JOURNAL OF MANAGEMENT AND ENGINEERING INTEGRATION

Scope: The Journal of Management and Engineering Integration (JMEI) is a double-blind refereed journal dedicated to exploring the nexus of management and engineering issues of the day. JMEI publishes two issues per year, one in Summer and another in Winter. The Journal's scope is to provide a forum where engineering and management professionals can share and exchange their ideas for the collaboration and integration of Management and Engineering research and publications. The journal will aim on targeting publications and research that emphasizes the integrative nature of business, management, computers and engineering within a global context.

Table of Contents

Optimization of Group Scheduling Problem Using the Hybrid Meta-heuristic Extended Great Deluge (EGD) Approach: A Case Study

Ben Mosbah Abdallah and Thien-My Dao
Mechanical Engineering and Manufacturing Department, École de technologie supérieure (ÉTS), 1100 Notre-Dame West, Montréal, Quebec, Canada
abdallah.ben-mosbah.1@ens.etsmtl.ca, Thien-My.Dao@etsmtl.ca

Abstract

Many companies apply cellular manufacturing systems (CMS) in order to improve production. One of the most significant problems encountered in production management is the scheduling problem, which has also been proven to be NP-hard. The objectives of the group scheduling problem in manufacturing are considered in order to minimize the makespan, the total flowtime and machine idletime.

In this paper, we propose an approach for optimizing the scheduling of the manufacturing tasks of all parts of a product family, including exceptional elements. To solve this problem, an Extended Great Deluge (EGD) approach algorithm is applied in order to determine the optimal sequence of parts in each cell, minimizing the makespan and the total flowtime; following that, a heuristic method is applied to schedule the exceptional elements. A case study concerning the design and operating activities scheduling of a Celle manufacturing system (CMS) of 30 parts and 20 machines (big size problem) have been investigated and presented.

1. Introduction

Scheduling at the production line is primarily affected by the minimization of the makespan. However, we can also consider the minimization of total production time as an objective.

The scheduling in the production line was affected predominantly by minimizing makespan. Some heuristics known with this objective are described by Campbell and al. [1], Dannenbring [6] and Logendran and al. [12]. However, we can also consider the minimization of total time of production as an objective.

For multi-objective problems, such as minimizing makespan, production time and downtime of machines are most effective in minimizing the cost of production. Sridhar and al. [20] developed a multi objective model which minimizes the makespan, the total flow time and the machine idle time, however, their model aimed to optimize the makespan and flowtime in the cell, and so we can therefore not introduce the exceptional elements. Solimanpur and al. [19] developed a heuristic called SVS-algorithm to minimize makespan of a cell scheduling problem, with exceptional elements; however, with this method, the priority order of operations is not respected with a high number of inter-cellular movements. Intra-cell scheduling and inter-cell scheduling are the two stages of the SVS-algorithm, which determine the sequence of parts in the group and then determine the sequence of cells. Gupta and al. [7] studied the minimization of flow time in a flow-line manufacturing cell with family setup times. Schaller [16] presented a comparison of heuristics for family and job scheduling in a flow-line manufacturing cell. Safaei and al. [15] presented a fuzzy programming approach for a cell formation problem with dynamic and uncertain conditions. Cesani and Steudel [3] present a study of labor assignment in cellular manufacturing system.

In this work, we are interested in the group scheduling problem in manufacturing with exceptional elements. To solve this problem, we used an optimization algorithm based on the meta-heuristic Extended Great Deluge (EGD) (Figure 1). This algorithm was recently introduced in Burke and al. [4], where it was tested on a timetabling problem, and experiments confirmed its high effectiveness. Figure 1 shows the steps of the proposed algorithm.

2. Extended great deluge technique

2.1. EGD formulation

The EGD proposed in this paper requires the setting of a single parameter, which can be interpreted as search time.

The first step of the algorithm is to initialize *ΔB* and the initial sequence of parts randomly (*S*); then, the efficiency *α* (the makespan) of *S* is calculated, and the result is assigned to *B*; next, define the neighborhood *N(S)* and a neighboring solution S^* are been randomly selected from the set *N*; then compare the new solution N(S^*) with the old solution *N(S)* and *B*. If two conditions (α(S^*)≤ α(S) and B) are not satisfied, return to select a new neighboring solution *S*; if one of these conditions is true, the solution is accepted and we recalculate *B=B-ΔB*. Finally, the criterion arrest is tested, and if the number of iterations is reached, we have therefore reached the end of algorithm. Otherwise, return to select a new neighboring solution *S*.

2.2. The EGD algorithm: Performance evaluation

To prove the efficiency of the EGD, we applied it, in a first step, on a flow shop with large instances (100 jobs/5 machines, 100 jobs/20 machines, 200 jobs/20 machines and 500 jobs/20 machines) originally proposed by Taillard [22]. The algorithm was implemented using MATLAB on a 1.86 GHz Dual-Core PC. The results obtained were compared with those obtained using the genetic algorithm (GA) proposed by Reeves [14] and the hybrid simulated annealing (SA) proposed by Nearchou [13]. The performance of the proposed algorithm was tested over the flow-shop scheduling benchmarks generated by Taillard [22] and compared with those obtained by the GA and the Hybrid SA. We obtained results with the following parameters: ΔB=0.05 and the number of iterations were set to 5.10^5. These results are reported in Table 1. Figure 2 shows the variation of results (*%offset*) obtained by the GA, the Hybrid-SA and the EGD algorithms, with the best reported results found in Taillard [22].

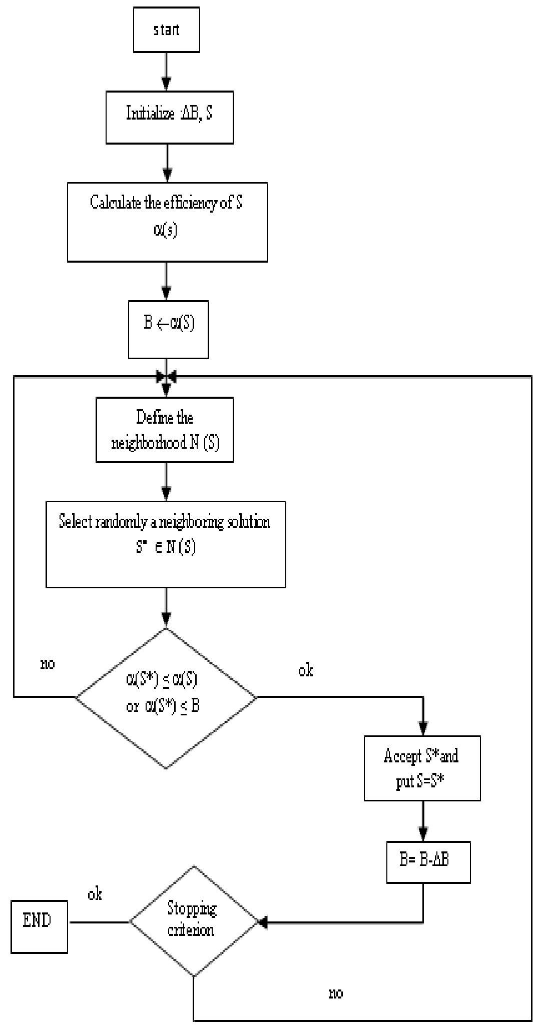


Figure 1. General flowchart of the EDG

%offset=Makespan-UBUB×100

average=(1/instance number)×sum(%offset)

To solve the scheduling cells problem, an optimization algorithm based on the EGD approach was used. The advantage of this approach is that only one parameter is tuned. As shown in Table 1 and Figure 2, the proposed approach gives very suitable results in both problems, particularly when we compare it with the GA.

Table 1. Results of solving 4 benchmarks problems (Taillard [22])

Problem size	GA[8]	Hybrid SA[7]	Proposed algorithm (EGD)		UB [14]
	Makespan	Makespan	Makespan	Time (sec)	Makespan
100x5	5523	5502	**5495**	22.24	5493
	5283	**5274**	5290	12.63	5268
	5213	**5185**	5193	23.73	5175
	5042	5029	**5023**	36.56	5014
	5297	5257	**5253**	26	5253
100x20	6450	6434	**6396**	523	6286
	6441	6397	**6333**	362	6241
	6488	**6451**	6496	251	6329
	6422	6425	6440	299	6306
	6519	**6497**	6524	370	6377
200x20	11529	11483	**11437**	1032	11294
	11708	**11600**	11601	821	11420
	11754	11721	**11536**	1262	11446
	11696	11597	**11530**	1118	11347
	11617	11576	**11492**	1228	11311
500x20	27338	26814	**26537**	2682	26189
	26843	26891	27028	2900	26629
	27334	26994	**26819**	2767	26458
	26973	26969	**26861**	2373	26549
	26298	26424	26792	2046	26404

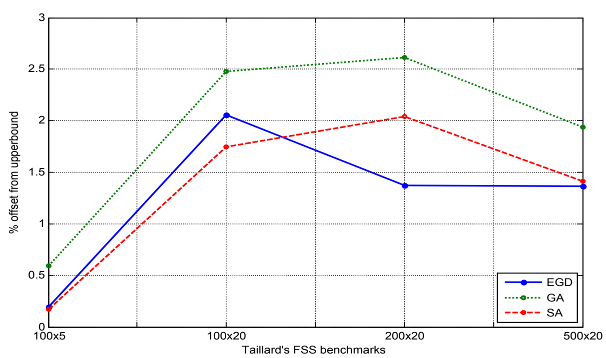


Figure 2. Variation of results obtained by the 3 algorithms

3. Optimization of cell scheduling with EGD simulation approach

3.1. Cells scheduling

Cells scheduling is carried out in two steps. In the first step, the EGD algorithm is applied to the scheduling cell problem, while assuming that there are no exceptional elements present (i.e., only the cells are scheduled, without the exceptional elements). The makespan is then determined using the technique proposed in [11]". In the second step, the exceptional elements are considered and the makespan has been recalculated using the proposed algorithm as indicated in fig. 3.

3.2. Formulation

In this paper, we applied a variant of a local search meta-heuristic, called *the Extended Great Deluge (EGD)*, for solving the manufacturing group scheduling problem, where it has been tested on time tabling problem and the experiments have confirmed its high effectiveness. The EGD proposed in this paper requires the setting of only one parameter, which can be interpreted as search time.

In this work, we are interested in the manufacturing group scheduling problem with exceptional elements. To solve this problem, we used an optimization algorithm based on the Extended Great Deluge (EGD) have been developed.

The objective function $\alpha(s)$ is determinate with the proposed model by Sridhar and Rajendran [21], as follows:

n the number of jobs to be scheduled in the cell.

m the number of machines in the cell.

t_{ji} the processing time of job j on machine i .

s the set of jobs already scheduled.

$q(s, i)$ the completion time of the partial schedule s on machine i .

F_s the flow time of all jobs in s .

The formulation of the problem for a flowline-based cellular manufacturing system is:

Initialize $T=0$, $F_s=0$ and $M_s=0$

For $j=1$ to n do

$i = 1$ to m do

if $t_{ji} > 0$

then

compute the completion time $q(sj,i)$ of partial schedule sj

$$q\ (sj,i)=\max[q(s,i);\ T]+ t_{ji} \qquad (1)$$

update

$$T = q(sj,\ i) \qquad (2)$$

else

$q(sj,i)= q(s,i)$ (3)

the total flowtime of jobs in *sj* is:

$F_{sj} = F_s + T$ (4)

The makespan α_{sj} of the partial schedule *sj* is:

$M_{sj} = \max (M_s , T)$ (5)

In the Fig. 1, the objective function α is

$\alpha_{sj} = M_{sj}$

3.3. EGD simulation approach

Cells scheduling is carried out in two steps. In the first step, the EGD algorithm is applied to the scheduling cell problem, while assuming that there are no exceptional elements present (i.e., only the cells are scheduled, without the exceptional elements). The makespan is then determined using the technique proposed in [21]. In the second step, the exceptional elements are considered and the makespan has been recalculated using the proposed algorithm as indicated in figure 3. An iterative improvement process has been used to optimize the final schedule.

The simulation approach is based on the EGD technique:

a) First step: EGD algorithm

To solve this problem, the EGD algorithm shown in Fig. 1 is applied, and the initial solution is randomly generated.

At each iteration, a neighbor *N(s)* solution is selected as follows:

- Step 1: randomly select a position *i* in the sequence.
- Step 2: randomly select a position *j* ($i \neq j$) in the sequence.
- Step 3: exchange the job at the i^{th} position and the job at the j^{th} position.

Once the optimal sequence of parts is determined with the EGD algorithm, a technique based on the method below is applied for scheduling exceptional elements:

b) Second step: scheduling of the exceptional elements

For each cell *i*, the jobs *p (i,j)* (*j* Є *N,* product index) with operations on machines belonging to another cell *k (k=i-1)* are determined, and these operations are called exceptional elements. Each exceptional element *p (i,j)* must be performed by the corresponding cell *k*, which will delay the start of operations of the cell *i*.

To introduce the exceptional elements, the following steps must be completed:

- Step 1: Determine the completion time for the optimal sequence of parts for each cell with the model developed by Sridhar et al. [21].
- Step 2: Determine the exceptional elements *P(i,j)*.
- Step 3: Determine the exceptional elements *P'(i,J')*.
- Step 4: Perform jobs *P(i,k)* by cell i and determine the completion time for exceptional elements *P(i,k)* with Sridhar's model [21].
- Step 5: Update the completion time for all parts of cells.
- Step 6: Perform jobs *P'(i,k')*, where the corresponding machine is free, and determine the completion time for exceptional elements *P'(i,j')*.
- Step 7: Update the completion time for all parts.
- Step 8: Determine the makespan, which is the maximum completion time for all parts in all machines.

3.4. Optimization process

The solution is improved immediately after the steps described in 3.*a)*, and in the improvement process, the sequence of parts on each machine is kept the same. As soon as a machine completes its tasks on the pieces belonging to set P (exceptional elements), the machine restarts to process the parts affecting in the cell where it belongs, taking into account the time constraints required to complete each operation on each machine.

4. Illustrative example and experimental results

4.1. Presentation of the problem and results obtained

To illustrate the performance of this approach, the proposed method is applied to the example developed by Solimanpur et al. [19], in which there are ten parts, grouped together into three part families. Eight machines are needed for processing these parts in this example, and the processing times are shown in Table2. In this example, there are 4 exceptional elements which require operations on other machines belonging to other cells. Part 1 requires one operation on machine E in cell 1, part 7 requires one operation on machine C in cell 2, and part 5 requires two operations on machines C and F, in cells 2 and 3, respectively. The set-up time for each part family is shown in Table 3. Solimanpur et al. [19] have proposed a heuristic named the SVS-algorithm, to be used in solving the scheduling of manufacturing cells problem.

Fig. 4 shows the Gantt chart representation of their proposed solution in our illustrative example. The makespan found by the SVS-algorithm is 78 [11].

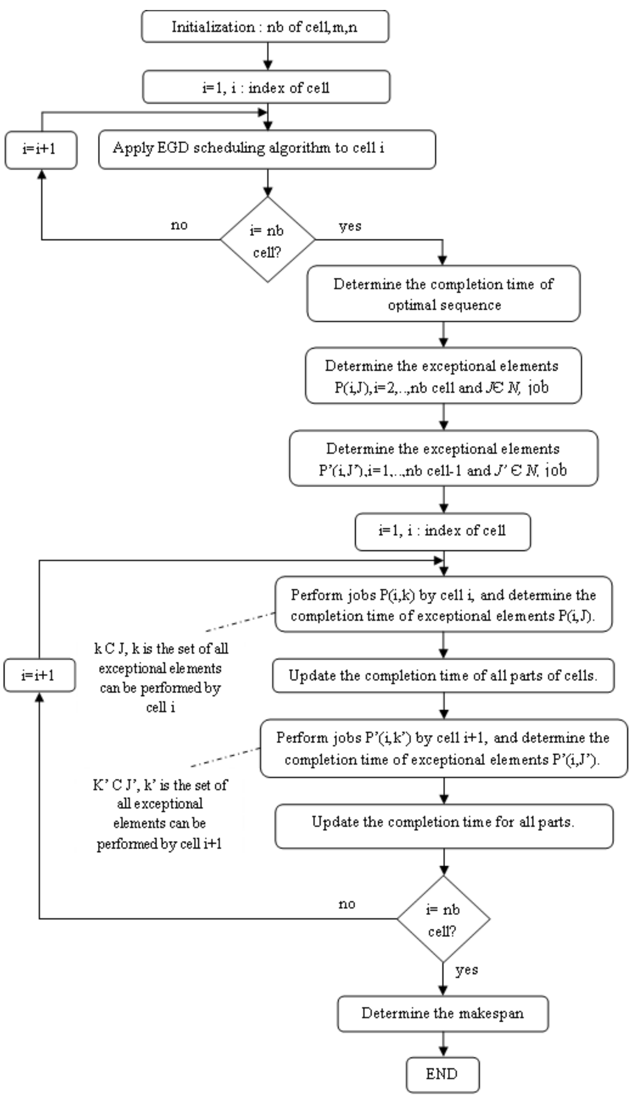


Figure 3. Flowchart for scheduling cells with exceptional elements

Table 2. Operation time

		Parts									
machines		5	6	9	10	1	2	4	3	7	8
cell 1	A	8	5	3	7						
	D	12	15		3						
	E	3	6	9		5					
cell 2	C	11				4	6	8		8	
	G					10	12	4			
cell 3	B								2	11	3
	F	4							14	8	6
	H								10	5	

Table 3. The setup time and the sequence of machines for each part family

	Machines								
cells	A	B	C	D	E	F	G	H	Sequence of process
1	3		2	4	4	1			A-D-E
2			2		3		6		C-G
3		3	3			7		2	B-F-H

Table 4. The sequence of parts for each part family

cells	Sequence of parts	
	SVS-algorithm	The proposed method
1	6-5-10-9	6-9-5-10
2	2-4-1	1-4-2
3	3-7-8	3-7-8

Using the proposed algorithm presented in Figure 3, we find a first feasible solution in the Gantt chart shown in Figure 5. The makespan found is 69, which is better than the result found by the SVS-algorithm shown in Figure 4, where the makespan is 78. This obtained solution is not optimum because in which the delay time is high. A summary of the processing sequence for each part family obtained by the SVS-algorithm and by our proposed method are presented in Table 4.

4.2. Optimum solution

To ensure a more optimal solution, we must reduce each machine's downtime. We therefore modified the first solution shown in Figure 5. For example, machine B can start performing part 3 at 0, but it must stop immediately after finishing part 3 at 5, and await the arrival of part 7 after a time equal to 11.

With the proposed method, a minimum value for inter-cell movements for exceptional elements is obtained when we carry out a comparison with the SVS-algorithm. The exceptional parts (parts 1, 5 and 7) are handled in more than one cell. Parts 1 and 7 are processed in two cells, and are sent to other cell just one time, and this is the same result obtained by the proposed approach and the SVS-algorithm. Part 5 is processed in three cells, and is transferred between these cells to complete all the operations. The inter-cell movement obtained by the SVS-algorithm for part 5 is shown in Figure 6, where this part is sent to other cells three times. With our proposed approach, however, part 5 is sent twice to other cells. Figure 7 shows these inter-cell movements.

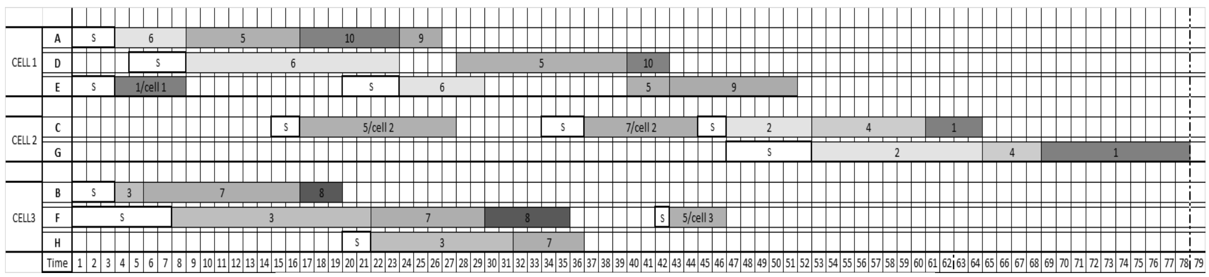


Figure 4. Solution proposed by Solimanpur and al. [19]

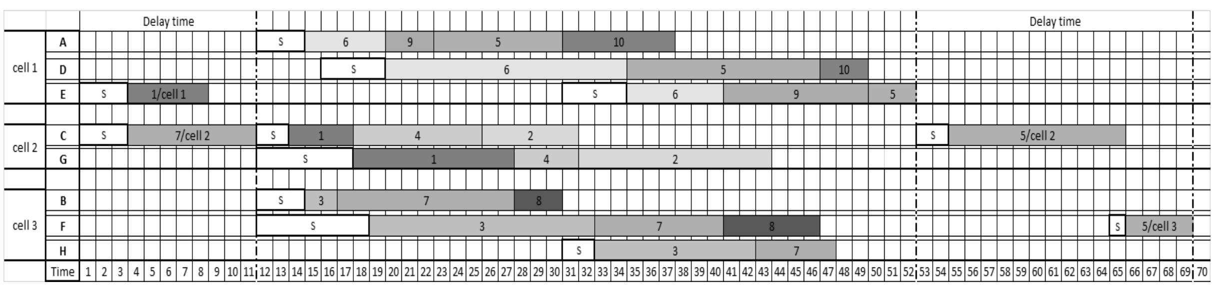


Figure 5. Our first proposed solution

For this example, the improving solution is shown in Figure 8. In Figure 4, Figure 5 and Figure 8, the letter *"s"* represents the set-up time for each machine.

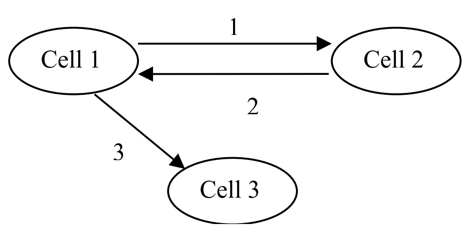


Figure 6. Inter-cell movement for part 5 with SVS-algorithm

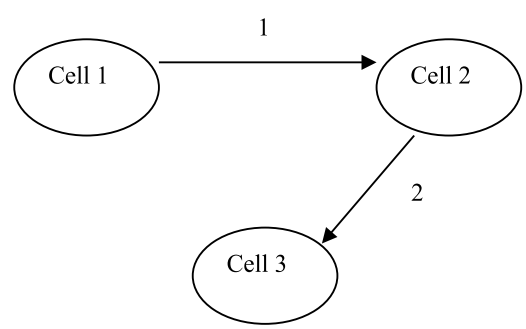


Figure 7. Inter-cell movement for part 5 with the proposed algorithm

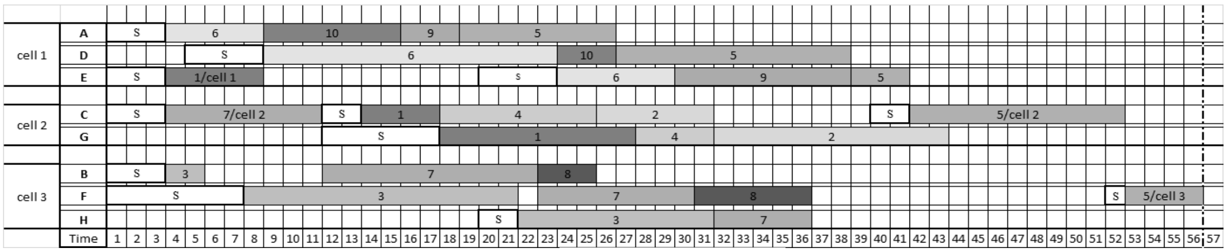


Figure 8. Improving solution

Each operation can be started as soon as the corresponding machine is free. The improving solution represented in Figure 8 allows us to obtain a makespan of 56. In comparison with the SVS-algorithm, the percentage of reduction in the average makespan (E %), after improvement, is 28.2%. This measure is calculated as follows:

E% = (the average makespan obtained by the SVS-algorithm - average makespan obtained by our proposed method) / the average makespan obtained by the SVS-algorithm.

