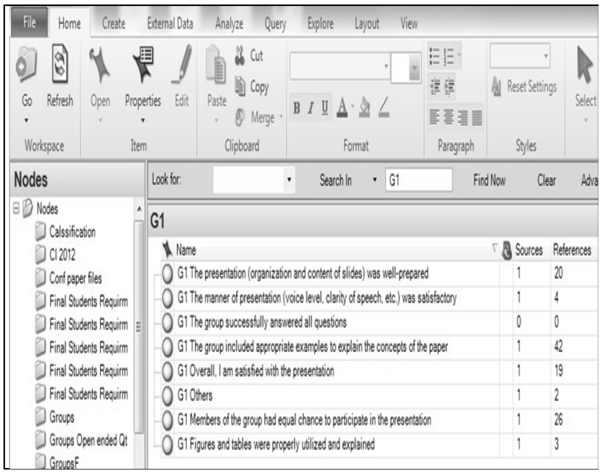

Figure 3: Snapshot of NVivo 10

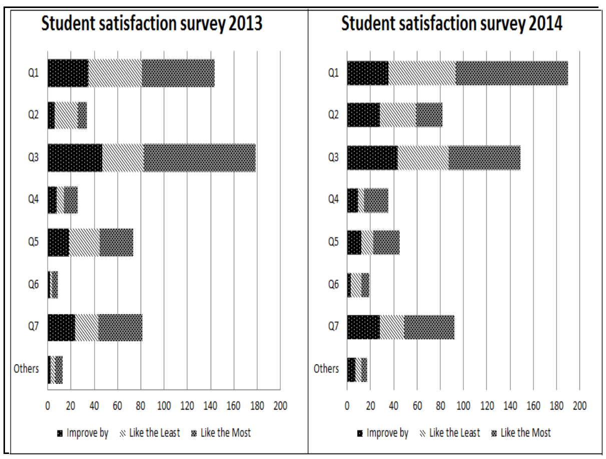

Figure 4: Distribution of statements in open–ended questions

These results were used to prepare a 30x30 binary matrix for each sorter. The matrix cells were filled with 1 for the units grouped together and with 0 otherwise. The five matrices were combined to form the similarity matrix a part of which is shown in Figure 6.

To evaluate reliability (internal consistency), the correlation between each sorter's binary matrix and the total similarity matrix was calculated as recommended by Nunnally [15].

As shown in Table 1, these values were consequently used to estimate the corrected reliability by utilizing the Spearman-Brown prophecy formula.

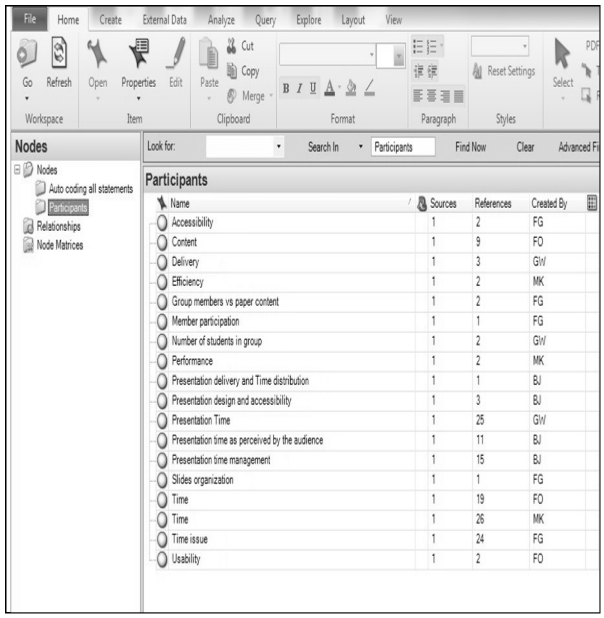

Figure 5: Clusters of requirements

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
S1	5	3	4	4	5	3	5	0	4	1
S2	3	5	4	4	3	2	3	0	3	1
S3	4	4	5	5	4	2	4	0	3	2
S4	4	4	5	5	4	2	4	0	3	2
S5	5	3	4	4	5	3	5	0	4	1
S6	3	2	2	2	3	5	3	1	4	0
S7	5	3	4	4	5	3	5	0	4	1
S8	0	0	0	0	0	1	0	5	0	2
S9	4	3	3	3	4	4	4	0	5	0
S10	1	1	2	2	1	0	1	2	0	5
S11	4	3	3	3	4	4	4	0	5	0

Figure 6: 30 X 30 matrix for the units (partially shown)

In addition, an estimate of the Cronbach alpha coefficient of 0.9690 was obtained indicating a high level of agreement among sorters.

As such, the similarity matrix was used as an input for the multi-dimensional scaling (MDS) procedure in SPSS [19].

The MDS generated the two-dimensional map shown in Figure 7, based on Euclidean distances computed from the similarity matrix. Clusters indicate units of analysis (statements) that were piled together most often by the sorters.

In order to identify the optimum number of clusters, a two-stage sequence was followed. In the first stage, a hierarchical cluster analysis utilizing Ward's method with squared Euclidean distance was used. This resulted in generating two clusters based on units' similarities. In the second stage, cluster analysis was rerun with two clusters to help locate each unit of analysis to the specific cluster.

Table 1: Correlation coefficients as measures of Individual to Total Reliability

Sorter	Correlation coefficients	Corrected reliability
GW	0.9632	0.992
FG	0.5954	0.880
MK	0.9028	0.979
FO	0.9172	0.982
BJ	0.7931	0.950

The final clusters with units were reviewed, examined and named by sorters. The two clusters were named "presentation time" and "presentation availability". Figure 8 represents two clusters as identified.

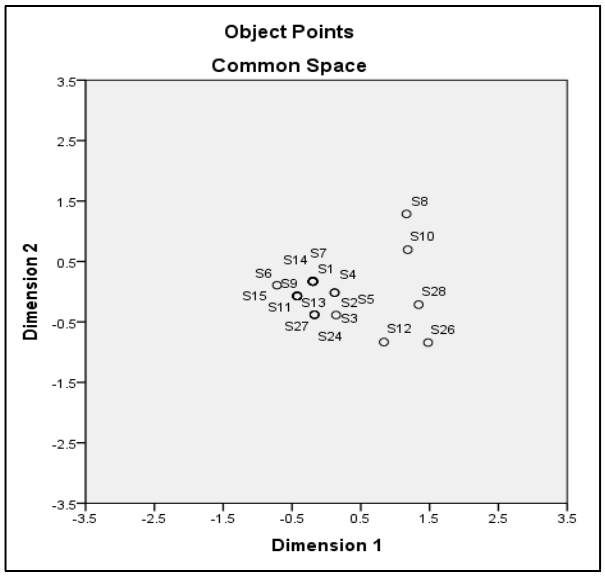

Figure 7: Two-dimensional map

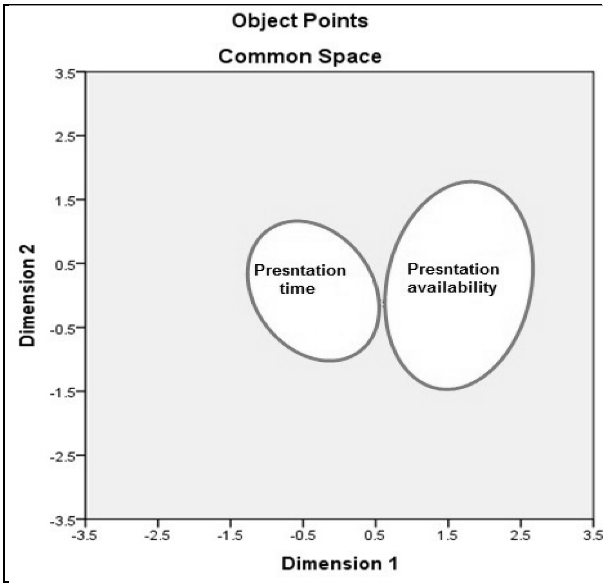

Figure 8: clusters of student requirements

5. Discussion

Student responses to open-ended questions were difficult to group into piles without filtering statements. Moreover, some of the statements included more than one unit of analysis. In order to advance the analysis, complex statements were divided into a number of units.

In CATA, the researchers performed the analysis without involving respondents in the initial steps. By utilizing NVivo, sorters were able to group similar units efficiently and in a manageable way. The time required to construct the concept map was reduced by utilizing the SPSS software. The results of the study indicated that students' requirements are dynamic and need to be validated over time. The survey was updated by adding two questions with appropriate scales to measure students' satisfaction with future presentations.

6. Conclusions

The literature provides strong evidence that both quality and customer satisfaction are dynamic concepts that continue to challenge product designers and service providers alike.

Surveys designed to measure customer satisfaction need to be reviewed periodically to ensure their relevance and validity. The availability of computer aided text analysis (CATA) software has made it possible to reduce the time to analyze customers' responses to open-ended questions. Traditionally, responses have been difficult to analyze and sort manually. CATA has provided the means by which the total number of units (statements) can be reduced to a manageable sum. A majority of the researcher's time is spent creating the similarity matrix required for multidimensional scaling and cluster analysis. These quantitative techniques add to the objectivity of results and help discover new requirements.

This paper provides a dynamic validation framework that can be used to update survey designs based on customers' responses to open-ended questions. An illustration of the proposed framework is provided through a case study involving applications of several qualitative and quantitative data analysis techniques. The results supported the need for dynamic validation and indicated its ability to identify new requirements and emerging patterns of customers' expectations.

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The Four P's of Technology Management

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Abstract

A common mistake in technology management is trying to change one element of the organization without considering the impact on other areas. Actions that solve a problem in one area may only lead to one or more problems elsewhere. Without consideration for the linkages in a technology organization, there is no guarantee of convergence on a complete solution. But what are the linkages to consider when planning, evaluating, or making decisions? The authors have identified four major areas of technology organizations that are critically dependent: People, Planning, Projects, and Process. These four P's of technology management are presented as an integrated model. Development of the model was accomplished through a survey combined with literature research that led to a conceptual model for technology management that can serve as a guide to future research and management practice. At the core of the model is the assumption that the organization is a community of knowledge workers. These knowledge workers engage in repeated cycles of planning, followed by project execution. Finally, some process is employed to structure their efforts. This paper substantiates the interdependence of these aspects of managing in a technology organization. Each area was shown to impact every other area. This has implications for any manager of technology organizations who is making a decision that will affect any one of these areas.

1. Introduction

High tech organizations are always trying to improve their performance. Some of the reasons are customer satisfaction, lower cost, and competitive advantage. Because of the rapid pace of technological change, organizations have to constantly adapt and optimize execution. What factors in a high-tech organization affect performance? What is the relationship between those factors?

At times, an attempt to improve in one area of the organization just results in problems with another area. When a decision is taken, the overall effect on the business is usually considered. What is often missed are the corollary effects that decisions have on different aspects of the organization. Do all of these areas impact the others? Understanding those connections could have major relevance for managers trying to make decisions without having unexpected consequences. Therefore, the goal of this research was twofold. First, determine a set of critical factors in managing a technology organization. Second, validate whether or not there are linkages among the four factors.

H_0: The key management areas of a technology organization are not independent, meaning that changes in one area are likely to have corollary impact in other areas.

2. Methodology

The methodology for this research was a combination of a survey followed by literature research based on the survey findings that was used to develop a conceptual model for technology management to guide future research efforts and management practice. Phase I of the research began with a survey among present and former managers of technology organizations. All of them were asked to list the most important elements in managing a technology organization. In choosing the factors, the managers were asked to focus on things that they would have the most direct control over. External factors (e.g., the state of the economy) and some internal factors (budget, sales volume) were deprecated because of this bias. The authors distilled the results into four key areas that were universally identified: people, planning, projects, and process (see Appendix A).

Preliminary evidence in the literature pointed to the need for investigating connections among these areas. Clark and Collins (2005) noted the lack of engagement between project management and human resources management in the literature. Although development processes such as CMM have been around for some time, there have been few studies that measure the improvement in project performance resulting from process maturity (Di Tullio & Bahli, 2013).

Based on the results of the survey and positive indications in the literature, the authors proceeded with the research using the following assumptions. First, this research is aimed at organizations that primarily use knowledge workers (Drucker, 1957) to accomplish their goals. Second, planning might occur at many levels in a company. It will be considered anywhere that it might impact the other three factors. Third, the activities of the knowledge workers are project-based. Fourth, some identifiable process is used for managing the projects. While not all organizations employ a formal process, it was indicated by all responders as a critical success factor.

2.1 The Four P’s

Phase I of the research resulted in the four P’s of technology management: people, planning, projects, and process. Figure 1 is a visualization that represents the relationship among the four P’s that this study intended to verify. That is, the heart of the organization is represented by knowledge workers. The workers are involved in recurring cycles of planning and project execution. Enveloping this planning and project cycle is some process or processes that guide project, planning, and people activities.

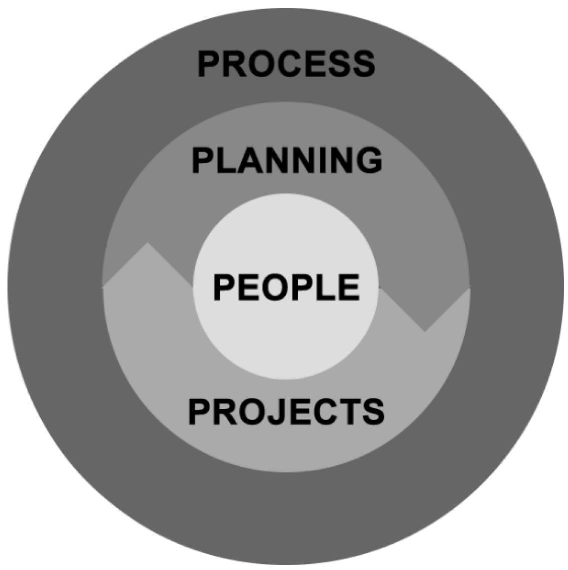

Figure 1. The Four P’s of Technology Management

Phase II of the research consisted of an in-depth review of the literature with the goal of establishing whether or not each of the four P’s has an impact on the other three. There has been literature – even seminal works – in the areas of knowledge workers (DeMarco & Lister, 1987), project management (Kerzner, 1995), process development and usage (Harry & Schroeder, 2000), and planning strategies (Mintzberg, 1994). Each work tends to be focused in its particular subject area. In some cases the effects of one area on another is the subject of the research. From a technical standpoint, these are useful. They can be used for risk mitigation in specific circumstances. From a management standpoint, they may fail to show how these connections fit into a larger picture.

It is a relatively boring tautology to state that an area has impact on itself. The point of this research and the visual model is to compel managers to look beyond the area that is immediately being affected so that the consequences in other areas are taken into consideration. Obviously, a single paper cannot consider all of the possible interactions among the four factors. However, the point of this paper is to substantiate the co-dependency of these areas in a technology organization. Therefore, it is sufficient to show that each of the factors can have a significant impact on each of the other factors.

In order to show that inter-dependence, the following four sections examine the four P's with a common format. First, the area will be identified and briefly discussed. Then, the relationship to the other three factors will be explored.

3. People

People are at the core of the model for a reason. Human resource management (including recruiting, retention, morale, and development) is the top success factor for high technology organizations (Menefee & Parnell, 2007). According to Ivancevich and Duening (2002, p.11-12), there has been a substantial shift from the labor-based workforce of the 1980's and earlier. Now, for a firm to compete effectively, it must have high-powered technology workers who are managed effectively and led with finesse. If not, the reality of the marketplace is that these workers are highly mobile and can find another job with relative ease (Massaro, 2012). Companies need to have HR policies and strategies for retaining these scarce resources (Holland, Hecker, & Steen, 2002).