13 problems are selected in the literature to evaluate the performance of the proposed method. The size of each problem in terms of the total number of parts, machines, and cells is reported in Table 5, and the results obtained do not represent an improvement, but rather, represent the worst proposed solution. The parameters of the problem were generated randomly from uniform distributions ranging between 0 and 100, and the problems selected did not contain processing and set-up times. Each problem was solved 100 times, each time with different data sets. The cell formation solution for each problem was obtained from the source in which the problem was reported. The algorithm was implemented using MATLAB on a 1.86 GHz Dual-Core PC.

To solve these problems, the proposed algorithm provides the best solutions for the parameters $\Delta B=10^{-3}$ and the number of iterations was set to $2x10^4$ after several tests on the illustrative example described above in Tables 2 and 3.

In Table 5, a summary of the results obtained by the proposed approach on mono- and multi-objective scenarios is presented, following a comparison of the makespan obtained by the SVS-algorithm. These results are for mono- and multi-objective scenarios, with the mono objective being to minimize the makespan and the multiple objective being to minimize two parameters, the makespan and the flow time, together with a weight of 0.9 for the minimization of the makespan, and 0.1 for the minimization of the flow time. In the multi-objective scenario, the objective function α becomes:

$$\alpha= 0.9* Makespan + 0.1*Flowtime$$

The average makespan obtained by our proposed approach on mono- and multi-objective cases with an improvement and those obtained by the SVS-algorithm are summarized in Table 5. In the 13 problems, 9 are improved in mono- and multi-objective scenarios with the number of inter-cellular movements optimized in order to achieve the exceptional elements.

4. Case study : Application and results

To illustrate the performance of this approach, the proposed method is applied to the case of large dimension (big size problem), in which there are forty (40) parts, grouped together into seven (7) part families. Twenty four (24) machines are needed for processing these parts in this case, the initial incidence matrix of the case study is shown in Table 6. The cell system design without the processing times is shown in Table 7 and with the processing times is shown in Table 8 respectively. In this case, there are 17 exceptional elements which require operations on other machines belonging to other cells and the setup times are not considered. To solve these problems, the proposed algorithm provides the best solutions for the parameters $\Delta B=10^{-3}$ and the number of iterations were set to $2x10^4$ after several tests. The algorithm was implemented using MATLAB on a 1.86 GHz Dual-Core PC. For this case study, the feasible solution with a reduced makespan is obtained in less than 10 seconds.

Table 5. Results for mono- and multi-objective scenarios with improvement

	size			Mono-objective			Multi-objective			SVS-algorithm	E %	
Problems	m	n	No. cells	Average delay	Average flowtime	Average makespan	Average delay	Average flowtime	Average makespan	Average makespan	**Mono-objective**	**Multi-objective**
1. Kumar and Vannelli [10]	30	41	2	112.84	20502	729,43	112.37	14471	795,29	**727,2**	-0,31%	-9,36%
2. Chandrasekharan et al. [5] (Fig. 1)	24	40	7	0	12786	555,21	0	11035	557,02	**353,8**	-56,93%	-57,4%
3. Chandrasekharan et al. [5] (Fig. 2)	24	40	7	166.59	12499	**516,81**	164.58	11650	**520,77**	1015,8	49,12%	48,73%
4. Carrie [2]	20	35	4	104.45	17033	**633**	104.45	13720	**638**	801,8	20,05%	20,43%
5. Harhalakis et al. [8]	20	20	5	271.13	5470	**514,1**	273.93	6005.9	**520,56**	711,5	27,74%	26,84%
6. Seifoddini [17]	11	22	3	312.5	8035.1	**602,99**	322.07	7258.3	**614,57**	1019,2	40,84%	39,7%
7. Seifoddini [18]	5	18	2	255.6	6771	**675,85**	253.44	6005.8	**677,99**	897,1	24,66%	24,42%
8. Kusiak and Chow [11]	7	8	3	0	1073.2	205,08	0	978.58	206,24	**150**	-36,72%	-37,5%
9. King and Nakornchai [9]	5	7	2	0	1265.1	245,18	0	1148.7	247,37	**226,4**	-8,3%	-9,26%
10. Waghodera and Sahu (1984), Fig.2	5	7	2	64.26	1236.1	**273,67**	64.76	1214.6	**282,33**	408,3	32,97%	30,85%
11. Waghodera and Sahu (1984), Fig.3	5	7	2	67.69	1396.8	**238,98**	70.79	1247.7	**277,8**	372,3	35,81%	25,38%
12. Waghodera and Sahu (1984), Fig.4	5	7	2	145.86	1817	**375,44**	146.3	1470.7	**378,99**	425,8	11,83%	10,99%
13. Waghodera and Sahu (1984), Fig.5	5	7	2	149.94	1790.1	**369,58**	149.94	1530,2	**373,21**	383,7	3,68%	2,73%

Table 6. The incidence matrix (part-machine relation) of case study

	Parts																																							
Machines	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
A	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
C	0	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
D	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0
E	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
F	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
H	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1
J	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
L	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
M	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
N	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
P	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	0
Q	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1
R	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
T	0	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
U	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
V	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
W	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
X	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Table 7. The 7 cells manufacturing system (7 CMS) with 17 EE of case study

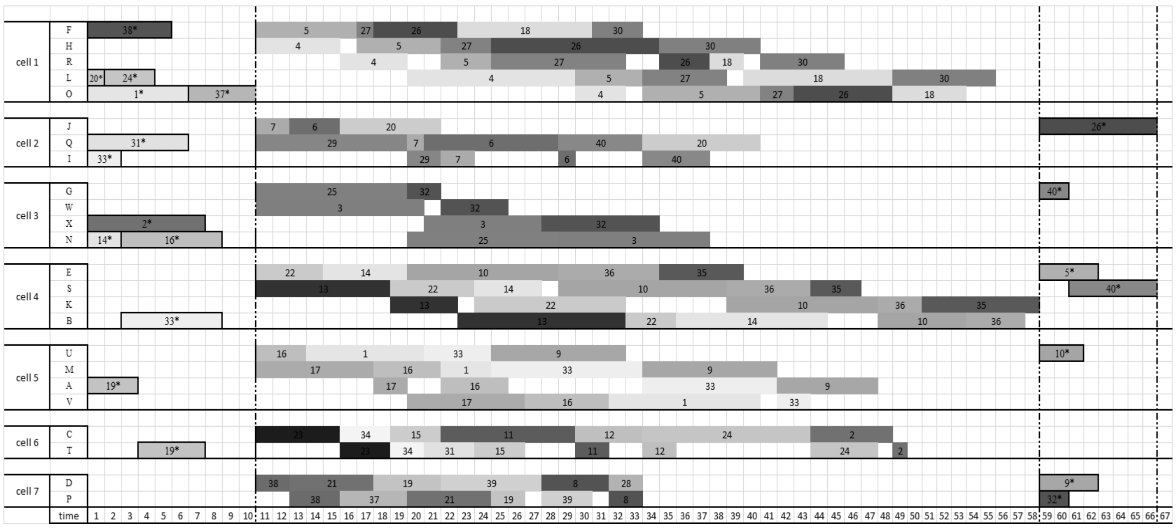
		Parts																																					
Machines		30	18	5	26	27	4	20	7	6	29	40	32	3	25	35	36	22	10	14	13	1	33	9	16	17	31	12	24	15	34	23	11	2	28	21	38	8	39	19	37
cel 11	F	1	1	1	1	1	0																														1				
	H	1	0	1	1	1	1																																		
	R	1	1	1	1	1	1																																		
	L	1	1	1	0	1	1	1																					1												
	O	0	1	1	1	1	1															1																			1
cel 12	J				1			1	1	1	0	0																													
	Q							1	1	1	1	1															1														
	I							0	1	1	1	1											1																		
cel 13	G											1	1	0	1																										
	W												1	1	0																										
	X												1	1	0																			1							
	N												0	1	1					1					1																
cel 14	E			1												1	1	1	1	1	0																				
	S											1				1	1	1	1	1	1																				
	K															1	1	1	1	0	1																				
	B															0	1	1	1	1	1		1																		
cel 15	U																		1			1	1	1	1	0															
	M																					1	1	1	1	1															
	A																					0	1	1	1	1														1	
	V																					1	1	0	1	1															
cel 16	C																										0	1	1	1	1	1	1								
	T																										1	1	1	1	1	1	1							1	
cel 17	D																							1											1	1	1	1	1	1	0
	P												1																						0	1	1	1	1	1	1

Table 8. The 7 MCS with the processing times of case study.

		Parts																																							
	Machines	30	18	5	26	27	4	20	7	6	29	40	32	3	25	35	36	22	10	14	13	1	33	9	16	17	31	12	24	15	34	23	11	2	28	21	38	8	39	19	37
cel 11	F	3	8	6	5	1	0																														5				
	H	6	0	5	10	3	5																																		
	R	5	2	3	3	8	4																																		
	L	7	9	4	0	5	10	1																					3												
	O	0	5	7	6	2	3															6																			4
cel 12	J				8			6	2	3	0	0																													
	Q							7	1	8	9	5															6														
	I							0	2	1	2	4											2																		
cel 13	G											2	2	0	9																										
	W												4	10	0																										
	X												7	7	0																			7							
	N												0	9	9					2					6																
cel 14	E			4												5	6	4	9	5	0																				
	S											6				3	5	5	10	4	8																				
	K															8	3	9	9	0	4																				
	B															0	4	3	6	9	10		6																		
cel 15	U																		3			7	4	8	3	0															
	M																					3	9	8	4	7															
	A																					0	8	6	4	2														3	
	V																					9	2	0	5	7															
cel 16	C																										0	4	10	3	3	5	8	5							
	T																										3	2	4	3	2	3	2	1						4	
cel 17	D																							4											2	5	2	4	6	4	0
	P												2																						0	5	3	2	3	2	4

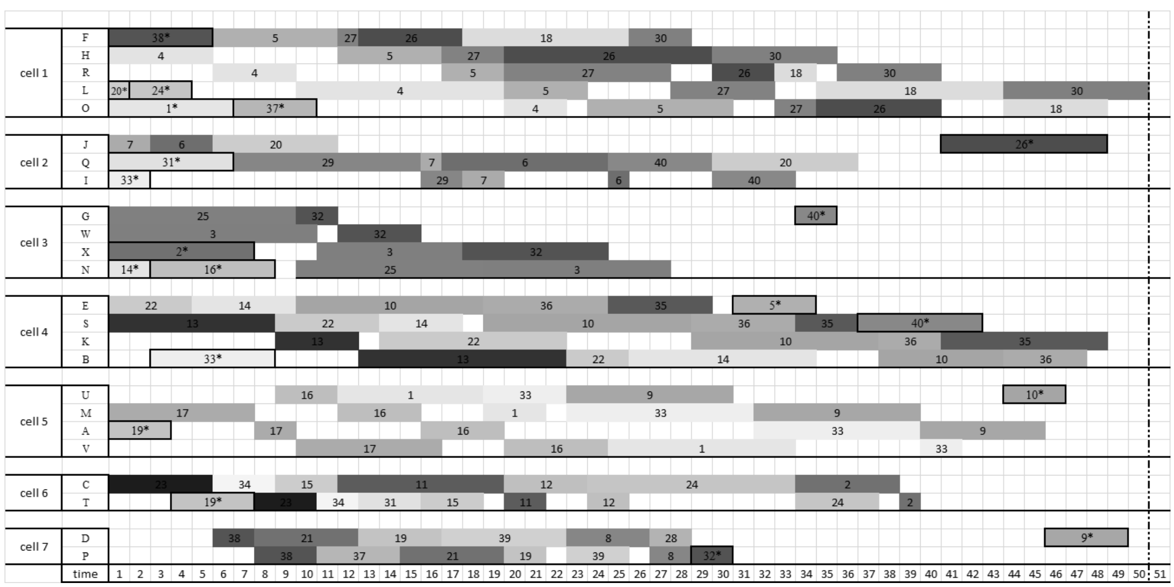
Table 9. The best sequence of manufacturing tasks in each cell

Cells	Sequence of parts		Makespan	
	sequence of parts **without** exceptional elements	sequence of parts **with** exceptional elements(**EE**)	Without exceptional elements	With exceptional elements
1	4-5-27-26-18-30	**20-1-24-38-37**-4-5-27-26-18-30	45	50
2	29-7-6-40-20	**33-31**-29-7-6-40-20-**26**	30	48
3	25-3-32	**14-16-2**-25-3-32-**40**	27	35
4	13-22-14-10-36-35	**33**-13-22-14-10-36-35-**5-40**	48	48
5	17-16-1-33-9	**19-**17-16-1-33-9-**10**	37	46
6	23-34-31-15-11-12-24-2	**19**-23-34-31-15-11-12-24-2	39	39
7	38-37-21-19-39-8-28	38-37-21-19-39-8-28-**23-9**	23	49



* : exceptional elements

Figure 9. Optimal solution given by proposed approach before improvement



* : exceptional elements

Figure 10. Optimal solution given by proposed approach after improvement

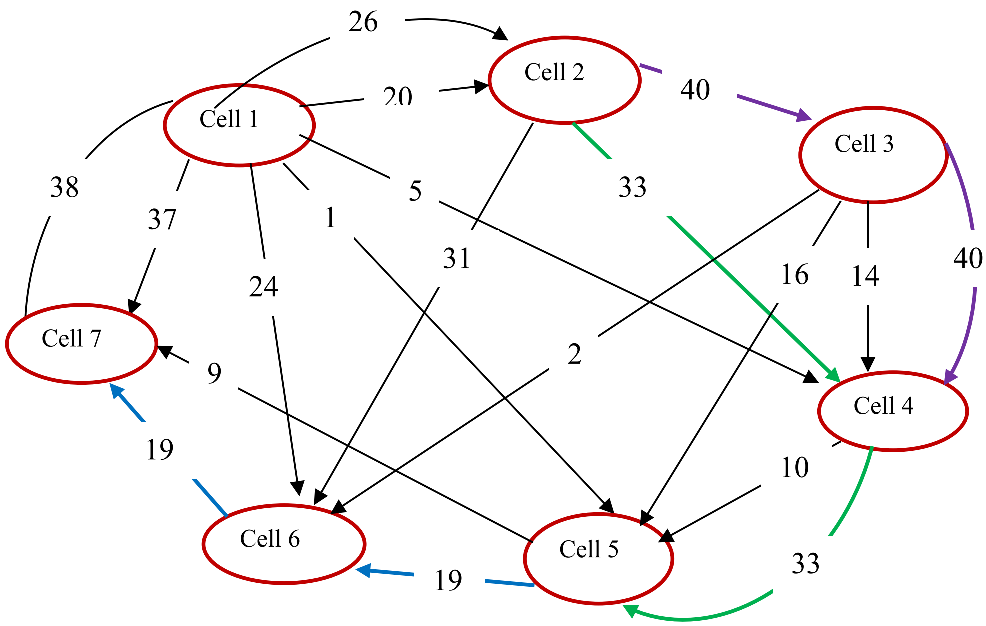


Figure 11. Inter-cell movements for all exceptional elements (EE)

The proposed algorithm presented in Figure 3, is applied and the Gantt chart of feasible solution is shown in Figure 9. The total makespan found is 66. The improving solution is represented in Figure 10 and as indicated, the better makespan is 50. A summary of the obtained processing sequence for each part family obtained by the proposed algorithm are presented in Table 9.With the proposed method, a minimum value for inter-cell movements for exceptional elements is obtained and as shown in the figure 11, we can observe that the part 33 is sent to other cells three times :first, it is send to cell 2 to achieve an operation on the machine I. after, it was sent to the cell 4 to achieve an operation on the machine B. Finally this part is sent to cell 5 where it belongs to finish the other operations. All the inter-cell movements of 17 exceptional elements of this investigated case are shown in the figure 11.

5. Conclusion

This study addresses the group scheduling problem in CMS. An optimization algorithm based on the extended great deluge (EGD) is proposed in order to select the optimal sequence of parts in each cell, following which a technique to schedule the exceptional elements is also introduced. The advantage of this approach is that it only requires a single parameter (ΔB) to be tuned. The proposed approach including the improving process provides very suitable results in the selection of an optimal sequence of parts and the minimum number of inter-cell movements for scheduling of exceptional elements. In 13 instances when it was processed and the obtained results with the case study also show that the proposed hybrid approach based on the meta-heuristic technique, the EGD, is particularly powerful for big size problems with a great number of exceptional elements.

6. References

[1] Campbell, H.G., Richard, A. D., Milton, L. S. (1970) 'A heuristic algorithm for the n-job, m-machine sequencing problem', *Management Science*, Vol. 16, No. 10, pp.630-637.

[2] Carrie, A.S. (1973) 'Numerical taxonomy applied to GT and plant layout', *International Journal of Production Research,* Vol. 11, No. 4, pp.399–416.

[3] Cesani, V. I., Steudel, H. J.(2005) 'A study of labor assignment flexibility in cellular manufacturing systems',

Computers & Industrial Engineering, Vol. 48, pp.571-591.

[4] Burke, E., Bykov, Y., Newell, J., Petrovic, S., "A time-predefined local search approach to exam timetabling problems", *IIE Transactions*, vol. 36, no. 6, pp. 509-528, 2004.

[5] Chandrasekharan M. P., Rajagopalan R. (1989), GROUPABILITY: an analysis of the properties of binary data matrices for group technology', *International Journal of Production Research*, Vol. 27, No. 6, pp.1035-1052.

[6] Dannenbring, D.G. (1977) 'An evaluation of flow shop sequencing heuristics', *Management science*, Vol. 23, No. 11, pp.1174-1182.

[7] Gupta, J.N.D., Schaller, J.E. (2006) 'Minimizing flow time in a flow-line manufacturing cell with family setup times', *Journal of the Operational Research Society*, Vol. 57, pp.163–176.

[8] Harhalakis, G., Nagi, R., Proth, J.M. (1990) 'An efficient heuristic in manufacturing cell formation for group technology applications', *International Journal of Production Research*, Vol. 28, No. 1, pp.185–198.

[9] King, J.R., Nakornchai, V. (1982) 'Machine-component group formation in group technology: Review and extension', *International Journal of Production Research*, Vol. 20, No. 2, pp.117–133.

[10] Kumar, K.R., Vannelli, A. (1987) 'Strategic subcontracting for efficient disaggregated manufacturing', *International journal of production research*, Vol. 23, No. 12, pp.1715-1728.

[11] Kusiak, A., Chow, W.S. (1987) 'Efficient solving of the group technology problem', *Journal of Manufacturing Systems*, Vol. 6, No. 2, pp.117–124.

[12] Logendran, R., Nudtasomboon, N. (1991) **'**Minimizing the makespan of a group scheduling problem: a new heuristic', *International Journal of Production Economics,* Vol. 22, pp.217-230.

[13] Nearchou A. C. (2004) 'A novel metaheuristic approach for the flow shop scheduling problem', *Engineering Applications of Artificial Intelligence,* Vol. 17, pp.289–300.

[14] Reeves, C.R. (1995) 'A genetic algorithm for flowshop sequencing. *Computers and perations Research*, Vol. 22, No. 1, pp.5-13.

[15] Safaei, N., Mohammad S.M., Reza T.M. (2008) 'A fuzzy programming approach for a cell formation problem with dynamic and uncertain conditions', *Fuzzy Sets Systems*, Vol. 159, pp.215-236.

[16] Schaller, J. (2008) 'A comparison of heuristics for family and job scheduling in a flow-line manufacturing cell', *International Journal of Production Research,* Vol. 38, No. 2, pp.287–308.

[17] Seifoddini, H. (1989a) 'Single linkage versus average linkage clustering in machine cells formation applications', *Computers & Industrial Engineering,* Vol. 16, No. 3, pp.419–426.

[18] Seifoddini, H. (1989b) 'A note on the similarity coefficient method and the problem of improper machine assignment in group technology applications', *International Journal of Production Research*, Vol. 27, No. 7, pp.1161–1165.

[19] Solimanpur, M., Vrat, P., Shankar, S. (2004) 'A heuristic to minimize makespan of cell scheduling problem', *International journal of production economics,* Vol. 88, pp.231-241.

[20] Sridhar, J., Rajendran, C. (1996) 'Scheduling in flowshop and cellular manufacturing systems with multiple objectives-a genetic algorithmic approach', *Production Planning & Control*, Vol. 7, No. 4, pp.374-382.

[21] Sridhar, J., Rajendran, C. (1993) 'Scheduling in a cellular manufacturing system: a similated anneling approach', *International Journal of Production Research*, Vol. 31, No. 12, pp.2927-2945.

[22] Taillard, E. (1993) 'Benchmarks for basic scheduling problems', *European Journal of Operational Research*, Vol. 64, pp.278-285.

Development of a Manufacturing Engineering Curriculum for Alabama's Black Belt Region

Daniel J. Fonseca, Kevin W. Whitaker, Jill S. Driver and Terri C. Boman
Department of Mechanical Engineering, The University of Alabama, Tuscaloosa, Al 35487, USA
dfonseca@.eng.ua.edu, kwhitaker@eng.ua.edu, jshearin@bamaed.ua.edu, tboman@bamaed.ua.edu

Abstract

In order to increase enrollment in engineering programs and employment in skilled positions in the growing manufacturing sector of the southeastern United States, especially of minority and underprivileged youngsters, a partnership between the University of Alabama's College of Engineering, the Alabama Science In Motion (ASIM) program, and around 30 high schools in Alabama's Black Bet was formed in September 2008 to create high school curricular materials based on the field of manufacturing engineering. The *Building Alabama* project, funded by the U.S. Department of Education, focused on the development of a supplementary curriculum consisting of instructional modules in mathematics, physics, biology, and chemistry. Emphasis was placed on quality hands-on, technology-based activities conducted in a classroom setting, as well as professional development for the classroom teachers, all this supported by a state-of-the-art website created and maintained by the University of Alabama's College of Engineering.

1. Introduction

1.1 Project Background and Goals

The consensus among leaders in the manufacturing community is that the necessary increase in the engineering labor supply will come about only through the development of a more diverse workforce (ACT, 2003). DeReamer and Safai (2004) concluded that employment opportunities in the U.S. requiring science, technology, engineering, and mathematics (STEM) expertise are not being adequately fulfilled. However, the available domestic STEM labor supply has and will not be able to satisfy these opportunities because of the long-term trend of fewer students entering STEM programs in college, thus threatening the ability of U.S. businesses to compete in the global marketplace. The situation is so dire that the National Science Board has stated that the federal government and its agencies must step forward to ensure the adequacy of the U.S. STEM workforce, and that all stakeholders must mobilize and initiate efforts that increase the number of U.S. citizens pursuing STEM studies and careers. According to May and Chubin (2003), the STEM workforce, despite years of efforts to diversify it, remains overwhelmingly white, male, and able-bodied, and the available pool of talented women, minorities, and persons with disabilities remains significantly underutilized (i.e. 26%). It is an interesting fact that, if individuals from these underrepresented groups were represented in the STEM workforce at the same percentage as their representation in the total workforce population, the current shortage in the STEM labor supply of about 4.3 million jobs (Light, 2011) would largely be filled.

Hence, as it is estimated that just in the last decade, the number of STEM degrees earned failed to keep pace by 22 percent with the national average increase in all degrees earned; this STEM labor shortage could be reduced to fewer than 13% if minorities were equally engaged in STEM-related careers as the rest of the population. Also, the fact that currently underrepresented groups are projected to increase from about a quarter of the workforce to nearly half by 2050 suggests that the U.S. must cultivate the STEM talents of all of its citizens, not just those from groups that have traditionally worked in STEM fields.

Many efforts have been put forth to increase the percentage of underrepresented populations in the STEM workforce. These include summer and after-school programs for high school students and the integration of STEM applications into high school curricula. The unfortunate outcome of many of these efforts is that they are temporary and disappear once they no longer have funding. Their positive effects then dissipate over time, and the same problems with lack of diversity and shortage of human resources in STEM disciplines resurface.

The fact that women and minorities are underrepresented in the engineering labor force has led to the development of the following three questions:
1. What are the psychological mediators of both gender and ethnic group differences in entry into and persistence in the engineering labor force?
2. What are the family and school forces that underlie the gender and ethnic group differences in these psychological mediators?
3. How do experiences in tertiary educational settings and in manufacturing work settings influence gender and ethnic group differences in entry into and persistence in the engineering labor force? (Eccles and Davis-Kean, 2003).

The *Building Alabama* project intended to address the issues involved in these questions by providing underrepresented populations in the southeast U.S. with the opportunity to be exposed to manufacturing engineering concepts and techniques during their high school education. The initial focus was on the state of Alabama's Black Belt region, which for many years has had a declining standard of living due to the infeasibility of agriculture as the dominant economic base. The demographics of this region's school systems reveal that the majority of the students enrolled are non-white. Despite the region's vast agricultural resources, the school systems in Alabama's Black Belt have poverty rates above 50%. The correlation between high poverty rates and low academic achievement is well documented.

Nevertheless, Alabama is currently experiencing an exciting process of expanding and enhancing its manufacturing sector; consequently, the engineering opportunities associated to manufacturing systems are also growing. This is especially valid relative to automotive industries. Mercedes Benz U.S. International, Inc., Honda Manufacturing of Alabama, LLC, and Hyundai Motor Manufacturing Alabama, LLC already have operational manufacturing facilities in Alabama. With them, several other hi-tech businesses have begun operations in this state. To ensure that the manufacturing sector continues to be a driving force for economic development, Alabama must have an adequate workforce that is not only knowledgeable in manufacturing principles but also technologically educated in advanced technological platforms. Because approximately 26.0% of Alabama's population is African American (according to the 2000 U.S. Census), this can only be accomplished if the state's African American residents, especially those from regions of continuing economic inequality such as the Alabama Black Belt, are given the opportunity and the means to become educated in critical technological fields such as engineering and computer science. Thus, two fundamental goals were laid out for Building Alabama:

- Goal #1: Development of a series of manufacturing engineering instructional modules for high school mathematics and science teachers to supplement existing in-class activities and exercises with additional hand-on activities.
- Goal #2: Development of meaningful collaboration and relationships between high school mathematics and science teachers and engineering faculty at the University of Alabama.

Through these two goals, the *Building Alabama* project directly addressed the objectives of the US Department of Education's FIE program: *to develop strategies that improve the quality of secondary education at the state and local levels and to help all students meet challenging standards of state academic content* *and student achievement* by encouraging high school students in the Black Belt region to be intellectually prepared for careers in manufacturing engineering and by equipping teachers with the resources necessary to ensure their students adequate instruction in the field.

1.2 Educational Objectives and Outcomes

Manufacturing engineering embodies all activities needed in the development and operation of processes oriented to transform raw materials, energy, and acquired components into end products. More specifically, manufacturing engineering deals with the design, selection, and optimization of equipment and processes to ensure the manufacturability of products.

According to 2009-2010 ABET Engineering Accreditation Commission's guidelines for accrediting manufacturing engineering programs (ABET, 2008), a manufacturing engineering program must demonstrate, among other things, that participants have an understanding of the behavior and properties of materials as they are changed by manufacturing processes; an understanding of the design and selection of equipment, tooling, and environment necessary for manufacturing practice; and an understanding of the analysis and control of manufacturing operations through mathematical and science-based methods.

Although these guidelines have been established by ABET to accredit college-level programs, its general educational objectives can also serve as didactic targets for programs oriented to the instruction of high school students in manufacturing engineering concepts, as it is the case with the *Building Alabama* project. Therefore, a high-school manufacturing engineering curriculum was developed and implemented by the partnership between the University of Alabama's College of Engineering, the Alabama Science In Motion (ASIM) program – a state-funded project which main goals are to provide high-tech laboratory experiences for students and effective professional development for teachers and students from all backgrounds –, and several high schools in Alabama's Black Belt region to achieve the following educational objectives:

- Enable students to recognize significant manufacturing concepts and operations by applying principles of mathematics and sciences (i.e., biology, chemistry, and physics).
- Exercise student's abilities to use appropriate mathematical and computational skills needed for basic engineering manufacturing applications.
- Instruct students on the use of oral, graphical, and written communication skills to present and direct manufacturing-oriented activities.
- Enable students to think critically and identify, evaluate, and solve basic manufacturing-related problems.
- Encourage students to become informed and participating individuals cognizant of engineering and manufacturing matters.

These educational objectives led to the following expected student learning outcomes on the part of the students:

a. Participants must acquire information on careers centered on the manufacture of goods. In this context, 'manufacturing' is a process or procedure through which plans, materials, personnel, and equipment are transformed in some way that adds value.

b. Students must demonstrate an understanding of fundamental applications of mathematics, science and engineering principles to the solution of manufacturing problems.

c. Students must demonstrate the ability to successfully complete basic design experiments or activities related to the field of manufacturing.

d. Students must participate in creative and critical thinking cross-discipline activities of manufacturing nature.

2. Project Methodology

2.1 Curriculum Development and Implementation

The developed Manufacturing Engineering Curriculum consists of a set of instructional modules that can be utilized in the existing mathematics and science courses imparted in the participating high schools of the region. These instructional modules combine hands-on practice on previously mastered concepts with the introduction of new manufacturing-related concepts.

Twelve master high school science and mathematics teachers were selected to work on module development teams along side with UA faculty and students from the College of Engineering. These instructors were divided into four teams: Biology, Chemistry, Mathematics, and Physics, and their activities were coordinated and monitored by the Management Team of *Building Alabama*, made up by the director of UA's In-Service Education Center and the principal investigators from the College of Engineering. Eighteen sets of activities or modules were developed across the four subject areas. Each module was designed to take between 3 and 7 class periods to complete (i.e., introduce, administrate and evaluate). During the two years of the *Building Alabama* projects, the modules were administrated in the participating high school of the Black Belt region using the existing structure of the Alabama Science In Motion project.

Due to the interdisciplinary nature of manufacturing engineering, the created instructional modules have connections to more than one high school course, and they were designed so that there is an intrinsic correlation between the modules' activities and the required content of current STEM courses in Alabama high schools. Furthermore, each one of these activities was constructed to ensure the achievement of four expected student learning outcomes mentioned before.

2.2 Teacher Training

As mentioned earlier, the second main goal of the *Building Alabama* project was teacher training on the developed modules for further exposure to manufacturing engineering and other STEM disciplines. This was accomplished through periodic meetings throughout the two years that the project lasted between the team leaders, instructors involved in the development of the modules, personnel from the UA's In-Service Education Center, and faculty from the UA's College of Engineering.

Furthermore, to insure teachers have the content knowledge and skills to incorporate the developed supplemental instruction modules in their classrooms, "peer-coaching study teams", that is, groups of instructors committed to sustained use of the modules, help and support each other through shared teaching/ planning/developing of lessons, and collect data on the implementation of the modules and the effects on students learning were established and monitored by UA's In-Service Education Center, and supported by the Alabama Science in Motion program.

Finally, a one-day workshop was conducted in the summer of 2010 to disseminate the *Building Alabama* modules among instructors from high schools across the Black Belt region. The workshop consisted of 60-minute sessions where participating teachers (numbered around fifty) had the choice to rotate through the different sessions during the day. Each one of these sessions focused on one set of activities from a particular module. During this project, the participant high school teachers were compensated for their time in the workshops as well as their involvement in the development of the instructional modules.

2.3 Building Alabama Website

Manufacturing engineering education has traditionally focused on teaching mathematical models using simplifying assumptions. Recent pedagogical approaches to manufacturing education have focused on developing a more holistic view through the use of computer-based platforms (Dessouky *at el*, 2001). Following such an approach, the developed modules were integrated into a web-based system for instructional support to students and teachers while carrying out the activities in the classroom, as well as for a more wide-spread dissemination of the curriculum. The *Building Alabama* website can be accessed at http://bama.ua.edu/~bap.

3. Conclusions and Remarks

The high school manufacturing engineering curriculum developed through the *Building Alabama* project is ground-breaking. It creates a permanent engineering presence in the high schools of the region that was previously inexistent.

The impacts of the program can be summarized in three major areas. First, the benefits obtained from the implemented curriculum will be disseminated throughout Alabama's Black Belt region, and potentially, across the southeast U.S. Hundreds of lives will be enlightened in the design and development of manufacturing systems through the use of mathematics and sciences. This will cause an increase in the number of underrepresented students pursuing university and/or associate degrees in engineering related fields.

In addition, the high school faculty trained through the *Building Alabama* project, and that were imparting the activities to the students have gained a greater knowledge and appreciation for engineering technologies and their role in the planning, controlling, and execution of manufacturing systems. This will lead to better mentoring of high school students.

Finally, the developed instructional modules represent a solution to the need expressed by the majority of Alabama's mathematics and science teachers of not having the adequate access to technology, equipment, and quality hand-on activities for mathematics and science instruction.

4. Acknowledgements

The authors want to thank the U.S. Department of Education for funding this initiative. Thanks are also extended to Dr. Jill Shearing Driver and Mrs. Terri Boman from UA/UWA In-Service Center, as well as the team of programmers led by Mr. David Grubic who were in charge of the development of the *Building Alabama* website.

5. References

ABET, (2008), 2009-2010 Criteria for Accrediting Engineering Programs, Baltimore, MD.

ACT, (2003), ACT Policy Report: Maintaining a Strong Engineering Workforce, Information for Life's Transitions, Washington DC.

DeReamer, S.M. and Safai, N.M., (2004), "Promoting Science and Engineering in Grades K-12 By Means of a Summer Workshop – A Universal Model," *Proceedings of the American Society for Engineering Education Annual Conference and Exposition*, Session #1460.

Dessouky, M.M., Verma, S., Baily, D.E., and Rickel, J., (2001), "A Methodology for Developing a Web-based Factory Simulator for Manufacturing Education," *IIE Transactions*, Vol. 33, pp. 167-180.

Eccles, J. and Davis-Kean P., (2003), Women, Minority, and Technology, University of Michigan, Michigan.

Garcia, O., (2003), Minorities in Information Technology Occupations: Final Report from a Cyberconference. Wright State University.

Light J., (2011), "Labor Shortage Persists in Some Fields," The Wall Street Journal, February 7, 2011.

May, G.S. and Chubin, D.E., (2003), "A Retrospective on Undergraduate Engineering Success for Underrepresented Minority Students," *Journal of Engineering Education*, Vol. 92, pp. 27-39.

Optimizing Availability Analysis using a Lean Six Sigma Process

Daniel Sillivant, S. E. Gholston and W. Wessels
University of Alabama, Huntsville, AL 35899-0001, USA
sillivd@uah.edu, gholston@ise.uah.edu, wrw0001@uah.edu

Abstract

The Reliability and Failure Analysis Laboratory at UAHuntsville performs availability analysis on different systems throughout the United States. Availability analysis on the system uses failure, logistics, and maintenance properties that are associated with each part to determine the probability of the part being available. The individual parts availability are rolled up to determine the system availability based upon the design configuration. The current process is very time consuming, because it relies heavily upon manually sorting through data which creates the potential for data entry errors. The goal of this project is to reduce the time it takes to perform the analysis and eliminate areas that are causing the majority of the errors in the process. Under the current procedure we do not possess the capability of meeting our expectations. A Lean Six Sigma approach was used to improve the current state of our process so that we could possess a reliable process and meet customers' expectations. Currently, we are in the implementation phase of this project and are starting to verify that the improved process can meet the predicted improvements. This article focuses on the application of Lean Six Sigma to improve the availability analysis process. The preliminary results show that by following the Lean Six Sigma process, the availability analysis process has a reduced cycle time and a significantly reduced number of errors.

Introduction

The University of Alabama in Huntsville's Reliability and Failure Analysis Laboratory performs Availability Analysis on different systems throughout the world. To perform this analysis we need to gather information about the Failure, Maintenance, and Logistic Properties for each of the parts in the schematic diagram to build a reliability block diagram for the system. Once the information is gathered, it is compiled and imported into RELEX the reliability analysis software that is used to run the simulations for the given model. A full analysis can be preformed containing the prediction interval for the availability of the system upon completion of the simulations

Because of this capability, an organization within the Comprehensive Test Ban Treaty Organization (CTBTO) approached us to analyze a large number of systems for them. To prove that we could meet the needs of our customer the analysis was initially preformed on five different systems. The completion of these systems ensured that we could meet the needs of the customer, but it also showed that it would be difficult to complete this task while ensuring the quality of the analysis and meet deadlines under the current procedure. Internal audits were used to catch errors that were made during the process and able to give us data which we could use to determine where potential problem areas in the process where located. A Lean Six Sigma approach was used to eliminate these errors and improve the throughput time of the process.

The two areas that needed to improve in the analysis were the process time and the number of errors that were produced during the analysis. A process flow diagram illustrates the steps that take place to perform the analysis when it first began.

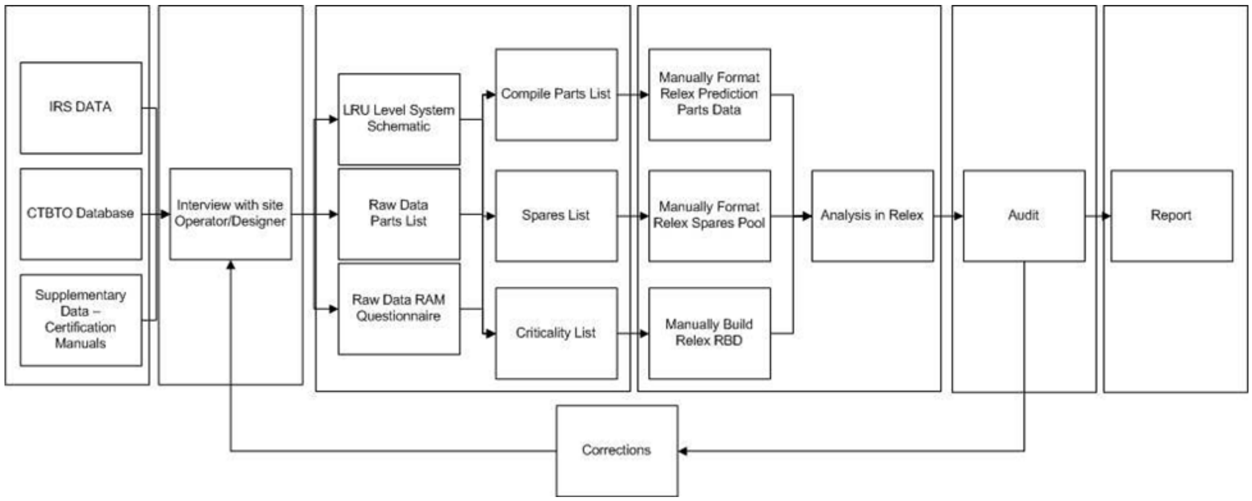


Figure 1: Initial Process Flow Diagram

The initial site that was analyzed was not used in the benchmarking of the analysis. During the initial site, it took longer to convey what type of data we were looking for to complete our analysis. After the initial site we had a much better understanding on how the organization operates and how to obtain the appropriate information. Following the process flow diagram; data is gathered from CTBTO's database, certification manuals, and interviews with the subject matter expert. A parts list was built from this data, to include: maintenance, failure, and logistics data, a schematic diagram and a reliability block diagram for the system. Based upon the audits, errors were broken down into different categories based upon where they occurred: Reliability Block Diagram, Schematic Diagram, Missing Parts, Typos and Formatting Errors.

Site	# Parts	Time	RBD	Schematic	Typos	Missing Parts	Formatting	Total Errors
A	24	8	3	2	0	0	3	8
B1	171	13	5	10	1	15	23	54
B2	239	15	6	6	2	20	25	59
C1	74	10	11	3	2	19	20	55
C2	80	10	14	3	1	17	20	55
			39	24	6	71	91	**223**

Table 1: Summary of Data

An error early in the process will affect each of the different steps and will be counted for every instance of its occurrences. A Pareto Chart was used to group the errors to give a visual representation of where the majority of the errors occurred [2]. From this data we are able to determine what types of problems were causing the majority of errors in the process.

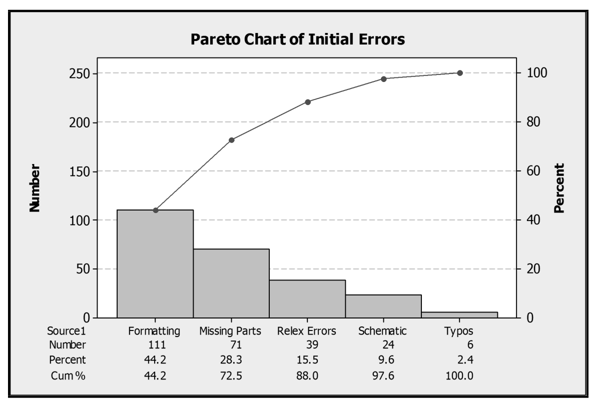


Figure 2: Pareto Chart

From the Pareto chart we can see that the majority of the errors are related to formatting the data into its various formats for the analysis. Examining the process flow diagram shows that there was a large portion of the process required manually formatting of the data in order for the software package to use it in the analysis. Transferring data from one format to another was not a value added step and should be an area that needs to be looked into to be improved. The missing parts are the parts that do not affect the calculation in the analysis but they should be documented in order to show the integrity of the process.

A brain storming session with the team was used to get an initial assessment of all of the potential areas that may have a negative effect upon our process. All of the proposed information is compiled into a cause and effect diagram to further show potential problems that could have an effect on the process [3].

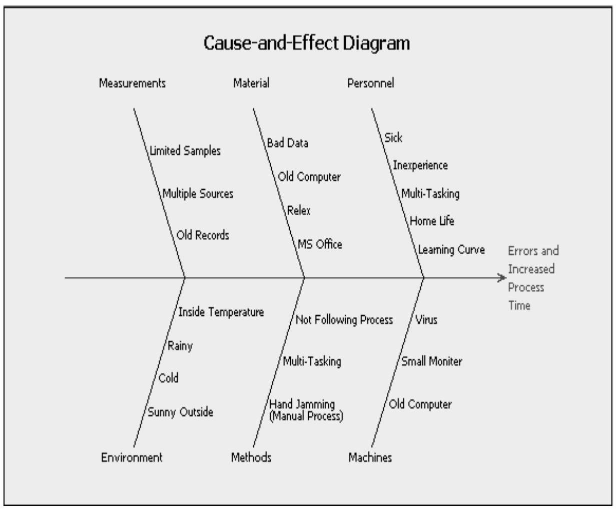


Figure 3: Cause and Effect Diagram

A baseline was established based upon the contractual agreements and estimation on the size of the remaining systems that are to be analyzed. Over the course of the year an additional twenty eight systems need to be analyzed, with an approximation 120 parts per site comes out to an estimation of 3300 parts total. In order to meet this goal, the analysis would need to process 13.5 parts per day.

Ideally getting the number of errors down to zero would be desirable, but not always possible. A goal of fewer than 5% of the parts having discrepancies in them would be reasonable expectation. This goal seems reasonable, because most of errors that are made in the analysis have an effect on multiple steps creating a snow ball effect. An error in the initial parts list or schematic diagram will cause an error to be made in the reliability block diagram and the data that is imported into Relex. The internal audit should catch most of these mistakes and minor corrections should be able to correct most of the issues.

Based upon these baselines, we are able to determine the current process capability for this process.

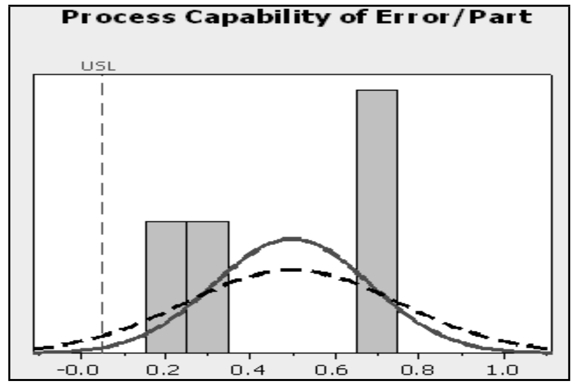


Figure 4: Cp Analysis Errors per Part

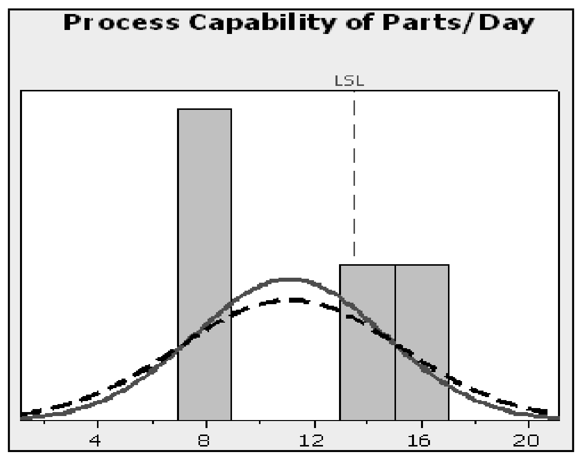


Figure 5: Cp Analysis Parts per Day

The process capability graphs illustrate the target value of the process to the actual. From the graphs it is clearly shown that the process has far more than the desired result of less than 5% of the parts containing some sort of errors. The number of parts analyzed per day process capability was slightly better than the errors per part, but still not capable of meeting the requirements. The analysis does not take a single part and follow it through the entire process, but rather taking the entire system in a stepwise progression as we are able to obtain the necessary information to perform the analysis.

- Goal: 5% of Parts have errors
    - Current: 49.8% of parts have errors
    - Current Cpk: -0.81
- Goal: Processing 13.5 parts/day
    - Processing 11.12 parts/day
    - Current Cpk: -0.23

The negative Cpk values are due to the data falling outside of the specification limits [1]. The number of errors found in the analysis exceeded the upper spec limit which is why its Cpk value is negative. The number of parts analyzed per day is below the lower spec limit causing it to have a negative Cpk value as well. As the process is improved, the mean should fall within the specification limits and the Cpk value will be positive.

Several critical areas stuck out that the team felt was causing the majority of the problems under the previous procedure. Upon the collection of the data a repetitive process was then used to transform the data into a format that could be understood by the analysis software. Due to the repetitive nature of the process it was time consuming and also created a large number opportunities for mistakes.

From this initial list, our team decided to focus on the manual process and how it can be improved. By looking at the Key Process Input Variable (KPIV) and the Key Process Output Variables (KPOV) we can see what is needed in the process and what needs to be produced [2].

KPIV

- CTBTO's part database
- Initial Schematic Diagram
- Interview with Subject Matter Experts
- Certification Manuals

KPOV

- Updated Schematic Diagram
- Parts List of the Site
- Reliability Block Diagram in Visio
- Relex Simulation output
- Full Report

CTBTO's part database is the list of parts that CTBTO collects data upon; this is a majority of what goes into our parts list. We used interviews with the subject matter experts to update the schematic diagram, complete the parts list and assist in the building of the Reliability Block Diagram. We are able to format the data and insert it into Relex for our analysis. The manual process of formatting each individual data sheet is repetitive and time consuming.

The Analyze Phase

It was evident that the manual process of formatting the data to insert into RELEX was causing the majority of the errors associated within the process as shown in the cause and effect diagram. An improved process flow chart was developed to eliminate any steps that were not value adding steps and to illustrate the process that we follow.

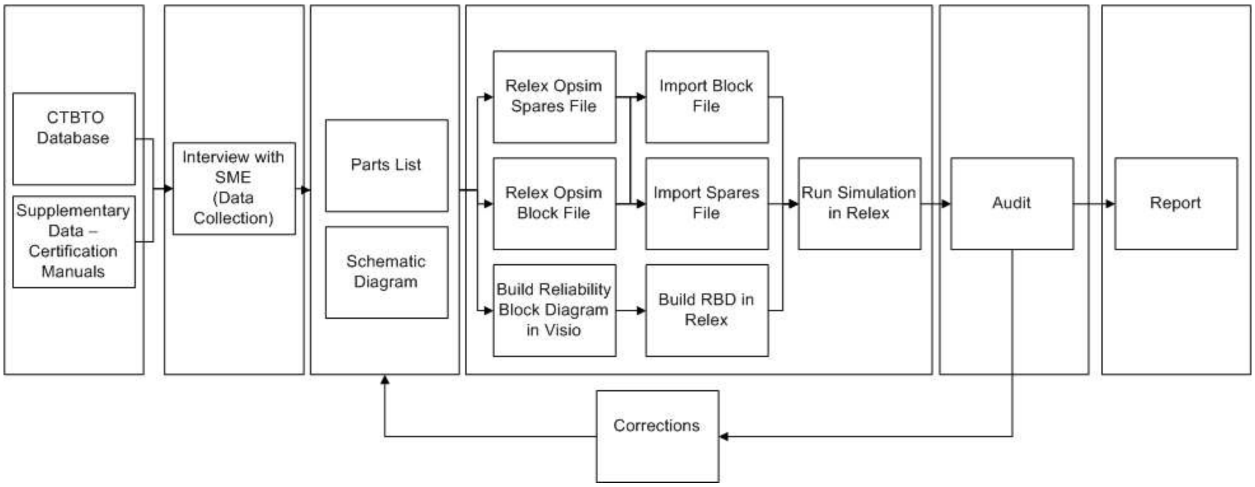


Figure 6: Proposed Improved Process Flow Diagram

The Improvement Phase

Several solutions were proposed that could potentially improve the performance of the process. One such solution would be to hire several undergrads to help in the process. From a financial stand point undergrads would not be a major burden on the budget. However they would create more opportunities for errors. Not that they could not complete the work; the process is very tedious and the lack of understanding of more advance statistical applications would pose a problem for this solution.