3.1 People Impact on Planning

That mobility and availability of the right people can impact the number and type of projects for which a company can plan. If knowledge workers are the key drivers of the company, availability of people with the needed skills can limit planning options. The shortage of skilled knowledge workers, particularly in IT-related fields, is a significant problem in many western economies (Holland, Hecker, & Steen, 2002).

Some types of workers may not mind if they are told what to do without knowing why. Knowledge workers are not like that. They do not necessarily have to be part of the planning process, though that is advisable, because it is critical that they understand and support the company's mission (Massaro, 2012).

3.2 People Impact on Projects

How the people in a company are organized can have an impact on projects. On the one hand, projects are more successful when team members reported to a functional manager. The expertise of the manager is another people dimension that contributes to team success. But the project team should have more power than the functional organization to maximize project success because empowered teams are more successful (Case, 1998).

People on empowered teams are also likely to be more committed to the project. Research has definitely shown the importance of commitment in achieving success in any initiative (Shepherd, Haynie, & Patzelt, 2013). Case (1998) found that the level of emotional commitment from team members was a key ingredient in the performance of a successful, empowered project team.

Having people with the right skills on a project is essential. The higher the concentration of knowledge workers on a project, the more likely it is to succeed (Waters

& Beruvides, 2012). But if those people don't get along with one another, it is likely to have a negative impact on the project's outcome (Liu, Chen, Klein, & Jiang, 2009). A manager has to consider the social fit of the people on the team as well as the technical fit.

Then there is simply not having enough people (Geambasu, Jianu, Jianu, & Gavrila, 2011). The longer a project is expected to take, the more likely that some employees will leave during the project. Turnover is disruptive to the project team as well as the project, even to the point of reducing the competitive advantage of the organization (Parker & Skitmore, 2005). Because firms have to deal with turnover, recruiting has to be sufficient to keep projects staffed (Ivancevich and Duening, 2002, p. 26).

3.3 People Impact on Process

Managers must develop a culture that motivates its knowledge workers (Massaro, 2012). Bruno et al (2011) found that motivation was a key component in improving business process management. It may be easier to motivate different types of people. The nature of the people in a knowledge organization may contribute to the adherence to a process. Chatzogou (1997) found that people in technology organizations chose to use a methodology 75% of the time versus 33% for general industry projects.

Agile methods are gaining in popularity. One of the key assumptions in using agile methods is that there will be a high level of effective communication among team members (Geambasu, Jianu, Jianu, & Gavrila, 2011). This makes it essential to choose people who can collaborate on a team.

Conflict can occur among team members. It has been thought that process could be a mitigating factor. However, process cannot totally mitigate bad team dynamics (Liu, Chen, Klein, & Jiang, 2009). This makes it even more important for managers to motivate and foster effective communication on their teams early in the process. Communication is the ultimate success factor for projects (Frese & Sauter, 2014).

4. Planning

It is almost too obvious to point out that poor planning can adversely affect almost everything that follows. Poor financial or product planning can have disastrous effects on every part of the company. For this section, the focus is on some of the more direct effects between planning and the other P's.

4.1 Planning on Projects

Simple bad planning is often cited as one of the top reasons for project failures (Shaker, 2010). The most important area of planning is understanding the requirements of a project. Frese & Sauter (2014) found that inadequate requirements was a top factor in both challenged and failed projects.

Planning happens at multiple levels. At the highest level, the company has strategic planning that should guide all of its efforts. The strategic plan results in a tactical plan with a variety of projects, activities, and initiatives around the company. Within each project or activity, planning occurs at different phases depending on the approach taken. Failure to align the tactical projects with the strategic plan is one of the main reasons for project failures (Slaughter et al, 2006).

4.2 Planning on Process

Given that poor requirements lead to project failures, undertaking a long-range project without complete requirements is a poor choice. Perhaps this is why agile methods like SCRUM have been gaining in popularity (Murthi, 2002). In SCRUM, projects are broken down into a series of sprints that are normally around two weeks long. Planning occurs at the beginning of each sprint. This allows for more flexibility and customer interaction during the project. If the project planning will happen incrementally, an agile approach will be more effective (Hanna, 1995).

An organization must align its efforts with the results of strategic planning. But a given process may not fit all strategic objectives. A company can be more effective if the choice of process is taken after consideration of the proposed strategy and goals (Slaughter et al, 2006).

4.3 Planning on People

There is perhaps no more important plan for a company than its overall strategic plan. Everyone has to be doing his or her part to implement the plan. But what if some people are not committed to implementing the strategy? In their research of technology companies, Kohtamäki, Kraus, Mäkelä, and Rönkkö (2012) found that participative strategic planning significantly increased personnel commitment to strategy implementation. Due to the pace of technology, it does not always seem like it is worth the time to include more people in the planning. Taking the time during planning to build consensus and inform the team can seem like a luxury (Mildon & Kleiner, 1999).

Forecasting the number of people needed for a project is a particularly important aspect of planning (Ivancevich and Duening, 2002, p. 27). In particular, understaffing a project will put a strain on all of the people involved in the project. A company can make allocations at the department / project level or at a higher corporate portfolio level. When projects are planned at the portfolio level by upper management, they are less likely to feel (or consider) the impact on the individuals working on the project (Shepherd, Haynie, & Patzelt, 2013).

5. Projects

There are companies that achieve many of their objectives through processes (chemicals, petroleum) or discrete manufacturing (automobiles, diapers). For the purpose of this research, the assumption is that the output of the organization is the result of one or more projects.

5.1 Project Impact on Planning

Projects have planned outcomes on which companies rely. When a project fails, it throws that plan into turmoil. Unfortunately, statistics like the often-cited Chaos report from the Standish Group show that over 30% of projects fail (Frese & Sauter, 2014). Many more are challenged in ways that require altering plans.

5.2 Project Impact on People

In an organization that is project-oriented, the nature of those teams will affect the kind of people that get hired (Clark & Colling, 2005). If the management of the project team is strong technically, they will have a stronger influence on the hiring choices than functional management.

Innovation is a key component of technology-driven organizations. It is often said that failure is an essential ingredient in ongoing innovation. Unfortunately, management often fails to support the people involved in failed projects (Farson & Keyes, 2002). Of all the consequences of project failure, the emotional impact on the people working on the project has rarely been studied (Shepherd, Haynie, & Patzelt, 2013). That will certainly occur if failed projects result in job loss or a less preferable assignment.

Medium-sized projects often occur in parallel and compete for the same resources (Swaroop, 2007). One of the issues faced by managers of multiple projects is resource allocation and commitment (Swaroop, 2007).

5.3 Project Impact on Process

Geambasu, Jianu, Jianu, & Gavrila (2011) showed that the nature of a project can have a significant impact on the success of different life cycle processes. They found that a number of project factors should be analyzed when choosing the type of life cycle project: clarity of the initial requirements, accurate initial estimation of costs and development time, incorporation of requirements changes during the development process, obtaining functional versions of the system during the development process, software criticality, development costs, length of the delivery time of the final system, system complexity, communication between customers and developers, size of the development team, costs and development time, incorporation of requirements changes during the development process, obtaining functional versions of the system during the development process, software criticality, development costs, length of the delivery time of the final system, system complexity, communication between customers and developers, and size of the development team. Without consideration for these factors, the nature of the project could conflict with the chosen process.

If the details of a project are very clear up front, a waterfall approach can be used. But if the full nature of the project will only be discovered as it proceeds, agile methods will be preferable and waterfall will be negatively impacted (Hanna, 1995).