Another alternative solution would be to build a database that would contain all of the data that is collected. Eventually down the road, this would be an excellent solution, for the time being, the cost and time that it would take to develop a functional database outweighs the benefits.

An audit at the end of each step was suggested to eliminate errors before proceeding onto the next step. This would eliminate the snowball effect, but drastically slow down the analysis. Audits are not a value added process and only add time to the analysis.

The recommended solution is to implement a common data collection template in Excel. Within Excel we would be able to build pages that would be linked and automatically place the data into the specific formats for Relex. This would eliminate most of the errors associated with formatting the data into a specific format for Relex. It would also ensure consistency for the RBD and Parts list since they are linked together. One of the more tedious and time consuming steps in the old process was formatting the data into the respected formats for the Relex spares and blocks imports. This would only require the time that it takes to gather the data, because the other outputs would be automatically assembled and ready to be imported into Relex without having to manually do it.

The major difference in the Process Flow Diagrams is the elimination and simplification of a few processes. One of the sources for data was removed because it was redundant. The data collection method was simplified to ensure the quality of the data that is collected. From a standardized data collection sheet the specific format that Relex needs to read the data was about to be automatically. The base models still have to be done manually, but this should enable the process to flow with a consistent manor.

Conclusion

Full implementation of the solution has not been set up due to the inability to obtain all of the required data to perform the analysis. Based upon the partial data that we have received so far, the excel datasheets have appeared to greatly improve the throughput time and reduced the number of errors produced during the analysis by eliminating non-value added steps in the process. As more data is acquired the control phase can be further examined and a conclusion can be determined.

Before the submission of the final draft, initial feedback from the internal audits was received. Only thirteen errors were found with the additional two sites which consist of 177 different parts. Approximately 7% of the parts have some sort of error associated with them which a great improvement from the 50% that was under the previous procedure. We are still in the last step of the process and waiting for the remainder of the set of data to be audited before finishing the analysis.

References

[3] Cleary, Michael J. How Capable Does It Have to Be? http://www.qualitydigest.com/oct01/html/spc.html.

[2] Montgomery, Douglas C. *Statistical Quality Control a Modern Introduction.* John Wiley & Sons, Inc., 2009.

[3] Pande, Peter S., Robert P. Neuman, and Ronald R. Cavanagh. *The Six Sigma Way How GE, Motorola, and Other Top Companies Are Honing Their Performance.* McGraw-Hill, 2000.

Analysis of Two-Machine Flexible Manufacturing Cell Under Unbalanced Machining Time

Mohammad M. Hamasha, Tariq H. Tashtoush, Sa'd M. Hamasha, and Mohammad T. Khasawneh
Department of Systems Science and Industrial Engineering, State University of New York at Binghamton, Binghamton, New York 13902, USA
mkhasawn@binghamton.edu

Abstract

In this work, a Markov chain model is developed to analyze the performance of a flexible manufacturing cell (FMC), consisting of a single-robot and two machines. The robot loads the available machine with the working part. If both machines are busy, the robot waits until the next available machine. Both machines are subject to failure, but only during the processing time due to high loading stresses. Even though the robot is assumed to be 100% reliable, the entire system will stop working if any machine fails. Robot loading time, machine processing time, failure time and machine maintenance time are assumed to be exponentially distributed. A numerical example is presented to simulate the effect of different parameters on the overall machine utilization and production rate. It was found that while the overall machine utilization and production rate increase with robot speed, they decrease with machine speed and failure rate. Furthermore, the overall machine utilization decreases with the failure rate and increases with machine maintenance rate.

1. Introduction

A flexible manufacturing system (FMS) is one that has a flexibility that allows it to respond and adapt in case of changes and variations in operational functions and production. In such systems, machines can perform different procedures and handle various products, primarily due to the existence of an automated handling robot and an intelligent control unit that manages the system. A great advantage of FMS is the cost reduction per item produced and productivity enhancement, wherein a wide variety of products can be produced on the same production line.

More advantages of using FMSs have been discussed extensively. For example, Dimitrov [1] showed a reduction of inventory for systems that adopt FMS technology, while Mansfield [2] compared the economic impact of the FMS and their profitability in different countries. Smith et al. [3] investigated the characteristics and benefits of FMS in the U.S.

On the other hand, FMS has some limitations, such as high capital and implementation costs [4]. Therefore, this technology could be limited to large (e.g., automotive) industries. However, some small factories use flexible manufacturing principles for some portions of their production lines. In such cases, the material handling system to and from some machines is performed automatically using flexible handing systems. The flexible part of the production system is usually called a flexible manufacturing cell (FMC), which usually consists of machines and automated handling device (e.g., one or two robots).

Different approaches have been developed to analyze and optimize FMCs to improve productivity and efficiency. Since the introduction of FMCs, researchers have studied their scheduling, products routing and modeling their performance using artificial intelligence, simulation, fuzzy logic, stochastic processes, etc. Mathematical modeling for scheduling FMCs has also been conducted by many researchers [e.g., 5, 6, 7]. For example, Tu et al. [8] implemented transportation control and provided the best route for parts according to the shortest path within the FMC. Moreover, Pezzella et al. [9] used genetic algorithms to schedule products and task flow in an FMC, which yielded similar results as the study by Tu et al. [8].

Stochastic modeling is a popular method to study FMCs, as presented by Viswanadham et al. [10], Yan [11], Sinha et al. [12], and Aldaihani et al. [13]. Furthermore, Buzacott et al. [14], Sabuncuoglu et al. [15], and Henneke et al. [16] presented Markov chain models to estimate FMC performance according to different process parameter, such as processing rate, robot and pallet speeds. In addition, Koulamas [17] investigated the effects of tool failures on system performance, while Vineyard et al. [18] studied the influence of maintenance policies on their efficiency within the FMC.

In this study, a Markov chain model is developed to estimate the utilization of an FMC. A numerical example is presented to show the effect of the various FMC parameters on the utilization.

2. System description

The selected FMC consists of two machines (*M1* and *M2*) and one automated handling device (robot), as illustrated in Figure 1. The working part flow to the robot is continuous because a high capacity buffer is placed before the robot stage. Therefore, parts are always available for pick up by the robot. Each machine starts processing once having the part, then delivers it to the next processing stage without involving the robot in the unloading process.

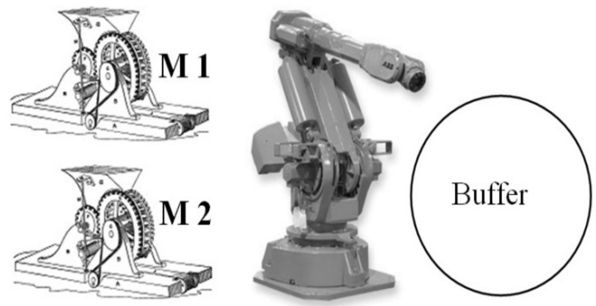


Figure 1. FMC Structure

The performance of the FMC system depends on the robot loading time and machine processing time. In this research, both times are assumed to follow an exponential distribution. Furthermore, the robot is assumed to be 100% reliable, while the machines are subject to failure during processing due to high loading stresses. However, it is assumed that the machine failure does not occur during idle time. If any machine fails, the entire system stops working until appropriate maintenance procedures are completed. In this research, both machines are considered unreliable.

3. Notations

The notations used in this paper are as follows:

i	Robot status (i.e., i=1 if robot is loading a machine with a part, i=0 otherwise)
j	*M1* status (i.e., j=0 if the machine is idle, j=1 if the machine is processing a part, j=d if the machine is down, j=0 otherwise)
k	*M2* status (i.e., k=0 if the machine is idle, k=1 if the machine is processing a part, k=d if the machine is down, k=0 otherwise)
S_{ijk}	Steady state of the FMC in term of parameters i, j, and k
P_{ijk}	Probability of the system being in state S_{ijk}

L	Robot's loading rate of the (parts per unit time)
v_1, v_2	$M1$ and $M2$ processing rates (parts per unit time)
λ	Machine failure rate (machine per unit time)
μ	Machine maintenance rate (machine per unit time)
U	Overall machine utilization
PR	Production rate

4. Proposed model

In this section, a Markov chain model for the FMC understudy is introduced. The following assumptions have been used:

- The machine processes one part at a time.
- The robot transfers one part at a time.
- The buffer is large enough to insure continuous working parts flow to the robot.
- Working parts are identical.
- Machines' speed may not be identical.
- Robot loading speed is the same for both machines.
- Machines can fail during processing.
- The system is stopped once/if a machine fails until the required maintenance takes place.

The state of the system is described by three variables: the status of the robot, the status of *M1*, and the status of *M2*. Considering the FMC with two reliable machines, the system can be in one of the following four states: (1) one part is being loaded by the robot and no part is being processed (S_{100} with probability P_{100}), (2) one part is being loaded by the robot and *M1* is processing a part (S_{110}, P_{110}), (3) one part is being hold by the robot and *M2* is processing a part (S_{101}, P_{101}), (4) no part is being hold by the robot and both machines are processing parts (S_{011}, P_{011}), (5) *M1* is failed (S_{0d0}, P_{0d0}), and (6) *M2* is failed (S_{00d}, P_{00d}). When the system is in state S_{100}, the next transition will be to either state S_{110} or S_{101} with an equal probability of ½. Therefore, the transition rate to either state is the robot loading rate, L, multiplied by ½.

Both states, S_{110} or S_{101}, can transition back to state S_{100} if part processing is completed before the robot loads the next machine with a part (transition rate is either v_1, if the current state is S_{110} or v_2, if the current state is S_{101}). Otherwise, the next transition will be S_{011} if the robot loads the next machine with the part before the working machine finishes processing the current loaded part. The transition rate in this case is L. However, there is a chance for the system to transition from S_{010} state to state S_{0d0} with transition rate λ_1 if *M1* fails, or from S_{001} to state S_{00d} with transition rate λ_2 if *M2* fails (λ_1 and λ_2 refer to the failure rates of *M1* and *M2*, respectively).

However, the system can be recovered when the maintenance takes place with μ_1 transition rate if *M1* fails or μ_2 if *M2* fails (μ_1 and μ_2 refer to the maintenance rates of *M1* and *M2*, respectively). At state S_{011}, the robot should not load a part to any machine (both filled) and just wait for the next available machine. At this state, if *M1* finishes processing the part, the next transition will be to S_{101} with transition rate of v_1. Similarly, if *M2* finishes first, the next transition will be to S_{110} with transition rate of v_2. Figure 2 illustrates the transition flow diagram between the various possible states for an FMC with no failures. It can be seen that the system is totally recurrent.

Using the fact that the net flow rate at each state is equal to the difference between the rates of flow-in and flow-out, the following equations are constructed for the stochastic FMC to compute the steady state probabilities, keeping in mind that the sum of state probabilities is equal to 1:

$$v_1 P_{110} + v_2 P_{101} - L P_{100} = 0 \quad (1)$$

$$\frac{1}{2} L P_{100} + v_2 P_{011} + \mu_1 P_{1d0} - (L + v_1 + \lambda_1) P_{101} = 0 \quad (2)$$

$$\frac{1}{2} L P_{100} + v_1 P_{011} + \mu_2 P_{10d} - (L + v_2 + \lambda_2) P_{101} = 0 \quad (3)$$

$$L P_{110} + L P_{101} + \mu_1 P_{1d0} + \mu_2 P_{10d} - (v_2 + v_2 + \lambda_1 + \lambda_2) P_{011} = 0 \quad (4)$$

$$\lambda_1 P_{110} - \mu_1 P_{1d0} = 0 \quad (5)$$

$$\lambda_2 P_{101} - \mu_2 P_{10d} = 0 \quad (6)$$

$$P_{100} + P_{110} + P_{101} + P_{011} + P_{1d0} + P_{10d} = 1 \quad (7)$$

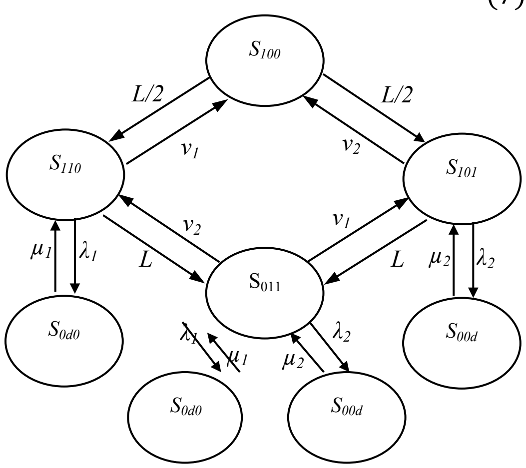


Figure 2. State transition flow diagram for an FMC operation with unreliable machine

This set of seven equations with six unknown variables can be solved to estimate the probability of the system being at a specific state. The performance metric involves the overall machine utilization, which is mainly the percentage of time that both machines are busy (P_{110}), plus the percentage of time that only *M1* is busy (P_{110}), multiplied by ½ because *M2* is idle, plus the percentage of time that *M2* is busy (P_{101}), multiplied by ½ because *M1* is idle. Then, the three terms are multiplied by 100% as expressed in equation (8).

$$U = (P_{110} + 1/2 P_{110} + 1/2 P_{101}) \times 100\% \quad (8)$$

The production rate of the system can be calculated by multiplying the overall machine utilization with the maximum production speed, which is $v1+v2$, as expressed in equation (9).

$$PR = U \times (v_1 + v_2) \quad (9)$$

A detailed explanation of the overall machine utilization and production rate calculations (including the mathematical explanation) is provided in the following section.

5. Numerical Example

In this section, a numerical example will be discussed to evaluate the model developed in the previous section for unreliable machines. The effect of machine and robot speeds on the overall machine utilization and production rate was investigated. Furthermore, the effects of the failure and machine maintenance rates were investigated as well.

Consider an FMC with unreliable machines, with a robot loading rate of 4 parts/min, *M1* processing rate of 2 parts/min, *M2* processing rate of 2 parts/min, failure rate of 0.1 failure/hour, and machine maintenance rate of 0.15 machines/hour. Solving this system leads to: P_{100}=0.158, P_{110}=0.158, P_{101}=0.158, P_{011}=0.316, P_{0d0}=0.158 and P_{00d}=0.316 and an overall machine utilization of 47.4%.

The effect of the robot loading rate on the overall machine utilization at different machine processing rates is shown in Figure 3, which showed that the utilization increases with the robot loading rate. However, the increase is sharp at low loading rates and then stabilizes at higher loading rates. In other words, the increase of the loading speed does not have a significant effect on utilization. Furthermore, it can be noticed that the utilization decreases with the machine processing rate at fixed robot loading rate, primarily because the faster machine processes parts quickly and waits longer for the next part. This increase in the idle time for the fast machine leads to a decrease in utilization. However, although the utilization decreases because of an increase in machine availability, the production rate is increased. Therefore, enhancing machine utilization should not be controlled by reducing their speed; instead, it should be performed by controlling other factors such as layout, maintenance, etc.

As shown in Figure 4, the production rate increases with robot and machine speeds as expected. However, at high robot speed, production rate tend to stabilized with further increasing of the robot speed. This because the machines are always busy and higher robot speed will not reduce the idle time of the machine so much. Moreover, the difference of the production rates for different machine speed become more significant at a higher robot speed.

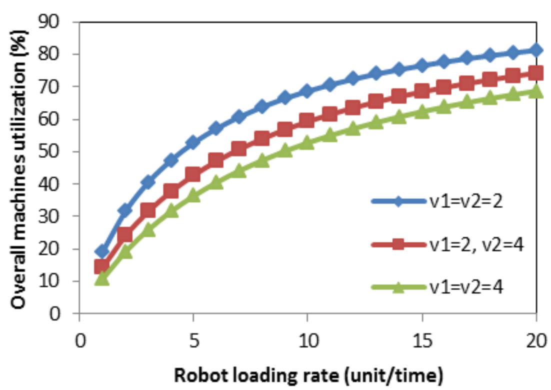


Figure 3. Effect of robot loading rate on overall machine utilization for unreliable machines FMC

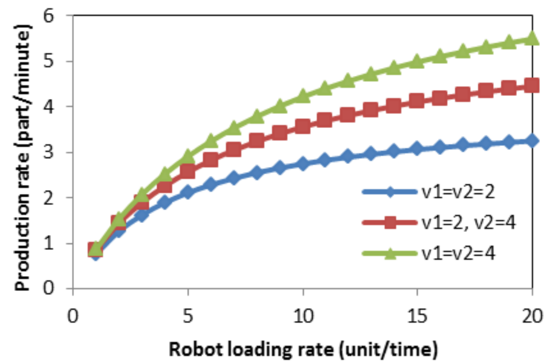


Figure 4. Effect of robot loading rate on production rate for unreliable FMC

The effects of failure and machine maintenance rates on the overall machine utilization and production rate were also studied (Figures 5-8). Higher failure rates decrease utilization and production rate due to an increase in down-time, whereas higher machine maintenance rates increase the overall machine utilization and production rate due to a decrease in down-time. Therefore, the target for any industry is to reduce the failure rate as much as possible and increase the machine maintenance rate, as expected, primarily due to the serious impact machine down-time has on facility operations and profit.

As shown in Figures 5-8, machine utilization and production rate tend to stabilize at a higher values of λ or μ. In other words, the overall machine utilization and production rate is not sensitive to λ at higher μ and vice versa (i.e., not sensitive to μ at high λ). Moreover, because failure rate is usually uncontrollable (i.e., random) and machine maintenance rate is costly but controllable, the optimizing of the machine maintenance rate by having appropriate levels of maintenance staff is required to increase the overall net profit.

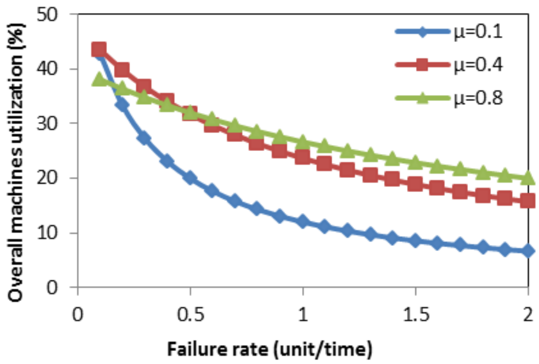


Figure 5. Effect of failure rate on overall machine utilization for unreliable FMC

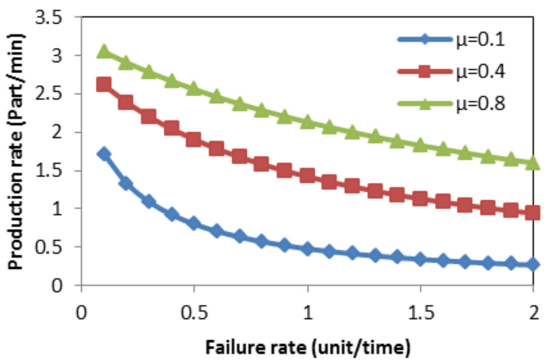


Figure 6. Effect of failure rate on production rate for unreliable FMC

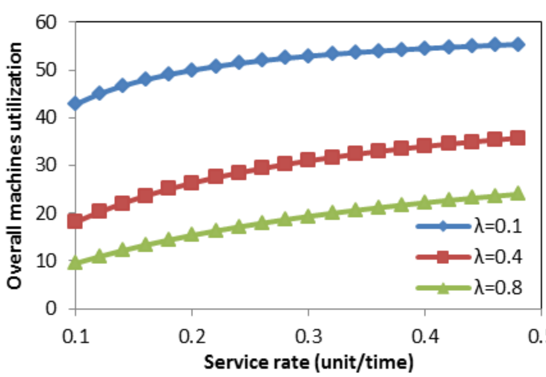


Figure 7. Effect of machine maintenance rate on overall machine utilization for unreliable FMC

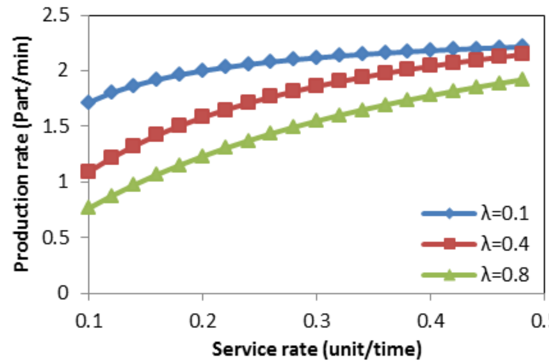


Figure 8. Effect of machine maintenance rate on production rate for unreliable FMC

6. Conclusion

As highlighted in the literature, an FMC can be effectively analyzed using Markov chains. Therefore, a Markov chain model for an FMC that consists of a single robot and two machines was developed to estimate the effect of robot loading rate, machining rate, machine failure rate, and machine maintenance rate on the overall machine utilization. Numerical examples were presented to simulate the constructed models. It can be concluded from previous discussion that the increase in utilization by reducing machine speed leads to a reduction in production rate. Therefore, increasing the overall machine utilization should not be controlled via an interruption of production units. Moreover, it can be concluded that the overall machine utilization and production rate is not sensitive to failure rate at higher machine maintenance rate and vice versa.

Future work in this area could include modeling an FMC with different structures, such as *n* robots and *m* machines. Moreover, scenarios involving random arrival (i.e., availability) of parts to the robot station can be considered. Furthermore, other performance measures can be considered, such as product quality. Finally, discrete event simulation can be used to analyze the FMC to compare the results with the Markov chains based approach.

7. References

[1] P. Dimitrov, "The impact of flexible manufacturing systems (FMS) on inventories", Engineering Costs and Production Economics, Vol. 19, No. 1-3, 1990, pp. 165-174.

[2] E. Mansfield, "Flexible manufacturing systems: Economic effects in Japan, United States, and Western Europe", Japan and the World Economy Vol. 4, No. 1, 1992, pp. 1-16.

[3] A. Kusiak, "Application of operational research models and techniques in flexible manufacturing systems", European Journal of Operational Research, Vol. 24, No. 3, 1986, pp. 336-345.

[4] M. Shah, L. Lin, and R. Nag, "A production order-driven AGV control model with object-oriented implementation", Computer Integrated Manufacturing Systems, Vol. 10, No. 1, 1997, pp. 35-48.

[5] D. Lee and Y. Kim, "Scheduling algorithms for flexible manufacturing systems with partially grouped machines", Journal of Manufacturing Systems, Vol. 18, No. 4, 1999, pp. 301-309.

[6] T. Sawik, "A lexicographic approach to bi-objective scheduling of single-period orders in make-to-order manufacturing", European Journal of Operational Research, Vol. 180, No. 3, 2007, pp. 1060-1075.

[7] H. Gultekin, M.S. Akturk, and O. E. Karasana, "Scheduling in a three-machine robotic flexible manufacturing cell", Computers & Operations Research, Vol. 34, No. 8, 2007, pp. 2463-2477.

[8] Y. Tu and A. Sorgen, "Real-time scheduling and control of transportation in flexible manufacturing cells", Computers in Industry, Vol. 16, No. 4, 1991, pp. 315-320.

[9] F. Pezzellaa, G. Morgantia, and G. Ciaschettib, "A genetic algorithm for the flexible job-shop scheduling problem", Computers & Operations Research, Vol. 35, No. 10, 2008, pp. 3202-3212.

[10] N. Viswanadham and Y. Narahari, "Stochastic modeling of flexible manufacturing systems", Mathematical and Computer Modeling, Vol. 16, No. 3, 1992, pp. 15-34.

[11] H. Yan, "Hierarchical stochastic production planning for flexible automation workshops", Computers & Industrial Engineering, Vol. 38, No. 4, 2000, pp. 435-455.

[12] D. Sinha and J.C. Wei. "Stochastic analysis of flexible process choices", European Journal of Operational Research, Vol. 60, No. 2, 1992, pp. 183-199.

[13] M.M. Aldaihani and M. Savsar. "A stochastic model for the analysis of a two-machine flexible manufacturing cell", Computers and Industrial Engineering, Vol. 49, No. 4, 2005, pp. 600-610.

[14] J.A. Buzacott and D.D. Yao, "Flexible manufacturing systems: a review of analytical models", Management Science, Vol. 32, No. 7, 1986, pp. 890–906.

[15] I. Sabuncuoglu and D.L. Homertzheim, "Expert simulation systems—recent developments and applications in flexible manufacturing systems", Computer and Industrial Engineering, Vol. 16, No. 4, 1989, pp. 575–585.

[16] M.J. Henneke and RH. Choi, "Evaluation of FMS parameters on overall system parameters", Computer and Industrial Engineering, Vol. 18, No. 1, 1990, pp. 105–110.

[17] C.P. Koulamas, "A Stochastic model for a machining cell with tool failure and tool replacement considerations", Computer and Operation Research, Vol. 19, No. 9, 1992, pp. 717–729.

[18] M.L. Vineyard and J.R. Meredith, "Effect of maintenance policies on FMS failures", International Journal Production Research, Vol. 30, No. 11, 1992, pp. 2647–2657.

Supplier Selection Using an Integrated Fuzzy Decision Making Approach

Mehtap Dursun and E. Ertugrul Karsak
Industrial Engineering Department, Galatasaray University, Ortakoy, Istanbul 34357, Turkey
mdursun@gsu.edu.tr , ekarsak@gsu.edu.tr

Abstract

A sound methodology for supplier selection requires the use of multiple criteria decision making techniques. Using linguistic assessments rather than exact numerical values is more realistic for expressing preference related to numerous features of the supplier selection process due to vague and imprecise judgments. In this paper, a novel fuzzy multi-criteria group decision making approach using the quality function deployment (QFD) concept, fusion of fuzzy information and 2-tuple linguistic representation model is developed for supplier selection.

1. Introduction

In facing an ever-increasingly competitive and changing environment, firms must focus on rapidly and precisely responding to customer demand and must be concerned with customer satisfaction. They also require to reorganize their supply chain management strategy and establish a sound strategic alliance against competitors. Supply chain management attempts to reduce supply chain risk and uncertainty, thus improving customer service, optimizing inventory levels, business processes, and cycle times, and resulting in increased competitiveness, customer satisfaction and profitability [1]. As organizations become more dependent on their suppliers, the consequences of poor decisions on the selection of individual suppliers and the determination of order quantities to be placed with the selected suppliers become more severe [2]. In order to achieve corporate competition in the global market, firms need to pursue strategies to attain higher quality, reduced costs and shorter lead times. Thus, supplier selection problem has become a critical issue for establishing an effective supply chain.

Supplier selection is one of the most popular areas of research in purchasing with methodologies ranging from conceptual to empirical and modeling streams. Earlier studies on supplier selection focused on identifying the criteria used to select suppliers. Dickson [3] conducted one of the early works on supplier selection and identified over 20 supplier attributes which managers consider when choosing a supplier. Ellram [4] noted that research on supplier selection tends to be either descriptive or prescriptive. Descriptive studies provide information on what buyers actually do in selecting suppliers. These studies have addressed a wide array of issues, and have been extended to identify supplier selection under specific buying conditions ([2], [5], [6]). Prescriptive studies in supplier selection has used a variety of methodologies including mathematical programming, weighted average methods, payoff matrices, and the analytic hierarchy process ([7], [8], [9]).

Most of the research on supplier selection focuses on the quantifiable aspects of the supplier selection decision such as cost, quality, and delivery reliability. However, as firms become involved in strategic partnerships with their suppliers, a new set of supplier selection criteria, which are difficult to quantify, needs to be considered. These factors involve high degree of uncertainty. Fuzzy set theory appears as an effective tool to deal with uncertainty. In the literature, there are a number of studies that use different fuzzy decision making techniques to evaluate suppliers. Several authors have used fuzzy mathematical programming approaches ([10], [11], [12]). A number of studies have focused on the use of fuzzy multi-attribute decision making (MADM) techniques for supplier selection process ([13], [14], [15]). Recently, few researchers have employed the quality function deployment (QFD) in supplier selection ([16], [17], [18]).

Although previously reported studies developed approaches for supplier selection process, further studies are necessary to integrate imprecise information into the analysis, regarding the importance of purchased product features and relationship between purchased product features and supplier assessment criteria. Supplier selection, which involves the need to trade-off multiple criteria exhibiting vagueness and imprecision, is a highly important group decision making problem. In group decision making problems, aggregation of expert opinions is critical for conducting the evaluation efficiently. The inherent imprecision and vagueness in criteria values justify the use of fuzzy set theory.

In this paper, a fuzzy multi-criteria group decision making approach based on the concepts of QFD, fusion of fuzzy information, and 2-tuple linguistic representation model is proposed. This method identifies how well each supplier characteristic succeeds in meeting the requirements established for the product being purchased by constructing a house of quality, which enables the relationships among the purchased product features and supplier assessment criteria to be considered. Furthermore, the method enables the managers to deal with heterogeneous information, and thus, allows for the use of different semantic types by the decision-makers. The proposed decision making approach uses the ordered weighted averaging (OWA) operator to aggregate decision makers' opinions. The OWA operator is a common generalization of the three basic aggregation operators, i.e. max, min, and the arithmetic mean.

The rest of the paper is structured as follows. The following section provides information on QFD. Section 3 and Section 4 delineate the fusion of fuzzy information approach and 2-tuple fuzzy linguistic representation model, respectively. In Section 5, the fuzzy decision making framework is presented. The application of the fuzzy decision making framework to supplier selection problem is set forth in Section 6. Finally, conclusions are provided in Section 7.

2. Quality Function Deployment

QFD is a customer-oriented design tool that aims to meet customer requirements in a better way and enhance organizational capabilities, while maximizing company goals. QFD aims at delivering value by focusing on prioritized customer requirements, translating these into design requirements, and then communicating them throughout the organization in a way to assure that details can be quantified and controlled [19].

The reported benefits of QFD include better products or services that are highly focused and responsive to customer needs (CNs), developed in a shorter period of time with fewer resources.

One shall also note the intangible benefits of QFD such as increased customer satisfaction, enhanced multi-disciplined teamwork, and structured basis for improved planning [20].

The basic concept of QFD is to translate the desires of customers into technical attributes (TAs), and subsequently into parts characteristics, process plans and production requirements. In order to establish these relationships, QFD usually requires four matrices each corresponding to a stage of the product development cycle. These are product planning, part deployment, process planning, and production/operation planning matrices, respectively [21]. In this paper, we focus on the first of the four matrices, also called the house of quality (HOQ). According to Hauser and Clausing [22], the HOQ is a kind of conceptual map that provides the means for interfunctional planning and communications. It contains seven elements as shown in Figure 1.

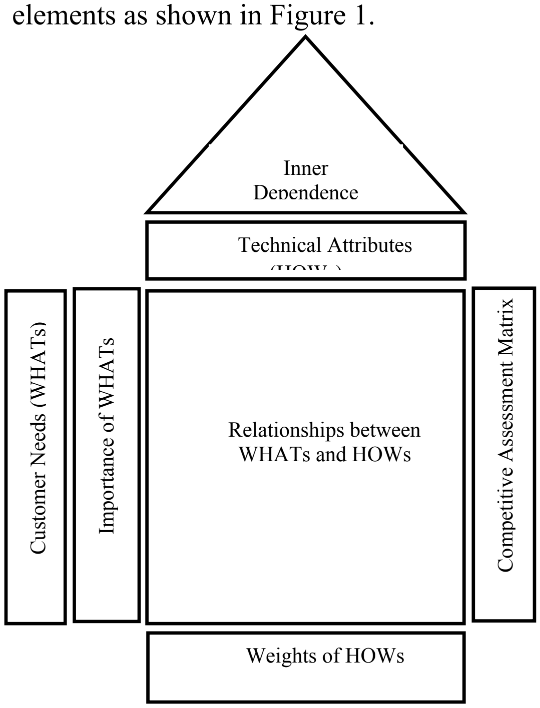


Figure 1. The House of Quality

3. Fusion of Fuzzy Information

Fusion approach of fuzzy information, which was proposed by Herrera, Herrera-Viedma, and Martínez [23] is used to manage information assessed using both linguistic and numerical scales in a decision making problem with multiple information sources. This approach is carried out in two phases:

Phase 1. Making the information uniform: The performance values expressed using multi-granularity linguistic term sets are converted (under a transformation function) into a specific linguistic domain, which is a basic linguistic term set (BLTS), chosen so as not to impose useless precision to the original evaluations and to allow an appropriate discrimination of the initial performance values [23]. The transformation function is defined as follows [23]:

Let $A = \{l_0, l_1, \dots, l_p\}$ and $S_T = \{s_0, s_1, \dots, s_g\}$ be two linguistic term sets, such that $g \geq p$. Then, the transformation function, τ_{AS_T} is defined as

$$\tau_{AS_T} = A \rightarrow F(S_T),$$

$$\tau_{AS_T}(l_k) = \{(s_i, \gamma_i^k)/ i \in \{0,1,\dots,g\}\}, \forall l_k \in A,$$

$$\gamma_i^k = \max_y \ \min\{\mu_{l_k}(y), \mu_{s_i}(y)\},$$

(1)

where $F(S_T)$ is the set of fuzzy sets defined in S_T, and $\mu_{l_k}(y)$ and $\mu_{s_i}(y)$ are the membership functions of the fuzzy sets associated with the terms l_k and s_i, respectively.

Phase 2. Computing the collective performance values: For each alternative, a collective performance value is obtained by means of the aggregation of the aforementioned fuzzy sets on the BLTS that represents the individual performance values assigned to the alternative according to each information source

[23]. Therefore, each collective performance value is a new fuzzy set defined on a BLTS. This paper employs the OWA operator, initially proposed by Yager [24], as the aggregation operator. This operator provides an aggregation which lies in between the "and" requiring all the criteria to be satisfied, and the "or" requiring at least one of the criteria to be satisfied. Indeed, the OWA category of operators enables trivial adjustment of the ANDness and ORness degrees embedded in the aggregation [25]. The OWA operator differs from the classical weighted mean in that coefficients are not associated directly with a particular attribute but rather to an ordered position. It encompasses several operators since it can implement different aggregation rules by changing the order weights.

Let $A = \{a_1, a_2, ..., a_n\}$ be a set of values to be aggregated. The OWA operator F is defined as

$$F(a_1, a_2, \ldots, a_n) = \mathbf{w}\mathbf{b}^T = \sum_{j=1}^{n} w_j b_j, \tag{2}$$

where $\mathbf{w} = (w_1, w_2, \ldots w_n)$ is a weighting vector, such that $w_i \in [0,1]$ and

$$\sum_{i=1}^{n} w_i = 1$$

and $\mathbf{b}$ is the associated ordered value vector, where $b_j \in \mathbf{b}$ is the jth largest value in A.

To apply the OWA operator for decision making, a crucial issue is to determine its weights. The weights of the OWA operator are calculated using fuzzy linguistic quantifiers, which for a non-decreasing relative quantifier Q, are given by

$$w_i = Q(i/n) - Q((i-1)/n), \quad i = 1, ..., n. \tag{3}$$

The non-decreasing relative quantifier, Q, is defined as [23]

$$Q(y) = \begin{cases} 0 & , y < a \\ \frac{y-a}{b-a} & , a \leq y \leq b \\ 1 & , y > b \end{cases} \tag{4}$$

with $a, b, y \in [0,1]$, and $Q(y)$ indicating the degree to which the proportion y is compatible with the meaning of the quantifier it represents. Some non-decreasing relative quantifiers are identified by terms 'most', 'at least half', and 'as many as possible', with parameters (a, b) given as $(0.3, 0.8)$, $(0, 0.5)$, and $(0.5, 1)$, respectively.

4. 2-Tuple Fuzzy Linguistic Representation Model

The 2-tuple linguistic model that was presented by Herrera and Martínez [26] is based on the concept of symbolic translation. It is used for representing the linguistic assessment information by means of a 2-tuple that is composed of a linguistic term and a number. It can be denoted as (s_i, α) where s_i represents the linguistic label of the predefined linguistic term set S_T, and α is a numerical value representing the symbolic translation [27].

Let $r_1 = (s_c, \alpha_1)$ and $r_2 = (s_d, \alpha_2)$ be two linguistic variables represented by 2-tuples. The main algebraic operations can be expressed as follows [28]:

$$r_1 \oplus r_2 = (s_c, \alpha_1) \oplus (s_d, \alpha_2) = (s_c + s_d, \alpha_1 + \alpha_2) \tag{5}$$

$$r_1 \otimes r_2 = (s_c, \alpha_1) \otimes (s_d, \alpha_2) = (s_c s_d, \alpha_1 \alpha_2) \tag{6}$$

where $\oplus$ and $\otimes$ represent the addition and multiplication operators, respectively.

The comparison of linguistic information represented by 2-tuples is carried out according to an ordinary lexicographic order as follows [29]:

- If $c < d$ then r_1 is smaller than r_2;
- If $c = d$ then

- If $\alpha_1 = \alpha_2$ then r_1 and r_2 represent the same information;
- If $\alpha_1 < \alpha_2$ then r_1 is smaller than r_2;
- If $\alpha_1 > \alpha_2$ then r_1 is bigger than r_2.

In the following, we define a set of transformation functions between fuzzy sets defined on the BLTS and numerical value, and between numerical value and 2-tuples.

Definition 1 [28]: Let $L = (\gamma_0, \gamma_1, ..., \gamma_g)$ be a fuzzy set defined in S_T. A transformation function χ that transforms L into a numerical value in the interval of granularity of S_T, $[0, g]$ is defined as

$$\chi : F(S_T) \rightarrow [0,g],$$
$$\chi(F(S_T)) = \chi(\{(s_j, \gamma_j), j=0,1,...,g\}) =$$

$$\frac{\sum_{j=0}^{g} j\gamma_j}{\sum_{j=0}^{g} \gamma_j} = \beta \tag{7}$$

where $F(S_T)$ is the set of fuzzy sets defined in S_T.

Definition 2 [26]: Let $S = \{s_0, s_1, ..., s_g\}$ be a linguistic term set and $\beta \in [0, g]$ a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function:

$$\Delta : [0, g] \rightarrow S \times [-0.5, 0.5),$$
$$\Delta(\beta) = \begin{cases} s_i, & i = \text{round}(\beta) \\ \alpha = \beta - i, & \alpha \in [-0.5, 0.5) \end{cases} \tag{8}$$

where 'round' is the usual round operation, s_i has the closest index label to 'β' and 'α' is the value of the symbolic translation.

Proposition 1 [26]: Let $S = \{s_0, s_1, ..., s_g\}$ be a linguistic term set and (s_i, α) be a 2-tuple. There is a Δ^{-1} function, such that, from a 2-tuple it returns its equivalent numerical value $\beta \in [0, g] \subset \Re$. This function is defined as

$$\Delta^{-1} : S \times [-0.5, 0.5) \rightarrow [0, g],$$
$$\Delta^{-1}(s_i, \alpha) = i + \alpha = \beta. \tag{9}$$

5. Decision Making Framework

In this section, a decision making approach that integrates the concepts of QFD, fusion of fuzzy information, and 2-tuple linguistic representation model is developed to address the supplier selection problem. The proposed approach considers the ambiguity resulting from imprecise statements in expressing relative importance of CNs, relationship scores between CNs and TAs, and the ratings of each potential supplier with respect to each TA by using fuzzy set theory. Furthermore, utilization of the fusion of fuzzy information and the 2-tuple linguistic representation model enables decision-makers to deal with heterogeneous information, and rectifies the problem of loss of information of other fuzzy linguistic approaches. The stepwise representation of the fuzzy MCDM algorithm is given below.

Step 1. Construct a decision-makers committee of Z $(z = 1,2,..., Z)$ experts. Identify the characteristics that the product being purchased must possess (CNs) in order to meet the company's needs and the criteria relevant to supplier assessment (TAs).

Step 2. Construct the decision matrices for each decision-maker that denote the relative importance of CNs, and the fuzzy assessment to determine the relationship scores between CNs and TAs.

Step 3. Let the fuzzy value assigned as the relationship score between the lth CN $(l = 1,2,..., L)$ and kth TA $(k = 1,2,..., K)$, and importance weight of the lth CN for the zth decision-maker be $\tilde{x}_{klz} = (x^1_{klz}, x^2_{klz}, x^3_{klz})$, and $\tilde{w}_{lz} = (w^1_{lz}, w^2_{lz}, w^3_{lz})$, respectively. Convert $\tilde{x}_{klz}$ and $\tilde{w}_{lz}$ into the basic linguistic scale S_T by using Eq. (1). The fuzzy assessment vector on S_T and the importance weight vector on S_T, $F(\tilde{x}_{klz})$ and $F(\tilde{w}_{lz})$, can be represented respectively as

$$F(\tilde{x}_{klz}) = (\gamma(\tilde{x}_{klz}, s_0), \gamma(\tilde{x}_{klz}, s_1), ..., \gamma(\tilde{x}_{klz}, s_6)),\ \forall\, k,l,z \quad (10)$$

and

$$F(\tilde{w}_{lz}) = (\gamma(\tilde{w}_{lz}, s_0), \gamma(\tilde{w}_{lz}, s_1), ..., \gamma(\tilde{w}_{lz}, s_6)),\ \forall\, l,z \quad (11)$$

In this study, the label set given in Table 1 is used as the BLTS.

Table 1. Label set [30]

Label set	Fuzzy number
s_0:	(0,0,0.16)
s_1:	(0,0.16,0.33)
s_2:	(0.16,0.33,0.50)
s_3:	(0.33,0.50,0.66)
s_4:	(0.50,0.66,0.83)
s_5:	(0.66,0.83,1)
s_6:	(0.83,1,1)

Step 4. Aggregate $F(\tilde{x}_{klz})$ and $F(\tilde{w}_{lz})$ to yield the fuzzy assessment vector $F(\tilde{x}_{kl})$ and the importance weight vector $F(\tilde{w}_l)$. The aggregated parameters obtained from the assessment data of Z experts can be calculated respectively using Eq. (2) as

$$\tilde{x}_{kl}(s_m) = \phi_Q(\gamma(\tilde{x}_{kl1}, s_m), \gamma(\tilde{x}_{kl2}, s_m), ..., \gamma(\tilde{x}_{klz}, s_m)),\ \forall k,l,m \quad (12)$$

and

$$\tilde{w}_l(s_m) = \phi_Q(\gamma(\tilde{w}_{l1}, s_m), \gamma(\tilde{w}_{l2}, s_m), ..., \gamma(\tilde{w}_{lz}, s_m)),\ \forall l,m \quad (13)$$

where ϕ_Q denotes the OWA operator whose weights are computed using the linguistic quantifier, Q. Then, the fuzzy assessment vector on S_T with respect to the lth CN, $F(\tilde{x}_{kl})$, and the importance weight vector on S_T, $F(\tilde{w}_l)$, is defined as follows:

$$F(\tilde{x}_{kl}) = (\gamma(\tilde{x}_{kl}, s_0), \gamma(\tilde{x}_{kl}, s_1), ..., \gamma(\tilde{x}_{kl}, s_6)),\ \forall\, k,l \quad (14)$$

$$F(\tilde{w}_l) = (\gamma(\tilde{w}_l, s_0), \gamma(\tilde{w}_l, s_1), ..., \gamma(\tilde{w}_l, s_6)),\ \forall\, l \quad (15)$$

Step 5. Compute the β values of $F(\tilde{x}_{kl})$ and $F(\tilde{w}_l)$, and transform these values into a linguistic 2-tuple by using formulations (7) and (8), respectively.

Step 6. Calculate the 2-tuple weighted average for each TA.

Step 7. Construct the decision matrices for each decision-maker that denote the ratings of each potential supplier with respect to each TA.

Step 8. Apply *Steps* 3-5 to the ratings of each supplier obtained at *Step* 7.

Step 9. Calculate the 2-tuple weighted average for each supplier. The associated weights are considered as the 2-tuple weighted average for each TA computed at *Step* 6.

Step 10. Rank the suppliers using the rules of comparison of 2-tuples given in Section 4.

6. Illustrative Example

A supplier selection problem addressed in an earlier work by Bevilacqua et al. [16] is used to test the effectiveness of the proposed fuzzy MCDM framework. The problem can be summarized as follows:

There are 10 suppliers who are in contact with the company that manufactures complete clutch coupling. There are six fundamental characteristics (CNs) required of products or services purchased from outside suppliers by the company considered in this study. These can be listed as “product conformity”, “cost”, “punctuality of deliveries”, “efficacy of corrective action", "availability and customer support", and "programming of deliveries". Although the fundamental characteristics required are by no means comprehensive and may include a few more such as "service after sale", "projected maintenance cost", "update cost" etc., they are limited to the abovementioned ones for comparison purposes. Seven criteria relevant to supplier assessment are identified as "experience of the sector (EF)", "capacity for innovation to follow up the customer's evolution in terms of changes in its strategy and market (IN)", "quality system certification (SQ)", "flexibility of response to the customer's requests (FL)", "financial stability (FS)", "ability to manage orders on-line (RR)", and "geographical position (PG)". The evaluation is conducted by a committee of three decision-makers. The decision-makers used the linguistic variables given in Table 2 to denote the level of importance of each CN, the impact of each TA on CNs, and the ratings of the suppliers with respect to each TA.

Table 2. Linguistic term set

Very low (VL)	(0, 0.1, 0.2)
Low (L)	(0.2, 0.3, 0.4)
Medium (M)	(0.4, 0.5, 0.6)
High (H)	(0.6, 0.7, 0.8)
Very high (VH)	(0.8, 0.9, 1)

First, the weights of CNs and the fuzzy assessment corresponding to the impact of each TA on each CN are converted into the BLTS employing formulations (10) and (11). Next, by using the linguistic quantifier 'most' and the formulations (3) and (4), the OWA weights for three decision-makers are computed as $\mathbf{w} = (0.067, 0.666, 0.267)$. Then, the weights of CNs and the fuzzy assessment corresponding to the impact of each TA on each CN converted into the BLTS are aggregated employing formulations (12)-(15). The β values of these weights and ratings are computed and transformed into a linguistic 2-tuple using formulations (7) and (8), respectively. Then, the 2-tuple weighted averages for each TA are calculated. The results are shown in Table 3.

The ratings of each supplier converted into the BLTS are aggregated and transformed into a linguistic 2-tuple. Finally, the 2-tuple weighted average for each supplier is calculated and the suppliers are ranked according to the 2-tuple weighted average score. The ranking order of the suppliers is obtained as Sup 5 ≻ Sup 2 ≻ Sup 7 ≻ Sup 8 ≻ Sup 3 ≻ Sup 6 ≻ Sup 4 ≻ Sup 1 ≻ Sup 9 ≻ Sup 10.

Table 4 summarizes the results obtained from the proposed decision algorithm in comparison with the results obtained by Bevilacqua et al. [16]. Supplier 5 is determined as the most suitable supplier by both methods, which is followed by supplier 2. The fuzzy ranking principle of Bevilacqua et al. [16] cannot compare suppliers 1, 9, and 10, while the algorithm proposed in this study provides a complete ranking of all suppliers. This is due to the minimization of the loss of information by using the 2-tuple fuzzy linguistic representation model.

7. Conclusions

In today's competitive manufacturing environment, the selection of suppliers is critical to the success of a manufacturing firm. Purchasing managers need to evaluate supplier performance to identify suppliers who meet their requirements in terms of several performance criteria. In this paper, a fuzzy multi-criteria group decision making algorithm based on the concepts of QFD, fusion of fuzzy information, and 2-tuple linguistic representation model is presented to rectify the problems encountered when using classical decision making methods in supplier selection. The decision making approach set forth in this paper disregards the troublesome fuzzy number ranking process, which may yield inconsistent results for different ranking methods, and as a result improves the quality of decision. Furthermore, the algorithm enables managers to deal with heterogeneous information, and thus, allows for the use of different semantic types by decision-makers.