6. Process

There are a growing number of commercially-supported development methodologies available for managing projects (Chatzoglou, 1997). This is evidenced in process improvement initiatives like the Capability Maturity Model or CMM (Phillips, 2007) and Six Sigma (Harry & Schroeder, 2000). Relatively few companies have yet to follow a process as rigorous as CMM (Liaqat, Qureshi, and Shahid, 2012). As processes are improved, there may be implications in other areas to be considered.

6.1 Process impact on People

Given the independence of knowledge workers, the introduction of process can seem like a constraint. Six Sigma is one of the most explicit and statistically-driven processes for quality improvement. Yet it has been shown to improve job satisfaction among participants (Schön, Bergquist, & Klefsjö, 2010).

As discussed, knowledge workers can be highly mobile. Ton and Huckman (2008) studied the impact of process on high-turnover organizations. In addition to the loss of talent, there are negative effects on the people remaining in the organization. The good news is that the negative impact of turnover is much lower in high-process-conformance organizations versus low-process-conformance. So the introduction and enforcement of process is a positive influence.

Innovation is key to winning in today’s disruptive world. The Ritz-Carlton has developed a process for developing innovations internally, rather than sourcing them externally. This high degree of employee engagement has dual impact. First, the employees are happier through recognition, personal growth, and advancement. Second, the company benefits by more fully yielding the full potential of their workforce (Timmerman, 2009).

6.2 Process Impact on Planning

At the most basic level, adopting a process like Six Sigma or CMM requires planning in order to be compliant. It will require planning activities, but will also bring order to them. A waterfall approach will require a lot of planning to be done early in the project, whereas agile methods allow for more dynamic plans (Hanna, 1995).

Upper management support is a key factor in project success. If there is no process to translate the goals of upper management into the ongoing projects in the company, then projects may not align with upper-management objectives. Those projects run the risk of being derailed if a management review determines that it does not support their intended direction (Slaughter et al, 2006).

6.3 Process Impact on Projects

This is one of the most obvious, yet least practiced, relationships. Process has been considered an integral part of project management for some time.
Not all methodologies are suited to every type of project. Choosing the correct one can make a positive contribution to project success (Chatzoglou, 1997). One of the biggest choices today is between a traditional waterfall process or agile methods. Liaqat, Qureshi, and Shahid (2012) define criteria for deciding when to use agile models in order to reduce the failure rate of projects.

Perhaps the most important measure is that overall process maturity has been shown to have a direct impact on project outcomes (Di Tullio & Bahli, 2013). Requirements definition and management (RDM) is one of the most critical phases in project development. RDM process maturity has a very strong correlation with project outcomes (Ellis & Berry, 2011). There is even evidence that improving RDM maturity will translate into better project performance.

7. Discussion

The goal of this phase of the research was to determine if each of the four P's has impact on any or all of the others and to develop a conceptual model to represent those impacts.

People were shown to impact planning through availability or skills shortages as well as their need to be involved or informed of the plan's reasoning. They impact projects through their level of commitment, empowerment, attitude, and other qualities. That motivation and commitment has also been shown to impact process conformance. Agile methods may be particularly impacted if there is poor communication among team members.

Bad planning is one of the main reasons that projects fail. This can happen at the project level with poor requirements management. It can also be a problem if the overall strategic plan is not aligned with tactical project plans. Processes are more effective if the company's plan is taken into consideration first. The people will be happier if they are part of the planning or, at least, well informed. Also, the plan has to allocate the right people and the right number of people.

Project failures can derail the best of plans. The success or failure of a project will impact the people on the project, both emotionally and in terms of their job future. Managers also must deal with the impact that multiple projects may have when competing for the same resources. The nature of the project should dictate the chosen process for maximum success.

Adopting a process also requires specific planning. While processes can seem constraining, it has been shown to have a positive impact on the people using them. Use agile methods if project planning needs to happen incrementally. Not surprisingly, choosing the right process can contribute to project success.

After reviewing the relationships among the four P's, the conclusion is that each of the areas can impact every one of the others. This validates the model, including the inter-dependence of the factors. Based on this result, an expanded conceptual model is presented in Figure 2. This includes currently identified sub-factors in each of the four P's.

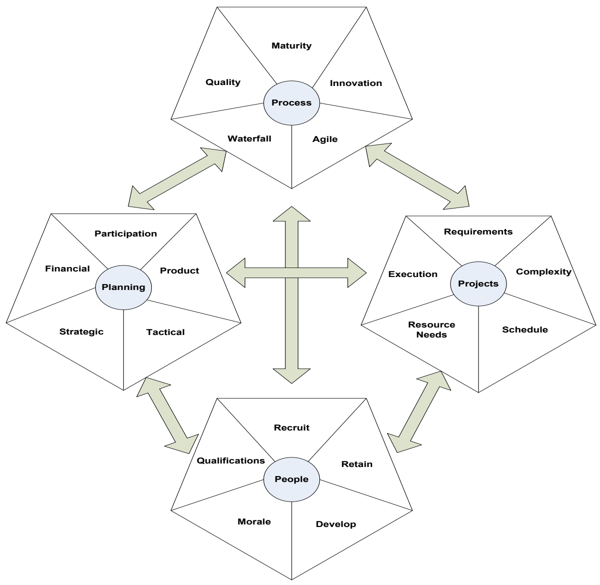

Figure 2. Expanded Conceptual Model for Technology Management

8. Future research

Now that the importance of the relationship between the four P's has been established and a conceptual model has been proposed, it would be useful to expand the number of known sub-factors in each relationship. To that end, a further survey and possibly the application of a case study could be performed to identify the most important connections between any one of the four Ps and the others.

One goal of the model is to use it to evaluate either a pending decision or the current state of the organization using the model as a guide to management practice. To do this, quantification of the relationships would have to be established. It is not clear that all relationships should have equal weight in assessing the state of the organization or where there should be intervention. Both the number of factors and their weights would be part of this future research.

9. Conclusion

Each of the four P's - people, planning, projects, and process – are key components in the management of a technology organization. Furthermore, they are not independent variables in the management equation. Each of the four has been shown to have a relationship with the others. Therefore, the original hypothesis (H_0) is shown to be true. Moreover, each has an effect on every one of the other factors. The implication for managers of technology organizations is that any decision that affects one of the four P's should consider all of them.

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11. Appendix A

It was felt that having the survey participants choose from a list of items would be biased by the choices on the list. So the survey instrument was a single, open-ended question:

List the top 5 aspects of managing a technology organization that are critical to your organization and within your control. That excludes external factors, such as the economy or competitors.

The survey was sent to 130 present and former managers of technology organizations, primarily in the software development area. Responses were received from 49 participants.

Because the survey was open-ended, the answers had to be manually collated and normalized. Other than minor issues like spelling, normalization involved grouping responses that were synonymous. For example, “hiring” and “recruiting” were considered the same answer.

Although the expectation was to end up with 5 categories (based on the lists being top 5), the answers grouped into four areas.

The table 1 below shows the top responses, response rates, and the resulting categories:

Response	Frequency	Category
Recruiting	35	People
Employee retention	22	
Motivating employees	18	
Training	15	
Using agile methods	25	Process
Process improvement	22	
Having an SDLC	15	
Choice of SDLC	18	
Project management	42	Projects
Scheduling	35	
Project staffing	30	
Requirements definition	21	
Budgeting	29	Planning
Strategic planning	28	
Participate in planning	25	
Product planning	19	

Table 1. Category Mapping of Normalized Survey Responses

Design and Fabrication of the Child Head and Neck Support Prototype for Child Car Seats

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Abstract

This study investigated the parameters and materials needed to produce the child head and neck support prototype for a 3 year old in the 50th percentile range called Baby Heads Up. Preliminary simulations in SolidWorks were performed and the anthropometry measurements of the head and neck of children 2 to 3.5 years of age were utilized as a basis for the shape of the prototype. It was determined the materials for the base of the prototype would be high density lightweight EVA foam, with memory foam covering the center, and a cotton pillowcase woven to the shape of the prototype with a kid friendly pattern. It was necessary to ensure the appropriate material was chosen for the safety of the children and to prevent future recalls due to hazardous materials. Four different AutoCAD designs of the base prototype have been completed and the final design has been entered into SolidWorks. The model was optimized and the design was improved based off of these results. A physical testing plan was developed to establish the desired variables such as the vehicle, car restraint, the angle, and different speeds for Baby Heads Up.