For future research, the decision framework presented in here can be applied to real-world group decision making problems in diverse disciplines that can be represented in a HOQ structure.

Table 4. Comparative ranking of the suppliers using the proposed algorithm and Bevilacqua et al.'s algorithm

Suppliers	Rank obtained using the proposed algorithm	Rank obtained using Bevilacqua et al.'s algorithm
Sup 1	8	Incomparable
Sup 2	2	2
Sup 3	5	5
Sup 4	7	6
Sup 5	1	1
Sup 6	6	7
Sup 7	3	4
Sup 8	4	3
Sup 9	9	Incomparable
Sup 10	10	Incomparable

Acknowledgement

This research has been financially supported by Galatasaray University Research Fund.

8. References

[1] D. Simchi-Levi, P. Kaminsky, and E. Simchi-Levi, Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, McGraw-Hill, New York, 2003

[2] L. Boer, E. Labro, P. Morlacchi, "A review of methods supporting supplier selection", European Journal of Purchasing & Supply Management, 2001, 7, pp. 75-89.

[3] G. Dickson, "An analysis of vendor selection systems and decisions", Journal of Purchasing, 1966, 2, pp. 28-41.

[4] L.M. Ellram, "The supplier selection decision in strategic partnerships", Journal of Purchasing and Materials Management, 1990, 26 (4), pp. 8-14.

[5] E.J. Wilson, "The relative importance of supplier selection criteria: A review and update", International Journal of Purchasing and Materials Management, 1994, 30 (3), pp. 34-41.

[6] V.R. Kannan, and K.C. Tan, "Supplier selection and assessment: Their impact on business performance", Journal of Supply Chain Management, 2002, 38 (4), pp. 11-21.

[7] C.A. Weber, "A data envelopment analysis approach to measuring vendor performance", Supply Chain Management, 1996, 1 (1), pp. 28-39.

[8] S.H. Ghodsypour, and C. O'Brien, "The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint", Int J Prod Econ, 2001, 73, pp. 15-27.

[9] S. Talluri, and J. Sarkis, "A model for performance monitoring of suppliers", Int J Prod Res, 2002, 40 (16), pp. 4257-4269.

[10] A. Amid, S.H. Ghodsypour, and C. O'Brien, "Fuzzy multiobjective linear model for supplier selection in a supply chain", Int J Prod Econ, 2006, 104, pp. 394-407.

[11] C. Araz, P.M. Özfırat, and I. Özkarahan, "An integrated multicriteria decision-making methodology for outsourcing management", Computers & Operations Research, 2007, 34, pp. 3738-3756.

[12] A. Amid, S.H. Ghodsypour, and C. O'Brien, "A weighted additive fuzzy multiobjective model for the supplier selection problem under price breaks in a supply chain", Int J Prod Econ, 2009, 121, pp. 323-332.
[13] C.T. Chen, C.T. Lin, and S.F. Huang, "A fuzzy approach for supplier evaluation and selection in supply chain management", Int J Prod Econ, 2006, 102, pp. 289-301.
[14] A.N. Haq, and G. Kannan, "Design of an integrated supplier selection and multi-echelon distribution inventory model in a built-to-order supply chain environment", Int J Prod Res, 2006, 44 (15), pp. 1963-1985.
[15] F.T.S. Chan, and N. Kumar, "Global supplier development considering risk factors using fuzzy extended AHP-based approach", Omega, 2007, 35, pp. 417 -431.
[16] M. Bevilacqua, F.E. Ciarapica, and G. Giacchetta, "A fuzzy-QFD approach to supplier selection", Journal of Purchasing & Supply Management, 2006, 12, pp. 14-27.
[17] S.H. Amin, and J. Razmi, "An integrated fuzzy model for supplier management: A case study of ISP selection and evaluation", Expert Systems Appl, 2009, 36, pp. 8639-8648.
[18] A. Bhattacharya, J. Geraghty, and P. Young, "Supplier selection paradigm: An integrated hierarchical QFD methodology under multiple-criteria environment", Applied Soft Computing, 2010, 10, pp. 1013-1027.
[19] E.E. Karsak, "Robot selection using an integrated approach based on quality function deployment and fuzzy regression", Int J Prod Res, 2008, 3, pp. 723-738.
[20] J.B. Revelle, J.W. Moran, and C.A. Cox, The QFD Handbook, John Wiley & Sons, New York, 1998.
[21] E.E. Karsak, "Fuzzy Multiple Objective Decision Making Approach to Prioritize Design Requirements in Quality Function Deployment", Int J Prod Res, 2004, 15, pp. 3957-3974.
[22] J.R. Hauser, and D. Clausing, "The House of Quality", Harvard Business Review, 1988, 66, pp. 63-73.
[23] F. Herrera, E. Herrera-Viedma, and L. Martínez, "A fusion approach for managing multi-granularity linguistic term sets in decision making", Fuzzy Sets and Systems, 2000, 114(1), pp. 43-58.
[24] R.R. Yager, "On ordered weighted averaging aggregation operators in multi-criteria decision making", IEEE Transactions on Systems Man and Cybernetics, 1988, 18(1), pp. 183–190.
[25] M. Zarghami, and F. Szidarovszky, "Fuzzy quantifiers in sensitivity analysis of OWA operator", Computers & Industrial Engineering, 2008, 54(4), pp. 1006–1018.
[26] F. Herrera, and L. Martínez, "A 2-tuple fuzzy linguistic representation model for computing with words", IEEE Transactions on Fuzzy Systems, 2000, 8(6), pp. 746-752.
[27] Z.P. Fan, B. Feng, Y.H. Sun, and W. Ou, "Evaluating knowledge management capability of organizations: a fuzzy linguistic method", Expert Systems Appl, 2009, 36, pp. 3346–3354.
[28] F. Herrera, and L. Martínez, "An approach for combining linguistic and numerical information based on 2-tuple fuzzy representation model in decision-making", International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 2000, 8(5), pp. 539-562.
[29] F. Herrera, and L. Martínez, "A model based on linguistic 2-tuples for dealing with multigranular hierarchical linguistic contexts in multi-expert decision-making", IEEE Transactions on Systems, Man, and Cybernetics – Part B: Cybernetics, 2001, 31(2), pp. 227–234.
[30] Y.P. Jiang, Z.P. Fan, and J. Ma, "A method for group decision making with multi granularity linguistic assessment information", Information Sciences, 2008, 178(4), pp. 1098-1109.

Table 3. Prioritization of the TAs using the proposed decision making framework

CNs	Weights of CNs	TAs						
		EF	IN	SQ	FL	FS	RR	PG
Conformity	(s_5, 0.20)	(s_4, 0.32)	(s_5, 0.35)	(s_1, -0.16)	(s_2, 0.01)	(s_1, -0.16)	(s_4, 0.18)	(s_2, -0.14)
Cost	(s_3, -0.12)	(s_3, -0.12)	(s_4, 0.03)	(s_5, 0.35)	(s_2,-0.14)	(s_3, 0.01)	(s_2, -0.28)	(s_3, 0.01)
Punctuality	(s_3, 0.14)	(s_4, 0.03)	(s_3, 0.01)	(s_2, -0.14)	(s_5, 0.20)	(s_2, -0.14)	(s_5, 0.35)	(s_4, 0.18)
Efficacy	(s_3, -0.12)	(s_4, 0.32)	(s_5, 0.35)	(s_2, 0.01)	(s_5, 0.20)	(s_2, -0.14)	(s_3, 0.04)	(s_1, -0.16)
Programming	(s_2, -0.28)	(s_4, 0.18)	(s_4, 0.03)	(s_2, -0.14)	(s_3, 0.01)	(s_1, -0.16)	(s_4, 0.18)	(s_1, -0.30)
Availability	(s_3, 0.01)	(s_4, 0.03)	(s_5, 0.20)	(s_2, -0.28)	(s_5, 0.20)	(s_3, 0.01)	(s_4, 0.32)	(s_4, 0.32)
2-tuple weighted average		(s_4, -0.01)	(s_5, -0.42)	(s_2, 0.13)	(s_4,-0.48)	(s_2, -0.22)	(s_4, -0.18)	(s_2, 0.45)

! " " #

! " # "$ % "

$ " " # " " ## " # # % # # "
& # " # & ( ) " " # #")
" " " # # * " # " # # ##
" " # + #) " "#) % # , % , #
") # + %# # +# #" ")
" " # - # # # ")
" # - #) " #) #) # # "
" # #) # #+ # # + # % %
)) " #) ## +) * # + "
+ # # # #))) #

" " # " ## #
) " # " - # #
" " " #) " # # #)) +
. # ## " " - #
" " # # + # " "# # # # # "
" " " # # #) ## ")
" /0 1/ 1 # " # # #
% " ") + - , # # # # %
# " , % # / 2 1/ 1 # " -) %))
) # #) # 1 #)))) +
3"# " " % #
4 + 5 " " # " - + " " # #
) % "# #) # " # #. " - % " # " * # " "
/ 1 / 6 1 #)) #) % " # # " # 9
" # # ") " " " #
) " " % ## - + # / 0 1/ 1 #
" # # # + " # " # *
) # " # # # # #
) " " + # # + 9
% ##) # # " " %) " " # +
# # " +# " # # #
# / 7 1 # " " + # " # # " "
) " # / 8 1 # # #
% " " #
# #) ## - "

.   )) +   * 1 %
$ # " #* 1 % "   ) " #
" #) # " . # #
" " # # # # % #
") #
) +)
") % A "# # #
) " # #
C - # + # # # ? "
& # ## + #) #
# > > ≠ #) "
# # # #)
) " + #
) # # . # #
" " # #
+ + # + #)
" " # # # #
> # +# # " " #
$ # #
? " & # # # ## #
"
% + #)
# " % #)
" " #
" - + # " #
" # # +)
" " # #
+ #
# " # +
# ## " "
# # # #" " #
# " % # # #
" # % #))) " #
" - #) " " "
" # # + " # # #
#? @ % , %
" % " "
" - # +
, #) # #
% " " # %
# # # % #
" # # # + #
% # # ## "
B # # # " #)3 #
+ # % #
") #

" - #)) % #
+ %# # "# B $
# ? " & #(#) # # %
# #
" # #
+ - # # # # # %
# " " % #
% # # # " #- + %
) # " # #
) B + #) " "
") % # # # # # #
") # " %
" - # # %
B $ # #? "
& #>+ #) # #
" " # + # %
+
" " # -
")
"
- #) " #) #
) #
% &

" > 0 0
, % , #") # % # #
)) "
9 @ " +
B 9 " + #
$ # # ? "
& #> # # " #
# + # " # +
" " " # # B + #
" ") # +#
) # # % @ #- + % # # #
" " # # % + % "
" " # # % # # #
% B ? " " # #
# # #"
) # # +
) # "
B) # *#
% " -) % # , #
% # # #?) #

%# # # " + # # # ") % # % # # #
+ % 9 ? % 0 # # " #
") # + # "- " #% # # # "
"" ## # "" + # # # # " # " #
: # "" $ # # # %" # #
? " & #>+ # % # % # # #)) #
" # "- #)
+ # "- # "+# ?
% "- % # # # 9) B # +#
* #) ") # A " # #
% # # # + #) ## % A# # # # # @
# ") ## % #) # A #
% # # ## # " # % # A # # #
# $ # ?# " & # " # # # #
># # # + "" ## + + . # A
" # , % # # # ? " & #> # +#
") + 9) " # A # "
" % 2> > 00") %A # E# # #
") # % # # # % # #) " ## # "
" #))) % # # " # - " #
"% # # # # #)) " #
) 9 " # ? ") # %
"- # # # % #
")) # # %) " # #? 9)
" # " +## %) % &
) + # # #) " *) # #
) # % " % +#
) ## " " # #
+ % # # % "
" # ") : # " + #
) #%# # # ") # % # # # B #
) " "" # # + %, % #+ ? " & #
># # # # # # # 3 #
) ! ") + %, % #
? " & +
+ % # " + + ""
" "" ") # % # # #
% + # # +#
"- " " # # . " #
" " # #) + B # #
+ # # %#" % # " # # "" # #)
# " # B " " # " # 2>
# #)) # # " # #+ " . # #
# # #) + #
"
+ " # # # " # "# "-

% + # %3 #" %
# " #" "
#
) # " "
B % #
# # # #
" % +
+# # % "
? 9) B # # #
) " #) # # "
) # # " .
" # #) "
# # #
) " ? " & #>
" # # # "
"+ " " %
+ # +
. " - + %
)
" ") " + # "
? " & #># #
) + + % , % #
$ # #? " & # # #
) " # # ## "%
+ % + % , % # # #
) %
" # +
+ # # % %
@ # #) # #
) " ") ##
#)) #) # # %
" % # " " %
))
" " ") # #) # + #
) # # % # # ")
) " # #)) # %
" " # # ##)
$ # # # # #
# + " # # #
))) " " # 3 #
? 9) # * #)
+ C
) " " " #)
? " & #># # +
) + % , % # B # # # "
" % # " " # # +

& " # % ?
# # # #+ # # #
) # C #) #)
? " & #># # # #
" ## + + " + "
) %# #
@ % # # "#) ##
# # ## " #
) % # "
" " -
? % # # # # #
+ " " #
+ # # #
" % # . "
" # # # # " #
" % # A
" #%) #
" - " " #
% # #
# # # # # # #
# # # #" # #
+ - # # # % # #
? # #
" # # # # # #
+# % # +
# # # # # #
" 9# #% + #
" " " -
" " # # + # " ")
+ % #
# # # # # # # #
" "
" #
" "
" - ? #
+) # # % "
# # # #
"
" " # # # "
") " # # " "
" -
") " # # " #
" " # #
" #

;

* !

/01 $ % @# # $ F #% "-
4 ") #) ") "
& ! "" " 5 "
C #) ;'0(>>)) 000,0 6

/ 1 @ G ! #+ C
4 "" ## ##
" " "") # 5
H " 6>' (0=8 =))
0=, 6

/21 % "I F 4I " <
")
) #) " I 5#) " #='2(0===)) 20>,
2 2

/ 1 G $ #F " "
") # + " < - ##
" ! < #
H)- # J I# ## >>

/61 @ # F & 4 %# # "
) #< +-+ " "#
" 5 " "
I #) " # 02'0(0===)) 02,27

/71 4 ""
) #) " " ")) #5
+ " # H " 0 2'0(
>>2)) 80,8;

" &
" # ? " & / #1 >>7$
$ 2D0 D >00
)<DD+++ # "#" " D) D>;08>6D " K >
" #)

/;1 @ # ?G " ' >>24(? "
))
" ## #<% " ##
" # L5 H "
8 ' (>>2 6)) 7;

/=1 ! & & ! ? #
$ #% $ G) # 4) "

)))) "
" , " # "
" # #5 H
" 88'0(>>7)) ;=,0 2

/0>1 #" G * I
4H +" "## #< "
$ # " 5>>6 ? " #" <## ,
! ##

/001 % " I G @ + * #- $
4? " < " "
$5 # "
H " 7' (>>6)) 062M0;

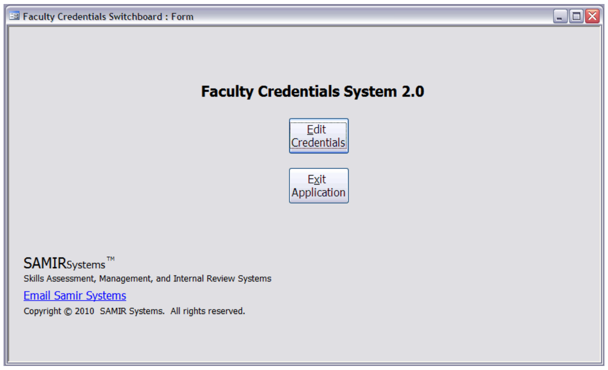
/0 1 F 4? " # " #
#5 J& &
)) $ # " >>2$ D D00

)#<DD+ - . # " D + D "
60=2667D? " J# & ,)

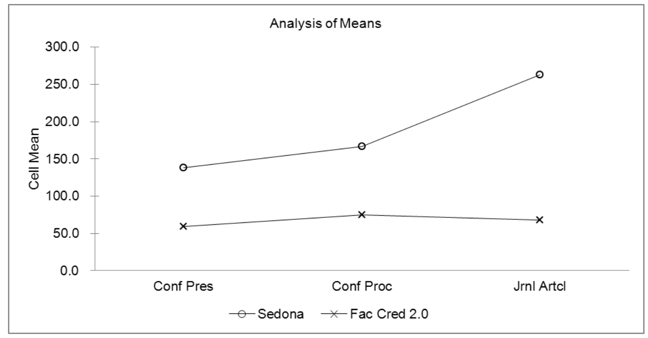
% 0< & "-
& &) #

# B #	& $ # # " ? " # >
$ # " " " " 9) " " 9) : " I ## " # ## " #	" " 9) " I ## 9) " I # # I % " # ## " # " & " # "") # #)) & # #

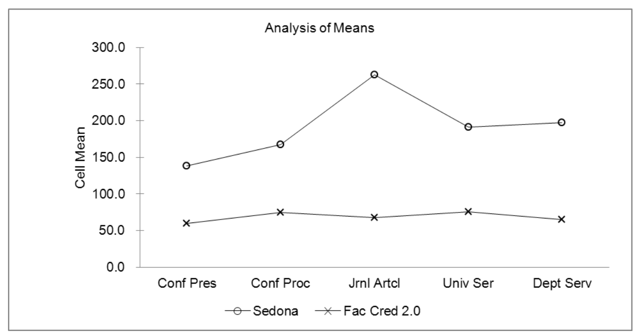
=


Faculty Credentials Switchboard : Form
Faculty Credentials System 2.0
Edit Credentials
Exit Application
SAMIRSystems™
Skills Assessment, Management, and Internal Review Systems
Email Samir Systems
Copyright © 2010 SAMIR Systems. All rights reserved.

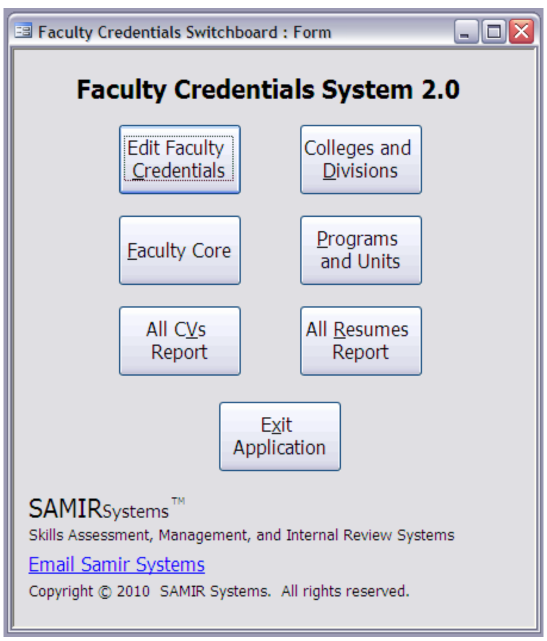
? 0 ? " & #? " " " # #
"


Analysis of Means
Cell Mean
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Conf Pres
Conf Proc
Jrnl Artcl
Sedona
Fac Cred 2.0

? 2 < # # # $)
F


Analysis of Means
Cell Mean
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Conf Pres
Conf Proc
Jrnl Artcl
Univ Ser
Dept Serv
Sedona
Fac Cred 2.0

? < # # #


Faculty Credentials Switchboard : Form
Faculty Credentials System 2.0
Edit Faculty Credentials
Colleges and Divisions
Faculty Core
Programs and Units
All CVs Report
All Resumes Report
Exit Application
SAMIRSystems™
Skills Assessment, Management, and Internal Review Systems
Email Samir Systems
Copyright © 2010 SAMIR Systems. All rights reserved.

? < ? & # > #
" " # # "

% < &) # #") # "#

!				
" # $				
% & ' '	(			(
) * ' '				(
+				
" & "				
, " & "				
& "				
&				

QMS Effectiveness: Development of a New Assessment Tool

Mark S. Phillips and Christopher Kluse
College of Technology, Eastern Michigan University, Ypsilanti, MI, 48197, USA
msteven18@comcast.net, ckluse@emich.edu

Abstract

Numerous companies are required to maintain a documented quality system to help assure product quality. Management audits represent the conventional tool used to assess compliance to a quality system standard. Recently, third party audit results and effectiveness have been under great scrutiny. Therefore, mere achievement of third party certification to an accepted quality standard such as ISO 9000:2008 does not necessarily predict nor assure quality system (QMS) effectiveness. Consequently, based on the current economic conditions, organizations will need to possess a tool, other than traditional audits, that will be a predictor of quality system effectiveness, yet be cost effective and efficient.

This exploratory study makes use of an instrument that may be used as a predictive tool for quality system effectiveness. It makes use of a modified Likert scaled survey to collect data utilizing a questionnaire (SERVQUAL) as designed and validated by Parasuraman, Berry, & Zeithaml (1988) [1]. The aim of this preliminary research is to illustrate how employee's perception of quality may be a predictor of quality system effectiveness. The research is in the early stages; future research will focus on further development of this alternate predictive tool. Furthermore, this study will discuss potential applications of this evolving instrument.

1. Introduction and overview

Quality affects our lives in large and small ways. When technology fails, "quality" is often blamed. With some products, it may be difficult or impossible to find a direct measure of quality. When product quality cannot be measured directly, sometimes the only practical way to measure manufactured goods level of conformance or "quality" is to destroy it. Because destructive testing damages the item, quality cannot be inspected into a product (Deming, 1982) [11]. Instead, to prevent defects, organizations rely on complex quality and manufacturing systems to "build quality into" the product (Deming). This model is reflected in an organization's reputation; not for an individual product but all of their products. This reputation becomes a reflection of their system to control quality. According to Walters (2009), "A low-customer perception of vehicle quality certainly contributes to a fall in market share and profitability" (p. 4) [2]. Businesses expend vast resources to measure consumer's perception of quality and the organizations' quality system. Public and private organizations are dedicated to measuring and analyzing these systems. However, organizational management often overlooks a potential predictor of QMS performance and critical to quality characteristics; *perception of quality*. Furthermore, it is the author's belief that organizations place undue emphasis on tools such as third party audits to assess QMS effectiveness thereby failing to utilize core principles of quality management. Such audits fail to capture items that may prove significant to organizational quality performance; the concept of *quality perception* is the crux of this exploratory study. Consequently, these authors deem the aforementioned concepts as better predictors of QMS effectiveness. It is the intent of this study to support this claim.

2. Background and review of literature

With the realization of mass production on an industrial scale, craftwork became expensive and complicated (Pascal, 2007) [3]. Mass production had the benefits of economies of scale and ease of reproducibility but in the process lost the instant feedback that craftsman had enjoyed regarding the quality of their craft work. According to King (1989, p. 4), "Around 1900, Fredrick Taylor concluded that not every supervisor was smart enough to figure out the best way to do a job, and decided that an engineer should plan the job and the supervisor should carry out the engineer's plan." [4]

This effectively put a wall into the PDCA cycle stopping the introduction of continuous improvement and lessons learned back into the process as detailed in Figure 1 below.

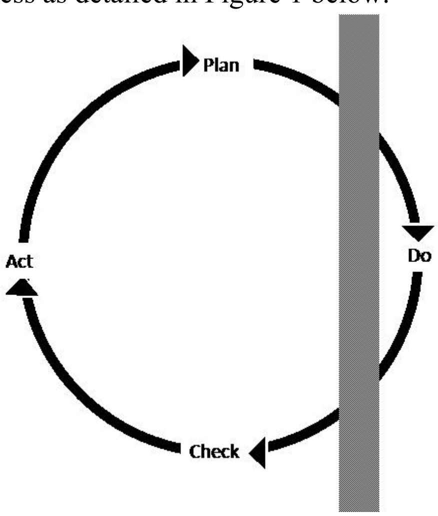


Figure 1. Taylor continuous improvement cycle, (King, 1989).