1. Introduction

Recently, the National Highway Traffic Safety Administration (NHTSA) and the Federal Motor Vehicle Safety Standards (FMVSS) have been involved in research regarding the effects of side impact collisions on children who are in child car seats. One of the major concerns of both organizations is head and neck injuries including severe brain damage. As a result, there have been discussions and meetings about implementing more standards for child car seats to include better protection to pedestrians during these side impact collisions.

Although there have been major strides in side protection being implemented in child car seats these restraints are expensive and not easily accessible to the majority of the households in the country. These factors indicate the need for a product to produce similar protection at a lesser cost which allows every child to have the protection they deserve, but at a price families can afford. The product developed allows the family to use their current car seat and place an additional accessory inside which provides the head and neck support needed during a side impact incident. It also helps the child from developing Torticolis by preventing their head from falling forward when they fall asleep and causing the muscles in their neck to contract on one side.

2. Background

According to Consumer Reports, the Child Passenger Safety Fact and Trend Report issued by the Children's Hospital of Philadelphia and State Farm Insurance in 2007, found that side impact crashes account for one in four crashes, but result in higher injury rates than frontal or rear impacts combined (Stockburger, 2010). Despite this information, only frontal impact tests are included in U.S. child car seat standards, resulting in a lack of direction or information to protect children involved in side impact collisions (Stockburger, 2010). Another problem most parents complained about, according to interviews conducted, is when the child falls asleep their head is in a seemingly uncomfortable forward position. Their head then, tends to kind of bounce and may cause Torticolis in their neck (Mamapedia, 2007). Although this awkward positioning is not as life threatening, parents want their children to be as comfortable as possible especially on long trips (Health, 2006). Most families spend an average of $100 on brand new child restraints, but the specialty side air bag car seat is around $400 which is more than double the average cost people are spending on car seats.

For most parents, side impact protection has been an oversight, until recently with child restraint companies' continuous advertising of addressing side impact safety. The main problem is there are no qualitative methods currently to ensure that across the board all of the manufacturers are doing adequate enough testing to deem their side impact product is tested and approved. There is no set standard to pass or fail for the manufacturer to know if improvements need to be made in the design. The NHTSA and the FMVSS have been working diligently to develop testing standards and regulations for manufacturers to abide by which would be included with frontal impact testing. This will ensure parents have a clear understanding if the child restraint they would like to purchase has actually passed a standard side impact test without taking the manufacturer's word for it. Then, manufacturers would have a more quality certified stamping of approval for their product that they can advertise.

Even still, most families don't want to throw away their current car seat just to buy another one for a much higher price that is not significantly different from their current one. Most of the manufacturers of child restraints only added a mere piece by the head area on both sides as shown in Figure 1 as a way to state that they have addressed side impact collisions which is not very effective in preventing Head and Neck injuries during a side impact collision according to several studies done by various organizations (Holmes, 2013; ANPRM, 2002). Even with the added "head protection" piece, parents are still complaining about the lack of support the children have when they fall asleep (Circle of Moms, 2013; Sionna, 2009).

Figure 1. Example of New Head Protection on Car Seats

It would seem more practical to keep the current seat and have an additional piece which could attach to it. Why haven't they created a specific device to support the neck and head that could be used for all car seats? Overall, there is a lack of efficient neck and head support devices available for children.

2.1. History of Creating Safety Guidelines for Child Restraints

The National Highway Traffic Safety Administration (NHTSA) started a side impact protection research program to establish standards regarding side impact collisions. Their research for side impact crash testing included developing dummies and implementing Kettering University's sled like simulation of the impact into the standardization of testing Children Car Seats also referred to as Child Restraints (CRs) (Louden, 2010). Currently this is still in progress and Kettering University is working with Hyundai-Kia to research the dynamics of what happens to children in side crash events. This research is not meant to test the actual car seat but to see if there are any changes that could be implemented in the vehicle itself to better protect children. The initial step is to compare the laboratory results built at Kettering to field-generated data to see how closely they match. There is little research in side impact collisions so the sled testing is a breakthrough in side crash safety (Kettering University, 2013). With all the outdated material available, some parents may not realize the risk they are taking by either allowing their child to be forward facing way too early or by not selecting an appropriate car seat according to their child's size. Just recently in 2011, the American Academy of Pediatricians changed their guidelines on the age a child should remain rear-facing from a year and three months until at least age 2 (Emmons, 2011). According to their website, children who are 2 years of age and younger are 75 percent less likely to die or to be severely injured in a crash if they are in a rear-facing seat (Emmons, 2011).

In 1984, the primary criteria for forward-facing restraints relative to a 3-year old simulated dummy were:

(1) Head Excursion, which is measured from the pivot point between the back and base of the standard bench seat to the leading edge of the dummy head, should not exceed 32 inches. This tends to be the most difficult criterion to meet and thus the most critical for misuse and innovative system tests.

(2) Head Injury Criterion (HIC) is a measure of the likelihood of head injury arising from an impact. Let t_1 *and* t_2 be the initial and final times (in seconds) of the interval during which HIC reaches maximum acceleration "**a**" that is measured in "**g**s" (standard gravity acceleration). The maximum time duration $(t_2 - t_1)$ is limited to a specific value between 3 and 36 ms, usually 15 ms. The HIC function shown in equation 1 is based on head acceleration, time duration of impact, and it should not exceed 1000. This criterion is rarely exceeded unless actual head impact occurs.

$$HIC = \left\{\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)\right\}\max \quad (1)$$

(3) Chest Peak Resultant Acceleration, which is calculated from triaxial chest accelerations, should not exceed 60 G for more than 3 milliseconds. This criterion is rarely exceeded with harness systems but can be critical for shield restraints.

(4) Knee excursion, which is measured from the pivot point of the standard bench seat to the knee pivot point, should not exceed 36 inches. This criterion is more difficult to meet in reclined forward-facing as opposed to upright forward-facing systems (Melvin, 1984).

Although the stated concerns suited the overall well being of the child, there were no guidelines required regarding the support of the child's neck which is critically important. A child's neck is just as important as the head because the vertebrae on a child are not fully developed. The head of a child is very heavy and large relative to the rest of their body constituting approximately twenty five percent of the child's weight. For an adult, the head is relatively six percent of their weight. When the head of a forward-facing child is thrust forward in an accident, a massive amount of stress is placed on the child's neck (Weber, 2012). While the child's neck is dealing with this amount of stress, at the same time it is also trying to hold back the heavy weight of the head (Weber, 2012). The weight of a child's head can stretch the spinal column up to two inches, but if the spinal cord is stretched more than ¼ of an inch it will rupture. There have been documented research and infant autopsies which have shown that a young child's skull could be literally ripped from their spine by the force of a crash. When the spinal cord stretches too far in an accident it is called internal decapitation, resulting in paralysis or the death of a child.

Parents need to be aware that even babies who "appear" to have strong neck muscles and good head control are susceptible to these types of injuries. This is why it is important to have the child rear facing for as long as possible (Kyle, 2009).

According to research, young children have immature cervical vertebrae that are still in pieces joined by cartilage. "These pieces are soft and have not ossified into a complete circle of bone which will enclose and protect the spinal cord" (Kyle, 2009). For children, the vertebrae do not completely ossify until ages 3-6 years old (Kyle, 2009). So at three years old, a child's vertebrae is not completely ossified, yet they may be in a forward facing car seat placing them at risk for serious injuries. Like NHTSA, announced it's better for them to be rear-facing until age two, but what about children three years of age and older?