Eventually, quality systems were adopted to track product quality. "By breaking down car assembling into a series of uncomplicated tasks, Ford made the jobs themselves infinitely simpler, but he made the process of coordinating the people performing those jobs and of combining the results of their tasks into a whole car far more complex" (Reis, Pena, & Novicevic, 2002, p. 369) [5]. Because assembly line workers only experienced part of a total product, they often did not know the true quality of a product; instead, they had to depend on their perception of the quality system for feedback. This would suggest that the full implementation of Talorism had a "de-motivation" affect (Deming, 1982) [6]. Without the direct feedback that was present when a craftsman performed work, the ability for the line worker to measure quality was lost. In effect, the measure of how "good" a product is, is based on how well the quality system performs (Hellofs & Jacobson, 1999) [7]. As companies grew larger, the distance between the people who touched the product and the people who controlled the process became greater. This difference may have an effect on quality. The following chart (Figure 2) represents four conditions that may be encountered in a manufacturing facility.

The upper quadrants represents conditions where an excellent quality system exist and good engineered process exist yet good parts may or may not be produced. The lower quadrants represent the worse case scenarios and exhibit the opposite condition, yet produce the same output. This would suggest that other unmeasured factors might be present in a manufacturing system.

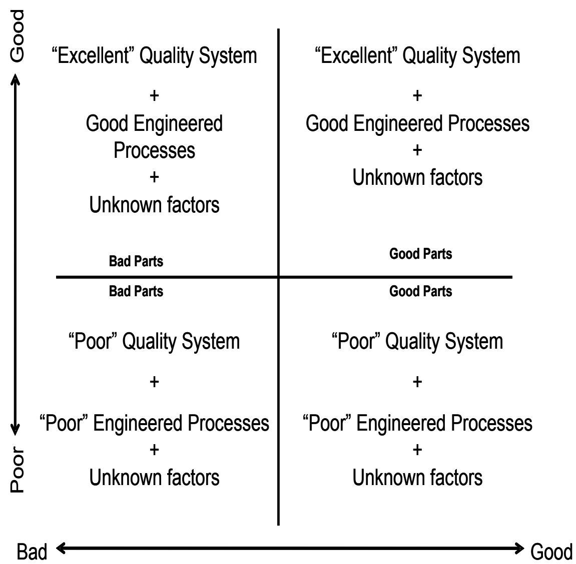


Figure 2 Relationship between quality, engineered systems, and unknown factors.

2.1. Perceptions of quality

Historically, quality is measured utilizing traditional dimensions of quality. According to Besterfield (1994, p. 452) these include:

1. *Performance* - These are primary product characteristics, such as the brightness of a picture.
2. *Features* - Secondary characteristics, added features, such as remote control.
3. *Conformance* - Meeting specifications or industry standards, workmanship.
4. *Reliability* - Consistency of performance over time, average time for a unit to fail.
5. *Durability* - Useful life, includes repairs. [8]

While these measures are useful in the traditional definition of quality, when we describe perceptions of quality the definition breaks down. Parasuraman (1985, p. 42) [9] defines quality as a comparison between expectations and performance. In particular: Service quality is a measure of how well the service level delivered matches customer expectations. Delivering quality service means conforming to customer expectations on a consistent basis (Lewis & Booms, 1983).

Parasuraman et. al. (1988) developed the SERVQUAL instrument to address the difficulties in measurement when techniques used for objective quality were adapted to measure perceived quality [1]. The refined SERVQUAL instrument measured the following (p. 23):

1. *Tangibles* - Defined as the "physical facilities, equipment, and appearance of personnel.
2. *Reliability* - Defined as the ability to perform the promised service dependably as accurately.
3. *Responsiveness* - Defined as the willingness to help customer and provide prompt service.
4. *Assurance* - Defined as the knowledge and courtesy of employees as well as the ability of the employee to inspire trust and confidence.
5. *Empathy* - Defined as the caring, individualized attention the firm provides its customers.

The purpose of SERVQUAL is to serve as a diagnostic tool to uncover broad areas of an organizations weaknesses and strengths (A. Parasuraman, et al., 1988) [1].

For this study, only one dimension was utilized. Reliability was adapted to measure the difference between employees' perception of their own quality system and an "ideal" or excellent quality system. As defined, tangibles, responsiveness, assurance and empathy do not fit within the theoretical framework of this investigation. In a 2007 article, Sullivan and Estes demonstrated that a modified version of the SERVQUAL dimensions would measure customer perception of quality in a human services setting (p. 39). Parasuraman et. al. (1988) also streses that SERVQUAL, "is a concise multiple-item scale with good reliability and validity" [1]. However, "when necessary, can be adapted or supplemented to fit the characteristics or specific research needs of a particular organization" (p. 31).

3. Research question

This exploratory study sought to determine if employee perception of quality could lead to prediction of QMS performance. Thus, the study focused on the following research question:

Is there a relationship between job assignment (hourly / salary) and employee's perception of their quality system?

4. Research design & setting

An exploratory study was used to examine perception of quality. Perceptions of Quality was measured using a modified SERVQUAL scale, in particular, an employee's perception of quality. The questionnaire for SERVQUAL consisted of ten items. One dimension was used. This dimension is "reliability" (Parasuraman, Berry, & Zeithaml, 1991, p. 446) [1]. This dimension was chosen and adapted to measure system quality (SQ). Cronbach's Alpha was 0.808 which is consistent with the levels of acceptability suggested by George & Mallery (2008 p. 243) [12]. The modified scale was adapted to measure the difference between employee's perception (EP) of their own quality system and an "ideal" or excellent quality system (EQS) Figure 3.

$$EQS - EP = SQ$$

Figure 3. The difference between (EP) and (EQS).

The scale will range from a score of 7 (Strongly agree) to 1 (Strongly disagree) with no anchors at the intermediate points (Weng, 2004, p. 964) [10].

The research setting is automotive manufacturing facilities. The facilities included twenty six (26) multiple locations in Michigan engaged in either automobile assembly or automobile component manufacturing. Employees were chosen randomly based on availability.

5. Assumptions and limitations

This study utilized a survey as the research instrument; the individual's responses are subject to their attitudes and personal experience regarding perception of quality within their respective organizations. Personal biases, experiences and judgments cannot be controlled, but is minimized through use of an effective instrument

Since the behavior of the population is predicted from a random sample, the researchers assume the selected sample will accurately depict the traits of the population. Responses from participants are understood to be accurate, honest and without personal bias. Furthermore, the individuals selected to participate in the interview process are knowledgeable, experienced individuals who's input will correctly portray the viewpoint and attitudes of the population.

6. Results and conclusions

Below is a summary of the results:

Table 1 - Perceptions of Quality. Hourly vs. Salary

Summary

Job Type	Mean	N	StDev
Hourly	8.2171	129	7.1559
Salary	5.4382	89	5.09446
Total	7.0826	218	6.52698

ANOVA Table

	Sum of Squares	df	Mean Square	F	Sig
Between Groups (Combined)	406.681	1	406.681	9.939	0.002
Within Groups	8837.833	216	40.916		
Total	9244.514	217			

As noted by an F value of 9.99 (0.002), there appears to be a statistically significant difference between salary and hourly employees perceptions of their quality systems. Based on this result, one can surmise that within an organization, a quality dissonance exits regarding perceptions of quality. This indicator has several implications;

1. Results from assessments such as third party audits or internal assessments (which are typically shared within an organization) may be interpreted differently. While salary employees may perceive a QMS is adequate based on third party or internal assessment, the hourly associates close to the process have reason to believe otherwise.
2. Perceived quality could be the tool to understand which QMS measures developed and reviewed by management provide relevant information regarding actual product quality. If agreement exists, then a positive correlation may exist between perceived quality and actual performance to the customer.
3. Development and use of an indicator such as perceived quality many allow for improved internal assessments thus reducing or eliminating the need for third party assessments and recommendations.

Contemporary debate suggests the value of external assessments and registration schemes are being questioned. Certification schemes are not a guarantee of quality. The associated certification audits are certainly not indicators of effective quality management systems. Intuitively, the use of an indicator that can be administered by the organization for use within the organization has far more value added implications versus current assessment methods. As an organization, one must consider; do we accept recommendations from an often inexperienced (at least with your product and within your plant) third party auditor or can resources be better allocated by exploiting an internal tool that accurately appraises the functionality of the QMS? Quality perception may be this tool.

The authors suggest the answer may reside in the evaluation of the social psychological realm. The evaluation of a quality system by a third party does not result in an improvement or accurate assessment of quality or QMS. The development of a culture that promotes quality does. The ability to measure ***culture and perception of quality*** may be the solution.

7. Future considerations

Although the results indicate a difference in perception of quality systems amongst salary and hourly associates, it is merely a preliminary investigation into the use and development of an alternate method to assess and predict QMS effectiveness. In future research, the value of third party audits, organizational climate, and knowledge management will be further explored. Additionally, correlation between perception of quality and organizational performance will be sought in order to substantiate perception of quality as a valid prediction tool.

It is certain that the current, accepted method to assess QMS effectiveness, i.e. third party audits, is clearly losing credibility and is a topic of spirited debate. In this economic climate, it will be necessary to possess a tool to accurately assess QMS effectiveness, yet avoid the tangible and intangible implications of a third party audit which may or may not add value to the organization.

8. References

[1] Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1988). Servqual: A Multiple-Item Scale For Measuring Consumer Percep. Journal of Retailing, 64 (1).

[2] Walters, J. (2009). Market quality perception of the American auto producers. Review of Business Research. Retrieved from http://www.allbusiness.com/company-activities-management/product-management/13066900-1.html.

[3] Pascal, D. (2007). Lean production Simplified. New York: Productivity Press.

[4] King, B. (1989). Hoshin Planning the Developmental Approach. Methuen: GOAL/QCP.

[5] Reis, D., Pena, L., & Novicevic, M. (2002). Widening quality gap: a historical interpretation. Total Quality Management, 13(3), 365(367).

[6] Deming (1982). Out of the Crisis. Cambridge: MIT.

[7] Hellofs, L. L., & Jacobson, R. (1999). Market Share and Customers' Perceptions of Quality: When Can Firms Grow Their Way to Higher versus Lower Quality? The Journal of Marketing, 63(1), 16-25

[8] Besterfield, D. (1994). Quality Control (4 ed.). New Jersey: Prentice Hall.

[9] Parasuraman, Zeithaml, V., & Berry, L. (1985). A Conceptual Model of Service Quality and Its Implications for Future Research. The Journal of Marketing, 49(4), 41-50.

[10] Weng, L.-J. (2004). Impact of the Number of Response Categories and Anchor Labels on Coefficient Alpha and Test-Retest Reliability Educational and Psychological Measurement, 64(6), 956-972.

[11] Deming (1982). Out of the Crisis. Cambridge:MIT.

[12] George, D & Mallery, P. (2008) SPSS FOR Windows. Boston: Pearson

Application of Lean Six Sigma in Healthcare – Nursing Shift Directors Process Improvement

Afsheen Mozammel and Lash Mapa
School of Technology, Purdue University Calumet, 2200 169th Street, Hammond, IN 46323, USA
mail.afsheen@gmail.com, mapa@purduecal.edu

Abstract

Six Sigma and Lean are two powerful performance improvement methodologies that are changing the face of modern healthcare delivery. Lean Six Sigma (LSS) can reduce variability resulting in bottom-line improvement. In this project the workload of Nursing Shift Directors (NSD) has been analyzed. NSD have the overall responsibility for appropriate utilization of nursing personnel and for patient placement, serving as a liaison to facilitate communication and problem solving within the healthcare facility. The purpose of this study is to (a) create a baseline metric of the existing process, (b) collect operational data and analyze ways to improve the work efficiency by eliminating the non-value added tasks from the daily workload, (c) automate some of the tasks performed by NSD and (d) monitor and provide control methodologies for sustainability.

1. Introduction

The cost of medical care is increasing at an alarming and unsustainable rate worldwide. One significant source of increasing healthcare cost can be broadly characterized as unnecessary operational inefficiencies and redundancies which are associated with the direct medical service delivery process. Others are associated with the administrative, logistical, and operational side of the healthcare delivery system. Lean Six Sigma has been applied to many different industries including healthcare, to reduce waste, add value and provide quality with success, but no specific research has been published to improve the working process of the Nursing Shift Directors (NSD). NSD are responsible for staffing, scheduling, resource allocation and administrative support, which is a key to the overall efficiency of the care-giving facility. Different kinds of non-value added tasks and process inefficiencies take up a large amount of time in their daily routine and overload them with additional burdens. Increasing NSD's efficiency is a challenge because the process involves crossing multiple operational levels and departments, which requires a system approach for improvement. The consequences of not addressing NSD workload is the potential for their inability to accomplish the tasks needed to ensure efficient operations of the hospital, which can lead to delays in providing quality care to the patients. As a result, physicians and patients may choose to go elsewhere for service, resulting in decrease in market share and revenue. Improving efficiency and effectiveness of NSD are not without obstacles. This project identified ways to increase the efficiency and effectiveness of the NSD through improved process steps and addressing the workload by which they can continue to evolve productively with the increasing volume and continuously changing healthcare environment. The purpose of this project is to:

(a) Create a baseline metric of the existing process

(b) Identify process incompetency and recommend a closed-loop sustainable system by eliminating non-value added tasks to improve the work efficiency.

(c) Automate some of the tasks will enable NSD to make use of their knowledge in strategic decision making and concentrate on performing value added tasks.

(d) Monitor and provide control methodologies for sustainability.

2. Lean Six Sigma in Healthcare

Six Sigma was originally a concept for company-wide quality improvement introduced by Motorola in 1987. It was further developed by General Electric in the late 1990s [1]. The program is characterized by its customer-driven approach, emphasis on decision making based on careful analysis of quantitative data, and a priority on cost reduction. It is deployed by carrying out improvement projects. While there is substantial evidence from manufacturing industries, there is limited empirical evidence demonstrating the relationship between factors associated with a Six-Sigma quality program and the performance of organizations in the health sector.

Six Sigma's approach is similar to that of good medical practice used since the time of Hippocrates—relevant information is assembled followed by careful diagnosis. After a thorough diagnosis is completed, a treatment is proposed and implemented. Finally, checks are applied to see if the treatment was effective. To operationalize this problem-solving strategy, Six Sigma deploys five phases—define, measure, analyze, improve, and control (DMAIC)—that are rigorously followed whenever a problem, large or small, is approached.

St.Margaret Mercy hospital in Hammond and Dyer, Indiana has successfully applied Lean Six Sigma methodologies to optimize operational processes related to ventilator associated pneumonia (VAP) and intensive glycemic control protocols. As a result of these improvements, the number of patient ventilation days has decreased from an average of 6.2 in the 18 months immediately prior to the study implementation to 4.8 following the implementation. Compliance to both the VAP and glycemic control protocols has been very high and sustained at the Dyer campus and vent days have decreased from 5.0 to 3.8 days post pilot. Compliance against protocols has significantly improved within the critical care units in the two St. Margaret Mercy Hospitals. In addition, the Intensive Care Unit Length of Stay (ICU LOS) has shown a corresponding decrease from 6.3 to 5.7 days following the intervention. These results have been sustained over time and have been linked to improved patient outcomes including VAP infection rates, patient vent days and ICU LOS [2].

There are some other hospitals which have applied other Six Sigma related techniques although not referred to as Six Sigma methodology. For example, BMC health services research at the University of North Carolina Hospital conducted Patient Flow Analysis (PFA) to improve patient visit efficiency by decreasing waiting time in a primary care-based disease management programs [3].

The Royal Victorian Eye & Ear Hospital was able to gain a deeper understanding of the effectiveness of the hospital's quality systems approach through the results of the study. They used statistical tools such as design of experiments (DOE), statistical process control (SPC) and multivariate analysis.

A study was conducted at Red Cross hospitals in Netherlands to find out nursing workload but no further scientific method was implemented to improve the total process. A total of 34 nursing activities were identified, defined, connected to educational levels and attached to time standards. Two independent raters completed a test computer program by assessing performed nursing activities in 36 patients. This yielded intra-class correlations of 0.82, indicating good reliability [4].

Like Six Sigma, healthcare organizations adopted Lean system principles from manufacturing. Lean calls for cultural change and commitment and what have been called the 4-P's – philosophy of adding value to customers, society, and associates; processes paying off over time; people and partners who are respected and developed; and problem-solving to drive organizational learning [5].

One of the key challenges in hospital nurse staffing is ensuring that there is always the right number and skill mix of caregivers. This can be challenging for several reasons: the census fluctuates and is hard to predict, especially on an individual department level, the nurse managers who are responsible for scheduling don't always know which qualified and, competent nurses are available for work, especially those from other departments, there is no real-time view of overstaffing or understaffing based on actual census and acuity, there is no real-time view of where nurses are working to allow managers to redeploy them as needed. Consequently, many hospitals are finding that they can easily either overstaff (thus incurring unnecessary costs) or understaffed (thus risking quality of care and employee morale). This is where Six Sigma, with its emphasis on reducing process variations, can help a hospital better match the number of nursing hours (and skill mix) to the fluctuating work volume [6].

3. Procedure

This project follows the Six Sigma DMAIC methodology as shown in figure 1.

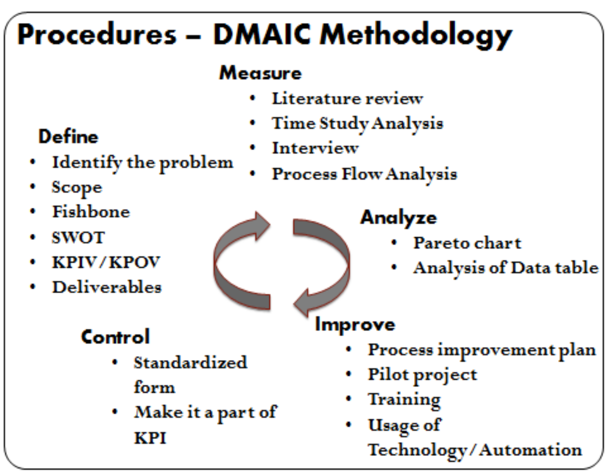


Figure 1: DMAIC Methodology

3.1 Define

A project charter was developed by the project team that defined the business case, problem statement and goal statement. The decision was made to limit the scope of this project only to the workload of Nursing Shift Directors. A workshop was conducted to introduce and apply key Lean and Six Sigma principles to the team members.

A Voice of the Customer (VOC) analysis was performed by interviewing the Six Sigma team and NSD asking four key questions (Evans Mary Beth, 2009).

1. What do you like about the existing processes related to NSD workload which includes staffing, bed placement planning?
2. What are the weaknesses within these processes?
3. What are the opportunities for improvement within these processes?
4. What could potentially threaten the success of this project team?

The SWOT analysis created from the VoC has been analyzed. The strengths (S) of the post improvement system were willingness of the NSD to make changes and the floor visit which is an effective way of communicating with staff. The weaknesses (W) are the unavailability of convenient technology to access and document patient information, bed placement and staffing, the NSD are overloaded with routine duties where some activities are non value added to the overall process and also the lack of communication amongst care providers as a major component of delays in patient care. The opportunities (O) for the improvements are the modifications and increase the user friendliness of the "Dash Board", making technology convenient to use to all the NSD and automate some of the staffing forms. However, the threats (T) for improvement include resource constraints, reluctance in using the updated automated version of forms and the sustainability of the improvements.

Critical to Quality (CTQ) factors were identified for establishing baseline data. The CTQs are

- Workload of NSD
- Time spent on value added activities
- Improved communication among staff
- Convenience in using technology
- Staff satisfaction

Impact to the CTQ is also established by identifying the key process input variables (KPIV) and key process output variables (KPOV). These measures are essential to establish the capability and stability of the process. The KPIVs and KPOVS are as follows:

Key Process Input Variables:

- Patient volume
- Staffing volume
- Availability of beds
- Communication method

Key Process Output Variables:

- Time taken for bed placement
- Time taken for documentation
- Time spent on floor
- Automation and standardization

A relationship between the input factors to the output factors was established by cause and effect analysis is shown below in figure 2.

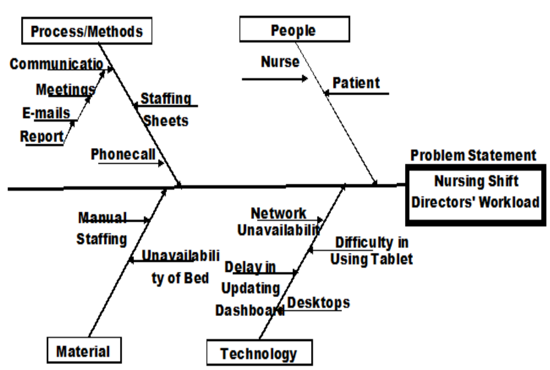


Figure 2. Cause & effect analysis

3. 2 Measure

The process in which the problems were occurring or improvement required was mapped out in detail and included time, people and material to ensure that the current state is clearly understood. In the measure phase the CTQs which were identified was measured. A sample of a process flow chart that was used during data collection along with data is shown in figure 3.

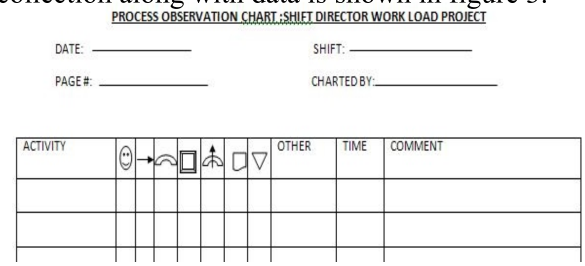
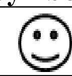
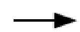
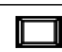
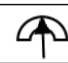


Figure 3- Sample process flow chart

Table 1- Sample process flow chart symbol keys

Symbols	Activities
	Talking
	Walking
	Phone calls
	Computer
	Talking & Walking
	Documentation
	Free Time
	Miscellaneous

Shadowing the NSDs was the primary tool for gathering the baseline data as the hospital did not have any. Job shadowing involves spending a period of time with a seasoned expert, observing everything a subject does related to the work which is expected to be accomplished as part of the daily job routine. In this project, shadowing was done with the use of a stop watch and the process flow chart. The stop watch was turned on when a NSD starts her shift and the time recorded for each task performed. At the end of each shift the total timing was calculated for every single type of task along with the frequency.

Data was gathered for two weeks and three different shifts, morning shift (7:00AM-3:00PM), evening shift (3:00PM-11:00PM) and midnight shift (11:00PM-7:00AM). The routine activities of the NSDs are, documentation, communication (talking), floor visits (walking), phone calls, working on the computer and "Free time". Shadowing NSD's included following them and recording the time needed to complete each activity during a shift.

3.3 Analyze

In this phase, a thorough data analyses was carried out to narrow down, from the trivial many reasons of a problem occurring to the critical few (Appendix E).

Pareto analysis was done which is a graphical representation that displays data in order of priority to identify the critical few from the trivial many. While a vital few causes may need special attention whereas the trivial many may warrant very little.

Table 2. Summary of activities of NSD in 2009

Symbols	Activities	% of time Consumed for 2009	Cumulative time distribution for 2009
	Documentation	39.0%	39.0%
	Phone calls	21.3%	60.3%
	Communication (Talk)	16.5%	76.8%
	Floor Visits (Walk)	9.5%	86.2%
	Computer	4.1%	90.3%
	Communication (Talk) & Floor visit	3.9%	94.2%
	Miscellaneous	2.9%	97.2%
	"Free" Time	2.8%	100.0%

From the composite time values obtained from all three shifts as shown in table 4, it is evident that 76.8% of NSDs time is spent on documentation, phone calls and talking. The rest comprised of floor visits/walk, working in the computer, walking and floor visit, freetime and miscellaneous.

Further analysis of documentation and phoning which are the two critical functions shows staffing sheet update, report for next shift, file arrangement, bed placement, patient update are the critical tasks which takes up approximately 70% of documentation activity.

The next most time consuming activity, phone calls consisted of bed placement, staffing schedule, patient update, fax update, file retrival, meeting update and miscellaneous is shown in above figure 10. Among those bed placement, staffing schedule and parient update takes up 90% of the total time and the rest constitutes only 10%.

Further analysis of the phonecalls shows the number of incoming and outgoing calls differ significantly.