Although there are car seats which allow rear-facing at age three, the cheapest car seat is about forty five dollars which allow them to be rear-facing to about 2½ to three years which means depending on the size of the child they may have to be in a forward facing seat. There needs to be a better option for parents who can't afford expensive rear facing seats, but have a facing forward seat (Kyle, 2009).

3. Design Methodology

Baby Heads Up was originally designed to be made of two main components, the neck brace which was to be placed inside the second component serving as the head support. In physical contact sports such as football, players are geared up to withstand life shattering game hits that could possibly cause permanent damage to the head and neck. Yet, when children are riding in a vehicle they are not equipped to withstand the same encounter. The original idea was to utilize the same material used for football players' neck braces for the neck support such as molded polyurethane foam. As further study into the safety of this material was conducted it was discovered to be toxic being made from petroleum derivatives making it highly flammable. As a result of it being extremely flammable, the material is treated heavily with polybrominated diphenyl ethers (PBDEs) or other brominate fire retardants which remedies the flammability, but allows these brominated fire retardants to bioaccumulate in the body. Past toxicological testing indicates these chemicals may cause liver, thyroid, and neurodevelopment toxicity along with possibly causing bronchitis, skin and eye irritation (Applewhite, 2013), thus, making it unsafe to use for the prototype and for kids. The next option explored was neoprene, but unfortunately it was found to have similar negative effects and toxicity as polyurethane foam. The next challenge encountered is how Baby Heads Up was going to prevent the wobbly head going forward while including the neck support inside the foam. One of the designs considered in Figure 2 had actually included more of a shoulder part placed in with the head and neck to prevent the wobbly head. But, once again the question is how would the shoulder part work with the different sized kids? The material for the inside neck support is desired to have similar properties to the type of material used for football players' neck braces.

After more research, there was a better material found to be possible to use called Acrylonitrile Butadiene Styrene (ABS) material for the head and neck support. The initial conceptual idea of the layers will be to have the hard foam layer on top of the ABS, and then finally on top of a thin layer of soft foam. This layered form was thought to possibly be the most effective solution, instead of making three different prototypes to test in a simulation using the ANSYS program. It was attempted to build the ABS prototype at the Mercer Lab, but due to the size needed it exceeded the size limits available for the prototype machine. In order to figure out the next step, there was brainstorming about what material should be used for the prototype base. The idea of the three layers was formed after reviewing a motorcycle seat which was handmade and comfortable for long periods of riding. With three layers being a good idea, it was not feasible with the resources given, and it may not have been necessary to have three layers to begin with.

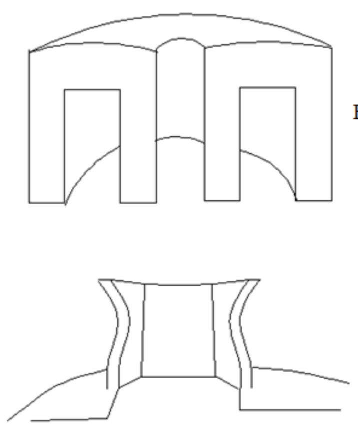

Figure 2. Initial Two Part Design of Baby Head Up

Instead of trying to make ABS plastic the base, it was thought that hard foam could be used instead as the base. High density Ethylene Vinyl Acetate (EVA) Foam Blocks is great hard foam that withstands a substantial amount of weight and gravity compared to other types of foam. The width of the EVA Foam block was determined to be an optimal length for most car seats. The next step was to determine how to work with that type of hard foam with precision and accuracy. The tools initially purchased to make the first prototype include: The X-Acto® products, Matt Knife, Heavy gauge plastic see-thru gridded ruler, and fine point Sharpie® markers. Using these tools, the first prototype made (failed attempt) is shown in Figure 3. There were several rough areas where the material was uneven and difficult to shape. Some of the material was loose while other areas on the prototype base had dents and bad cuts.

Figure 3. 1st Failed attempt at Baby Heads Up Prototype

4. Results and Discussion

Before attempting the 2nd prototype, Baby Heads Up was redesigned in SolidWorks for simulation testing. At this time, Kettering University had already been contacted and the expense of doing physical testing was between $3,000 and $10,000 per prototype. At least in SolidWorks, some weak areas could be identified before the 2nd prototype is attempted. The 3-D model of the Head and Neck Support is shown in Figure 4. The parameters entered were: the Fixed Area (back wall part of the neck), amount of force to be applied (1.4 kN), and the direction the force should to be applied. In addition, the type of foam material the model is to be made of was entered in the simulation parameters.

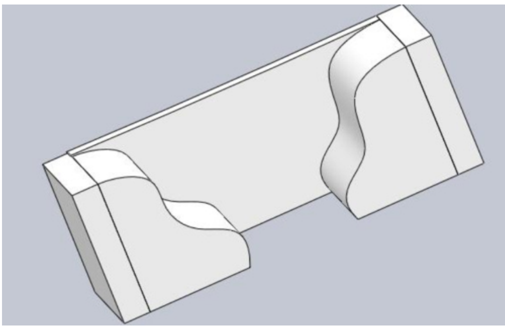

Figure 4. The Initial 3D Testing Model in SolidWorks

After doing several optimization trials, the product in Figure 5 is the most promising showing less stress around the general neck part with most of the stress going to the inside corner due to the thickness increases. In Figure 5, the most optimal model demonstrated improvement with the increased thickness in the back accompanied by thick sides which were included in the optimization parameters from the second trial.

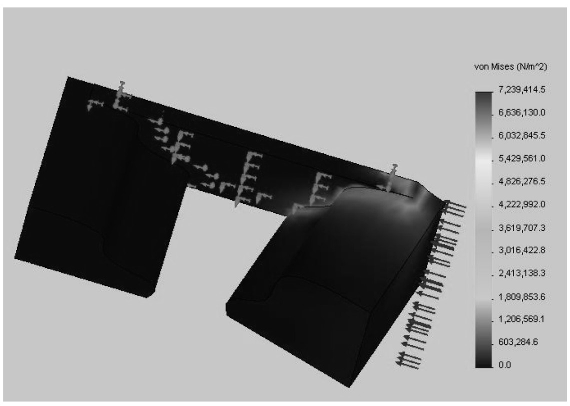

Figure 5. SolidWorks Optimal Model (Third Trial)

After this simulation, the top part of the prototype was redesigned to fit better around the middle of the head. Instead of making the top area square like, designing it to be cylindrical is similar to how the neck and head are shaped. Figure 6 is an AutoCAD screenshot of the top view of the prototype with measurement details such as the length and width of important areas needed for manufacturing.

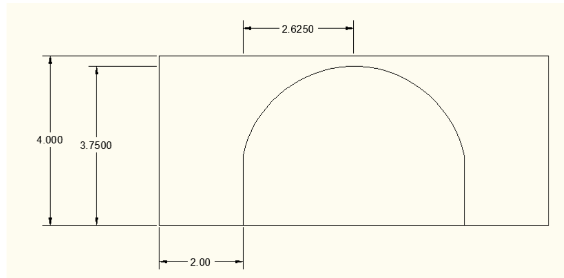

Figure 6. Top View of the Final Prototype Drawing

Table 1 is a list of the measurements needed to build the prototype for a 2.5 to 3 year old child from the 50th percentile. Since 2.5 to 3 year olds are the most fragile at the time they start to face forward, it was important for this size to be chosen. Over time, other sizes will be designed and tested. The length from the bottom of the cranium to the bottom of the neck measurement was not available in the book, as a result sample measurements were taken from 2.5 to 3 year old toddlers.

Table 1. Measurements of the Head and Neck Properties

Head Breadth	Head Length	Lower Face Height	Head Height	Tragion to Top of Head	Lateral Neck Breadth	Tragion to the Back of the Head	Bottom of Cranium to the Neck
13.6 cm	17.7 cm	8.6 cm	17.7 cm	11.6 cm	7.4 cm	8.7 cm	1.18 cm

Figure 7 (a) shows the basic frame of the Baby Heads Up with smooth edges and precise cuts. Figure 7 (b) shows the final prototype of kid friendly Baby Heads Up. Some kid friendly cotton fabric was purchased at the Hancock Fabric store to sew the covering of Baby Heads Up. There were paper patterns made of the top, bottom, and the side for future sewings.

Velcro® was placed on the back of the Baby Heads Up to prevent it from falling down in the car seat as shown in Figure 7 (c). It fits great in the car seat but only by itself. It's a challenge fitting it with the head rest down.

But, Baby Heads Up allows you to not have to have a head rest and still be comfortable.

(a) (b) (c)

Figure 7. (a) Basic Frame of Baby Heads Up; (b) Kid Friendly Baby Heads Up; (b) Baby Heads Up in a Car Seat

4.1. Test Results and Market Analysis for Baby Heads Up

The basic frame for Baby Heads Up was fitted on a 3 year old in Figure 8 (a) to gauge the tightness around the back of her neck and the side of her head. The prototype fits exactly around her head and neck as expected since it was based off of the Anthropometry measurements in Table 1. This fitting provided design information of how much could be taken off without affecting the basic frame's purpose of holding the child's head up. It was unforeseen that the child's car seat would be a Safety 1st Air Protect car seat. It was hypothesized that Baby Heads Up wouldn't fit in an Air Protect car seat due to the technology of having the extra padding inside around the head for protection. But, Baby Heads Up fits well in this particular model of the Air Protect car seat. This has opened new opportunities for Baby Heads Up. It would be interesting to test how Baby Heads Up would function in a side impact collision scenario with the Air Protect technology. Would it enhance or hinder the protection of the child's head and neck? The side view shown in Figure 8 (b) is a closer view of the side of the child's head in Baby Heads Up. It was a little tight and confirmed the shape was good around the head and neck. From the side, it is seen it doesn't go past the ear and allows the child to look from side to side without any problems. About a ¼ inch more of the material was measured around the top of the head and removed in the final prototype - Figure 8 (c).

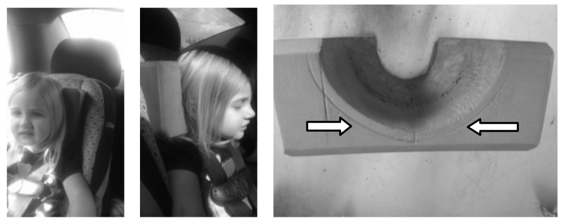

Figure 8. (a) 3 Year Old Fitted in Baby Heads Up; (b) Side View of the 3 Year Old in Baby Heads Up; (c) Top view of the Main Frame of Baby Heads Up

The Baby Heads Up's SWOT analysis is given in Table 2. The introduction of Baby Heads Up, being the first of its kind, will have to deal with the issues that come with being a first mover in an industry as shown in Table 2. Unlike established companies like Graco® or Evenflov®, Baby Heads Up is a new company with an even newer product. However, the major players in the baby market all started the same way this company will, which provides the groundwork for a successful product.

The next innovative product would combine vibration technology as well as Baby Heads Up, which will have to undergo safety and usability testing. Designing the model and ensuring its technological abilities are effective will be a challenge. The soothing technique involving motion has proven effective with direct human contact and vibrating swings/chairs. The success of this technology in other products will help Baby Head Up's advantage in the market, since it is known vibrations do in fact calm infants.

Table 2. Baby Heads Up - SWOT Analysis

Strengths
• Compatibility with most car seats • Side Impact and Neck Support issues relative to children is a new concern for parents (a need) • Provides an economical solution to side impact safety • Provides head support for kids on long trips which is a need most parents feel are unfulfilled making it a new breakthrough in the market • Car Seat Manufacturers are not providing quality side

impact protection along with head support • Easy to install and easy to use for parents
Weaknesses • Developing a prototype in a timely manner • Challenge of providing a quality product for a reasonable price • Strong safety legislation on the material that encompasses the product
Opportunities • Provides an economical solution to side impact safety for NHTSA to be able to create better regulation for it • Build a brand name that will retain customers • Develop a similar head support device for adults when they go on long trips • Introduce product on an international level
Threats • Complying with strong safety legislation for infant and toddler products • Small Margin of possibility for recalls due to legislation which may hurt the brand name • Copycats may try to reproduce a very similar product to Baby Heads Up • Car Seat Manufacturers have started implementing low quality side impact features on their car seats

The establishment and potential accomplishments in the baby market with Baby Heads Up will eventually be competing against other companies producing a similar product which is a threat listed in Table 2. There are a number of baby companies, who all produce similar products; the key to the longevity in the market will be to stay on the cutting edge for Baby Heads Up's car seat inserts. This will rely on the company being proactive and innovative when it comes to technological advancements and expansion.

Table 3 shows the SWOT analysis for Graco® a direct competitor for Baby Heads Up. It is an established manufacturer of baby products with a proven track record of sustainability within this market which is one of its strengths stated in Table 3. They have a loyal customer base and are very aware of the baby market needs of the public which could threaten the Baby Heads Up market. Their access to their customers allows them to constantly test and introduce innovative products to meet the needs of their customers. At the same time, they have had to deal with a number of recalls in the past which caused some damage to the brand as stated in Table 3.

Table 3. Graco® SWOT Analysis:

Strengths • Graco® is a well-established company, who produces a wide range of baby products • The designs of their products are innovative and meet all the safety requirements • Provides an economical solution to side impact safety
Weaknesses • Graco® produces major baby items, but not many accessories for these products making it difficult for them to compete with "baby boutique" products. • Their products are not focused on side impact crashes and only meet minimal requirements for side impact • Products are not universal • Graco® Head Support is not effective in preventing the infants head from wobbling when the baby falls asleep and provides no neck support
Opportunities • Graco® products are sold internationally giving them the ability to expand smaller products • Possibility of developing a derivation of its current head support device to be similar to Baby Heads Up
Threats • Loyal Customer Base • Decades of experience when it comes to designing and marketing new products in the baby market. • Developing cutting edge products may compromise safety regulations (number of recalls)

In addition, another weakness they tend to have stated in Table 3 is that their products are not universal and are only able to be used with other Graco® products. As an advantage, Baby Heads Up's philosophy is to provide affordable options to work universally with other brands. This projected image will draw a wider audience to Baby Heads Up as it would be thought to be more of an accessory to all other products establishing its own place in the market. On the other hand, if Baby Heads Up is seen as a threat to Graco®, they may try to redesign their car seats to have a similar function to Baby Heads Up eliminating the need to buy Baby Heads Up product. Baby Heads Up will be a smaller company who will have the advantage of staying ahead of safety regulations and design of their products accordingly preventing recalls or safety violations.

The break-even analysis was calculated by determining how much revenue was needed based on fixed and variable costs. The revenue per unit is $35.00 based on the set price of Baby Heads Up. The variable cost per unit is $19.27 which is based on the materials needed to fabricate each Baby Heads Up unit. The total fixed cost was the annual cost of operations including salaries, machinery, website, and warehousing utilites which was determined to be $809,000.

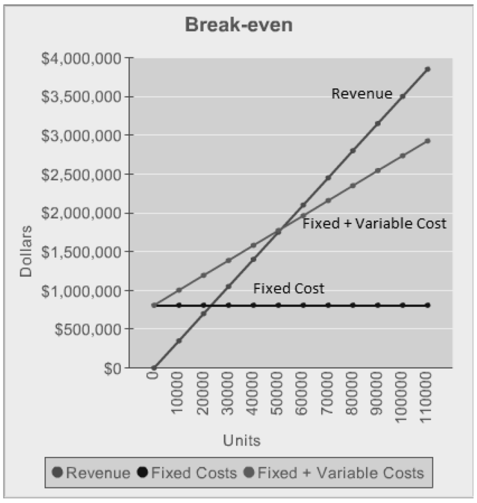

Figure 9. Break-Even Analysis Chart

Based on the Break-Even Analysis shown in Figure 9 there would have to be 51,430 units sold to break even. The amount of units to break even would net $1,800,064 in revenue. Based on the market research, the target markets will allow Baby Heads Up to sell almost twice the amount in the first year.

4.2. Testing Plan

For a thorough physical testing plan, the Takata Set Up is necessary. The factors considered for the basic testing include the type of car, type of car seat and the angles at which the force would be on impact. Based on NHTSA testing discussed earlier, Table 4 breaks down the factors needed to be included in each test. The car seats chosen were the most popular booster seats bought in 2012 (Diapers.com, 2012). The Britax Fontier™ 85 SICT Booster Car Seat, Graco Nautilus™ 3-in-1 Car Seat, and Evenflo Maestro™ Booster Car Seat would be the tested car seats for the Baby Heads Up Test Setup. Although NHTSA, concluded that 10 degrees reflected real world results more closely, it is important to understand the differences between the three angles 10^0, 45^0, and 90^0 as it relates to the product.

Another factor that would be favorable, but expensive to explore is the location of the car seat in the vehicle. If there is more than one car seat in the car it may be necessary for one of the seats to be next to a door. As a consequence, factors of near side and far side impact would come into play. Another factor, which is fairly new in this research, is making SUVs a critical factor for results. Most of the research assumes car to car impact, but a truck or SUV could make a difference on the amount of force involved in the accident. If the child is in a SUV, would it be safer than being in a 4 door car? What if the child is in a 4 door car and is hit by an SUV? Are the injuries more severe and critical? These test factors are important to be explored outside of just testing Baby Heads Up.

Table 4. Test Data Form Without Baby Heads Up

Type of Car	Type of Car Seat	Angle
Nissan Sentra	Britax Frontier 85	10^0
Nissan Versa	Graco Nautilus 3-in-1	45^0
Dodge Caravan	Evenflo Maestro	90^0
Nissan Sentra	Graco Nautilus 3-in-1	10^0
Nissan Versa	Evenflo Maestro	45^0
Dodge Caravan	Britax Frontier 85	90^0
Nissan Sentra	Evenflo Maestro	10^0
Nissan Versa	Britax Frontier 85	45^0
Dodge Caravan	Graco Nautilus 3-in-1	90^0
Nissan Sentra	Britax Frontier 85	45^0
Nissan Versa	Graco Nautilus 3-in-1	90^0
Dodge Caravan	Evenflo Maestro	10^0
Nissan Sentra	Graco Nautilus 3-in-1	45^0
Nissan Versa	Evenflo Maestro	90^0
Dodge Caravan	Britax Frontier 85	10^0
Nissan Sentra	Evenflo Maestro	45^0
Nissan Versa	Britax Frontier 85	90^0
Dodge Caravan	Graco Nautilus 3-in-1	10^0
Nissan Sentra	Britax Frontier 85	90^0
Nissan Versa	Graco Nautilus 3-in-1	10^0

Dodge Caravan	Evenflo Maestro	45^0
Nissan Sentra	Graco Nautilus 3-in-1	90^0
Nissan Versa	Evenflo Maestro	10^0
Dodge Caravan	Britax Frontier 85	45^0
Nissan Sentra	Evenflo Maestro	90^0
Nissan Versa	Britax Frontier 85	10^0
Dodge Caravan	Graco Nautilus 3-in-1	45^0

5. Conclusions

Car seats are designed to keep babies and young children safe, but a car seat is only safe when it is used properly. Consumer reports discovered that more than half of the infant seats when tested with 22 lbs dummy posed a serious head injury when the dummy's head hit the back of the front seat. Car seats that are not convertible normally cap out at a weight limit, between 30 and 35 lbs. Most parents make the mistake of focusing on weight limit, when the height limit really matters because the baby's head can hit the seat in a crash. When a child rides facing rearward, the whole body - head, neck and torso - is cradled by the back of the safety seat in a frontal crash. Riding in the rear-facing safety seat also protects the child better in other types of crashes, particularly side impacts, which are extremely dangerous, if not quite so common.

Depending on the type and brand, side impact car seats are available which are expensive and cost from $300 - $ 400. Baby Heads Up shows a promising alternative to buying the expensive side impact car seat and still providing great side impact protection. It provides comfortable head and neck support for kids on long trips (> 2 hours), which is a need most parents feel are unfulfilled, making it a new breakthrough in the market. If the side impact protection turns out to be inefficient it will still have the ability to sell based off the idea of providing great head and neck support for children when they fall asleep in the car. The cost of the Baby Heads Up is only $35/unit and it weighs about 2 lbs.

Efficient planning and design would need to happen quickly to ensure adherence to new side impact regulations placed into effect recently for manufacturers if side impact will be a function of Baby Heads Up. Although there has been significant progress in the research of the Baby Heads Up, there is much more work needed to be done to explore the efficiency of it in a side impact collision. Physical testing and creating a FEA non-linear simulation in LS-Dyna is necessary to identify improvements needed in the design of the product. The first prototype focused on 2-1/2 to 3 year old sizes since they are more vulnerable as they start facing forward in the car seat at this age. While SolidWorks® was only preliminary in creating a solution it helped us to discover a better shape around the top of Baby Heads Up. The optimal model helped to recognize a design flaw that needed improvement, and the new design helped to relieve the area from unnecessary stresses. Manufacturing the first prototype helped to identify failed methods such as the X-Acto® tools which led to improving the process and quality of the prototype. The first prototype lacked precision and quality cuts with smooth faces. The second prototype was developed using better tools such as the bread knife and different grinding wheels. Safety precautions have to be utilized with these types of tools due to the increased risk of injury. After fitting a 3-year old in Baby Heads Up the promising results led to the discovery of the possibility of Baby Heads Up being capable to fit in an Air Protect ™ Car Seat. This may allow Baby Heads Up to be compatible with all car seats. A sewing pattern was created for the kid friendly cover of Baby Heads Up. The testing plan includes three different car seats at three different angles inside three different cars. These are the cars the government had completed research on to institute parameters of side impact testing including the type of 3 year-old dummy and the padding on the door discussed earlier.

6. Recommendations

The first recommendation would be in designing a better attachment of the prototype to the car seat more like straps that lift Baby Heads Up easily when the child is getting out of the seat. If Velcro® will be used, make sure it is wide enough and strong enough to stay in place for a long period of time. The Velcro® used was too small to allow the prototype to stay in the car seat for long periods of time. All the practice and studying of the FEA ANSYS program dealt with linear interactions in the book the “Finite Element Analysis Theory and Application with ANSYS” by Saeed Moaveni.

This leads to the second recommendation in doing more research in modeling non-linear interactions involved in side impact crash analysis. Hopefully, Baby Heads Up will be able to access either physical testing resources or software resources to be able to fulfill the testing phase needed to go forward. Presently, it will cost 3,000 dollars to 10,000 dollars per unit for one test. More funding is necessary to create the prototypes needed to ensure enough pilots have been made for testing. The LS-Dyna Software is expensive as well and the limited license only allows 10,000 element points but a side impact crash model will need at least 500,000-1,000,000 elements to be an efficient and effective model. Some training will be necessary to understand this software fully and although it is not included in the cost it would be a suggestion for investors.

The third recommendation would be to consider testing the prototype with an Air Protect™ car seat to study the dynamics of how they co-behave in a side impact collision. This would give more insight into whether having both at the same time would cause a disruption in protection or enhance the amount of protection a child receives.

After the testing phase, a fourth recommendation would be to create an automated and standardized process to be implemented for any manufacturer planning to do mass production. For EVA foam, injection molding is a possible scenario which would critically reduce production time and error by eliminating measuring, cutting, and grinding each product by hand. OSHA and Safety training should be implemented for fabricators to decrease risk of injury.

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