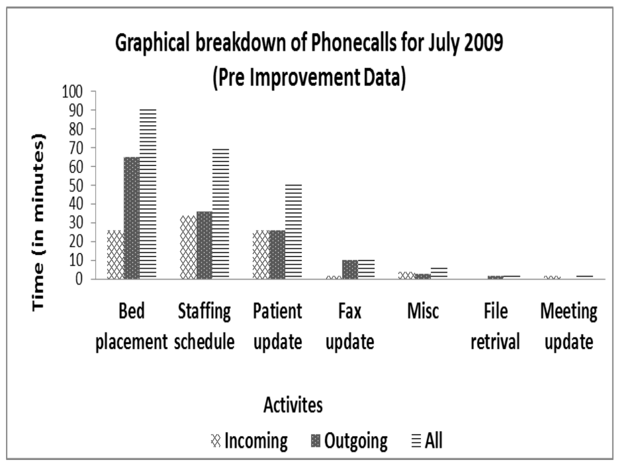


Figure 4. Breakdown of phone activities for 2009

Outgoing calls from the NSDs were more than the incoming as the NSDs were making phone calls for updates related to patient status, nurse staffing and bed placement (figure 4).

3.4 Improve

This phase is the most crucial phase where upon identifying the root-causes, solutions have been generated and tested by piloting it. During this phase the team generated solutions that resulted to maximize gains. Data collected during this phase was reviewed against the baseline data as a measure of improvement.

The recommendations to improve the process are:

Documentation

- Use digital staffing sheet instead of carrying a manual paper schedule during floor visits
- The digital excel sheet to be kept in a central system which can be updated on a real time basis as needed
- Eliminate the need for daily-update meeting report
- Improve communication to eliminate time taken for patient information fax updates
- Upgrade the central database to minimize file retrieval activities

Phone Call Activity

- Improve central database to reduce the need for excessive number of phone calls
- The reduced number of faxing due to improved system will reduce the number of phone calls to confirm about the fax update.
- Replace old phones with new phones with fewer dropped calls.

Usage of Technology

- Upgrade and modify the current nursing and patient database to make it more user-friendly
- Digitize the manual staffing form that that NSDs are currently using for keeping staffing log
- Install digital staffing board on each floor indicating nurse availability
- To install a call button in every patient room specifically for the use of housekeeper to indicate that a room is ready to accommodate a new patient
- Add new menu to the central database to show the patient length of stay and phone number

Improve Communication

- The use of technology will make the scheduled meeting for NSD's redundant
- Reduces the amount of non value added conversation regarding nurse and patient updates
- Train and involve the employees to become familiar to with the online database
- Communicate the employees about the significance of the improved process for sustainability

Post improvement data was gathered after a year of implementation and the critical few activities are documentation (26%) , free time (20%) and talking (14%). The rest includes phonecalls, working on the computer, walking, phoning while floor visit, miscelleneous etc.

A summary of pre and post improvements activity time data are given in table 3 and figure 5.

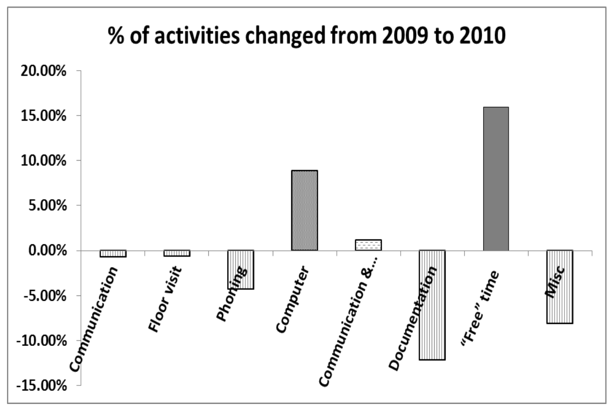


Figure 5. Percentage change in activity times from 2009 to 2010

Table 3. Summary of Percentage change in activity time-pre and post improvements

Symbols	Activities	% of time Consumed for 2009	% of time Consumed for 2010	% Change from 2009 to 2010
	Documentation	39.0%	26.20%	-12.84%
	Phone calls	21.3%	13.40%	-7.86%
	Communication (Talk)	16.5%	14.30%	-2.20%
	Floor Visits (Walk)	9.5%	8.50%	-0.95%
	Computer	4.1%	12.90%	8.84%
	Communication (Talk) & Floor visit	3.9%	3.10%	-0.84%
	Miscellaneous	2.9%	2.00%	-0.94%
	Free Time	2.8%	19.60%	16.78%

The greatest improvement was achieved in the documentation activity, where a 12.84% reduction was achieved. The next highest reduction was in phone calls. The outcome of these improvements freed up approximately 17% the NSDs daily routine. The computer usage increased by approximately 9% which contributed to in the reduction of non value added activity times.

Many managers do not even consider shadowing because it is time consuming. But this project demonstrated the significance of shadowing to identify the value added and non value added activities. The analysis from shadowing helped to free up time which could help a future healthcare manager see the benefit of this short term labor intensive evaluation method. Most Healthcare managers are known for data mining on the information that is in their computer systems, without realizing that sometimes one has to go beyond what he/she currently has.

3. 5 Control

In this phase, the improvements that are identified during 'Improve Phase' were documented and thoroughly captured. A roadmap of solving the problem was established. Implementation plans as well as change management procedures were suggested to ensure the successful transition of the solution to team that ultimately responsible to the process. As part of sustainability of the improvement phase, digital standardized form has been established. Moreover, for sustainability suggestion was made to the management for making the improved process as part of NSD's performance appraisal.

4. Conclusions and Recommendations

- With the DMAIC methodology, a consistent and standardized way of problem solving has been established throughout the organization.
- Time saved (17%) by this project has been utilized to enhance patient care. This may include strategic, administrative and other value added tasks such as bed placement, additional floor visits, improved employee satisfaction and morale
- The pre project data indicated that the NSD had only 2.8% free time during a shift for breaks but after the improvements they have a saving of 17% of an entire shift available time to invest in value-added tasks.
- The usage of technology has a significant increase of 8.84 %.
- The greatest achievement has been the reduction in overall documentation from 39% to 26%.
- Part of the additional time available has already been utilized to update the NSDs on pharmaceutical issues.
- One of the limitation of this project is that the dollar value of the NSD for the hospital in concern was not available for this project because of condifentiality.
- The Lean Six Sigma method that has been used in this particular project can be used replicated in any hospital with some modification if needed and the bottom line improvement can be calculated.
- To make the NSD use the automated staffing sheet along with getting involved in
- Some further work that can be done on this project are to develop standardized metrics to sustain the improvements achieved as part of the control phase and develop methodology to incorporate improvements as part of the NSD performance appraisal/KPI.

5. Reference

1. Hilton R., Balla M., Sohal A., (2008), Factors critical to the success of a Six-Sigma quality program in an Australian hospital, *Total Quality Management & Business Excellence*, Vol. 19 Issue 9, p887-902.
2. Woodward H., El-Harit J., Vanni C., Scott P., (2007), All Bundled Out" - Application of LeanSix Sigma techniques to reduce workload impact during implementation of patient care bundles within critical care, A Case Study, Proceedings 2007, ASEE Indiana/Illinois Section Conference, Indianapolis, IN, p3-13
3. Nicholas M., Robb M., Betsy S, Timothy I., Paul C., Darren D. & Michael P., (2007), Use of patient flow analysis to improve patient visit efficiency by decreasing wait time in a

primary care-based disease management programs for anticoagulation and chronic pain: a quality improvement study, *BMC Health Serv*, Research 2007, 7:8doi:10.1186/1472-6963,p7-8

4. (Jaap van den Heuvel1,*,†, Ronald J. M. M. Does2 and M. B. (Thijs) Verma quality and reliability engineering international, Qual. Reliab. Engng. Int. 2004; 20:419–426 (DOI: 10.1002/qre.656)
5. Joshua R., Larry D., (2009), A critical review of the research literature on Six Sigma, and StuderGroup's Hardwiring Excellence in the United States: the need to demonstrate and communicate the effectiveness of transformation strategies in healthcare, Implementation Sci. 2009; 4: 35, doi: 10.1186/1748-5908, p4-35
6. Currie V., Harvey G, West E, McKenna H., & Keeney S., (2005), Relationship between quality of care, staffing levels, skill mix and nurse autonomy, *Journal of Advanced Nursing*, Vol. 51 Issue 1, p73-82.

A Collaborative Decision Making Framework for Human Resource Selection: The Case of Academic Applicants

Ahmad D. Rahal and Larry H. Faulk II
College of Business, University of Arkansas, Fort Smith, AR 72913-3649, USA
ahmad.rahal@uafs.edu, larry.faulk@uafs.edu

Abstract

The human resource selection process is often characterized by dynamic interactions among various stakeholders who may be spread geographically to attain a mutually satisfying outcome. However, due to its unstructured nature, the human resource selection process most often needlessly suffers from individualistic personal biases, subjectivity, perceptional errors and preferences of individual stakeholders attempting to steer the final decision to a predefined destination.

To improve the working environment and minimize unnecessary friction among the participants in the selection process, the authors developed a computer-based, collaborative decision making framework capable of properly mitigating and aggregating the personal preferences of the individual stakeholders in order to identify, in a graphical format, those highly qualified applicants for the second stage of the human resource selection process. Furthermore, easy-to-adopt operational guidelines are thoroughly explained to assist the readers in the development of the proposed framework.

1. Introduction

The human resource selection process is a time consuming process with the ultimate goal of identifying the applicant(s) with the appropriate knowledge, skills, and abilities to assist the organization in developing a competitive advantage over rival firms (Gatewood, 2008). However, most often the choice of final candidates is more influenced by personal biases, perceptions and preferences of participants in the selection process than by a studied and collaborative assessment of needs (Cole, 1995).

To improve the working environment and minimize unnecessary friction among the participants in the selection process, this research proposed the development of a computer-based, collaborative decision making framework capable of properly mitigating and aggregating the personal preferences of the participants in the selection process to properly identify the most qualified applicants for the second stage of the selection process.

Furthermore, one of the important benefits of the proposed collaborative decision making framework can be easily appreciated when the selection decision needs to be made by participants in different geographical locations.

To achieve this end, multi-criteria decision making (MCDM) techniques will be reviewed focusing primarily on the analytic hierarchy process (AHP). This will be followed by a brief discussion of the human resource selection process. The effectiveness of the proposed framework is demonstrated through its actual application in the selection process of academic applicants. Finally, a brief discussion of the potential benefits and drawbacks of the framework will be provided.

2. Literature Review

Despite the importance and the long term implications of human resource selection on the ability of companies to successfully fulfill their strategic objectives and achieve a competitive advantage, most prevailing corporate hiring processes still frequently rely on either intuition or a single criterion instead of multiple criteria when comparing between applicants (Burke, 1988). Decision scientists have developed a wide range of methods and techniques for solving multi-criteria decision making (MCDM) problems such as human resource selection. These methods include Goal Programming (GP) (Charnes, Cooper & Ferguson, 1955), the expected utility theory (EUT) (Von Neumann & Morgenstern, 1947), the subjective expected utility theory (SEUT) (Savage, 1954), the multi-attribute utility theory (MAUT), and the multi-attribute value theory (Keeny & Raiffa, 1993; Barron & Edwards, 1994). Other procedures include ELECTRE (election et. choix traduisant la réalité) (Roy, 1968; 1996), PROMETHEE (preference ranking organization method for enrichment evaluations) (Brans, Vincke, & Mareschal, 1986), TOPSIS (techniques for order preferences by similarities to ideal solutions) (Hwang & Yoon, 1981; Hwang, Lai, & Liu, 1993), and the Analytic Hierarchy Process (AHP) (Saaty, 1980). Most of these MCDM methods have been described by Mollaghasemi and Pet-Edwards (1997).

Regardless of the ongoing criticism for its measuring scale, rank reversal, and transitivity of preferences (Gass, 2005), AHP became the MCDM methodology of choice, and found widespread acceptance by decision makers across multiple domains where decisions about choice and prioritization are required (Vaidya & Kumar, 2006). It has proven to be a methodology capable of producing results that agree with perceptions and expectations (Bhushnan, 2004). The successful implementation of the AHP methodology by many decision makers has led to its integration with other powerful techniques including the quality function deployment (QFD), fuzzy logic, SWOT analysis, data envelopment analysis (DEA), linear programming (LP), mixed-integer linear programming (MILP), and goal programming (GP) (Ho, 2008).

Although the AHP methodology has been used as an effective tool to make selection decisions in a wide range of venues, its application in the selection of human resources has been almost non-existent. As a result, this research proposes the building of a computer based collaborative decision making framework capable of properly mitigating the numerous problems common to group decision making and aggregating the personal preferences of each of the decision makers to properly identify, in a graphical format, the most likely finalists for the second stage of the human resource selection process.

3. The Analytic Hierarchy Process

The AHP is a decision making methodology for prioritizing alternatives when multiple criteria must be considered (Saaty, 1994). It decomposes complex problems into humanly-manageable sub-problems in the form of a hierarchy for easier comprehension by the decision maker. A hierarchy consists of a minimum of three levels. The highest level consists of the goal or the objective, while the last level consists of the alternatives. Between these two levels exists one or various levels of criteria and sub-criteria. By making pairwise comparisons at each level of the hierarchy, the decision makers can develop relative weights, called priorities, to differentiate the importance of the criteria (Saaty, 1994).

4. The Goals of the Human Resource Selection Process

The goal of any selection process is to choose the most qualified candidate who would most effectively perform the responsibilities associated with the position within the existing culture of the organization, while complying with federal and state laws. Although the task of selection sounds very simple, those who have served on selection committees and experienced its results know it is anything but simple.

Most hiring committees involve several people and numerous considerations to take into account when making the selection decision. An over-arching goal is to have a legally defensible system in place that uses valid and reliable methods that is free from discrimination. More specific concerns center around the importance placed on objectivity, person-job fit, and person-organization fit. These concerns will be discussed in the following paragraphs as they relate to the proposed multi-criteria framework to make collaborative selection decisions.

Many laws at the federal, state, and local levels have been passed over the years to prevent discrimination on the basis of numerous criteria such as gender (Equal Pay Act, 1963), race, color, creed, national origin (Civil Rights Act of 1964, Title VII), age (Age Discrimination in Employment Act, 1967), pregnancy (Pregnancy Discrimination Act, 1978), and disability (Americans with Disabilities Act, 1990). At the basic level, all of these criteria share something in common; they are not job-related. Organizations are required by law to use criteria that are job-related to make employment decisions of any type, including selection. Any criteria used to make a selection for a particular position must show a direct connection to the performance of that job.

To establish job relatedness, the selection criteria should be both valid and reliable. Validity is the extent to which a criterion actually measures what it is supposed to measure, while reliability reflects the accuracy or precision of a measuring instrument and its consistency (Kerlinger, 1986). In the human resource selection process validity is the extent to which a criterion relates to future success on the job, while reliability address both the consistency of the selection criteria in predicting different applicants' abilities to perform the required job and how consistently different members of the selection committee rate a specific candidate on a given criterion (inter-rater reliability). A lack of inter-rater reliability may indicate that the criterion allows for too much subjective judgment.

Although subjectivity cannot, and should not, be totally removed from the selection process, the use of criteria to make selection decisions that are as objective as possible (less subjective) is highly desirable as it reduces the likelihood that individual decision makers will use personal bias when evaluating candidates. Effort must be made to create a common understanding among the participants of the selection process regarding each of the criteria used to make a decision. This is not limited to understanding the definition of a particular criterion such as "knowledge" or "skills", but also sharing a common understanding of what is meant by a high or low level of that criterion. Even if different decision makers understand what is meant by job experience there may be variability between the decision makers as to what constitutes a high level of job experience. Some raters may perceive that two years working at any job is a high level of job experience while others might perceive at least 10 years in a specific job is necessary to achieve that level. To reduce the subjectivity levels effort must be put forth to create this common understanding before the selection process takes place for higher inter-rater reliability.

Although objective criteria are desirable, some organizations wish to incorporate criteria into the selection process that are, by their nature, subjective. This occurs when there is not only a focus on person-job fit, but person-organization fit. Person-job fit (P-J) is the degree to which the candidates' knowledge, skills, and abilities (KSA) match the responsibilities of a specific job (Edwards, 1991; Kristof-Brown & Johnson, 2005). This is the focus of the federal and state laws discussed above. When an organization can show that a criterion is directly associated to the performance of a job, candidates who score well on that criterion should have a good person-job fit. However, many organizations wish to go beyond this and try to determine how well the individual will conform to the existing group and organizational norms. This is known as person-organization fit (P-O) whose objective is to find individuals who have values, beliefs and personalities that are consistent with the organization's culture (Chatman, 1989; Kristof, 1996; Verquer, Beehr & Wagner, 2003). This desire arises from the common perception that it is easier to hire candidates who fit in well within an organization (high P-O fit) but do not have the specific skills for the job (low P-J fit) and train them, than to hire candidates who can perform the duties of the job (high P-J fit) but do not share the values and beliefs of the organization (low P-O fit) and then change their personalities. This does make sense, but it creates legal problems and reduces the ability to use objective measures.

5. The Case Study: The Selection of Academic Candidate (s)

Although the proposed computer-based decision making model can be easily applied for the selection process in different hiring environments, this paper will address the academic environment because one of the authors was assigned to a search committee to fill a faculty position in a college of business in a centrally located university in the United States. To assure uniformity in how candidates are evaluated by each decision maker, a weighted scale for the most critical and relevant criteria to the vacant position is first developed. Three primary selection criteria: Teaching; Research; and Others (service), were considered to be important, with each having its own sub-criteria which will be used to assist in the selection of the candidate best suited for the vacant position. These criteria and their respective sub-criteria are presented in Figure 1.

Figure 1. Decision Tree for the Selection of Academic Applicant(s)

Given the teaching emphasis of the university, the "Teaching" criterion is considered to be more important than the "Research" criterion, while both are more important than the service criterion. Using the AHP methodology where the scales can be interpreted as "1" when both criteria are equally important, while the other values are interpreted as one of the criterion is either moderately more important (3), strongly more important (5), very strongly more important (7), or extremely more important (9). Scales 2, 4, 6, and 8 are intermediate values to reflect fuzzy imputes (Saaty, 1980).

The priority for each of the criterion is then approximated in terms of its contribution to the overall goal using a synthesization process (Aczél, & Saaty, 1983) where the values in each of the columns in the pairwise comparison matrix (Exhibit 1) are normalized, and the average of each element in the rows is then used to estimate the relative priorities of the elements being compared.

The main criteria level shows that "Teaching" would carry 63.33 % of the decision weight, while the "Research" and "Others" criteria weight 26.05% and 10.62%, respectively.

Exhibit 1 Pairwise Comparison Matrix for the Selection of Academic Applicant(s)

	Teaching	Research	Others	Eigen Vector Priority Vector
Teaching	1	3	5	63.33%
Research	1/3	1	3	26.05%
Others	1/5	1/3	1	10.62%
		Total		100.00%

To measure the existence and the value of the inconsistency (poor judgment) of the decision maker, the maximum Eigen value (λ_{MAX}) and the eigenvector (the weights of the alternatives) of the comparison matrix with respect to the criteria with which these alternatives are being compared must first be determined. The degree to which the maximum Eigen value λ_{MAX} is greater than the number of alternatives being compared "n", reflects the natural measure of consistency, where a consistency ratio of zero reflects a perfect consistency of the pairwise comparison. The Consistency Index (CI) and the Consistency Ratio (CR) can then be determined using

$$CI = \frac{\lambda max - n}{n-1} \; and \; CR = \frac{CI}{RI}$$

where the random index "RI" is the average consistency index of many simulated pairwise comparison matrices of random judgment which depends on the value of the number of elements being compared, "n" (Saaty,1980). For the case at hand, a consistency ratio of 3.37% was far better than the acceptable level of 10%.

The next step was to decompose the "Teaching" criterion into the sub-criteria that are most critical to the vacant position in question including the candidate's education (ED), teaching experience (TEX), business experience (BEX), students' evaluations (SE), and his/her writing skills (WRT). Using the previously described methodology, a pairwise comparison matrix was then developed to determine the priorities of the related sub-criteria, their local, and their global impact on the final decision making.

To determine the global weights of each of the sub-criterion, the local weights were first determined and then multiplied by the global weight for each of the main criteria. For example the global weight of the teaching criterion is 63.33%, while the applicant's education (ED) carries 26.33% of the decision weight at the local level (teaching criteria) and 16.67% of the global weight of the hiring decision with an overall inconsistency ratio (4.112%) far less than the acceptable level (10%). The results are tabulated in Exhibit 2.

The same process was then applied to determine the local and global weights of the four critical "Research" sub-criteria identified as the applicant's publications in the field of expertise (Publications-PUBS), the applicant's contribution to the body of knowledge which can be measured by articles that cited his/her research (Citations-CIT), the applicant's past/future ability to receive grants (Grants-GRT), and the honors and awards that have been bestowed on the applicants (HA). The local and global weights on the research sub-criteria were determined, and overall consistency ratio of 3.04% was achieved, a result far less than the acceptable level of 10%. These results are presented in Exhibit 3.

Exhibit 2 "Teaching" Sub-Criteria Pairwise Comparison Matrix

Teaching Sub-Criteria	ED	TEX	BEX	SE	WRT	Local Level Priority vector	Global Level Priority vector
Education (ED)	1	1	2	1	6	**26.33%**	**16.67%**
Teaching Experience (TEX)	1	1	5	1	3	**28.11%**	**17.80%**
Business Experience (BEX)	1/2	1/5	1	1/5	2	**8.66%**	**5.48%**
Students Evaluations (SE)	1	1	5	1	6	**31.33%**	**19.84%**
Writing Skills (WRT)	1/6	1/3	1/2	1/6	1	**5.57%**	**3.53%**
			Total			**100.00%**	**63.33%**

Exhibit 3 "Research" Sub-Criteria Pairwise Comparison Matrix

Research Sub-Criteria	PUBS	CIT	GRT	HA	Local Level Priority vector	Global Level Priority vector
Publications (PUBS)	1	4	8	6	**65.04%**	**16.94%**
Citations (CIT)	1/4	1	1	1	**12.60%**	**3.28%**
Grants (GRT)	1/8	1	1	1 1/2	**11.89%**	**3.10%**
Honors & Awards (HA)	1/6	1	2/3	1	**10.47%**	**2.73%**
			Total		100.00%	26.05%

To address the publication venues, four "Publications" sub-criteria were identified as critical to the fulfillment of the mission of discovering, transferring, and disseminating knowledge. The sub-criteria are the refereed journal publications (RF), the refereed conference proceedings (RP), the non-refereed journal publications (NRF), and the conference presentations (CP). The overall inconsistency ratio (2.27%) was far less than the acceptable level (10%). The local and global priority weights were determined as shown in Exhibit 4.

Exhibit 4 "Publications" Sub-Criteria Pairwise Comparison Matrix

	Publication Sub-Criteria				Local	Global
	RF	**RP**	**NRJ**	**CP**	Priority Vector	Priority Vector
Ref Journal (RF)	1	5	5	10	65.896%	11.165%
Ref Proceed (RP)	1/5	1	2	2	16.120%	2.731%
Non-Ref Journal (NRJ)	1/5	1/2	1	2	11.394%	1.930%
Conf. Presentation (CP)	1/10	1/2	1/2	1	6.590%	1.116%
					100.00%	16.943%

The "Others" criteria was addressed by using five sub-criteria identified as essential such as the applicant's organizational skills (ORG), the quality rating of the program from which the applicant graduated (QP), the applicant's potential for future research (PFR), his/her commonality with other faculty (COM), and the applicant's teaching flexibility (TF). Using the previously described AHP methodology, the local and global priority weights were determined with an inconsistency ratio of 4.67% which far less than the acceptable level of 10%. These results are presented in Exhibit 5.

Exhibit 5 "Others" Sub-Criteria Pairwise Comparison Matrix

Others Sub-Criteria	ORG	QP	PFR	COM	TF	Local Level Priority vector	Global Level Priority vector
Organizational Skills (ORG)	1	1/2	1/4	1/4	1/4	**6.91%**	**0.73%**
Quality Rating of the Program (QP)	2	1	1/2	2	1	**19.86%**	**2.11%**
Potential for Research (PFR)	4	2	1	3	2	**36.97%**	**3.93%**
Commonality with faculty (COM)	4	1/2	1/3	1	1	**16.48%**	**1.75%**
Teaching Flexibility (TF)	4	1	1/2	1	1	**19.77%**	**2.10%**
			Total			100.00%	10.62%

Upon determining the local and global weights of the related sub-criteria, the Academic Applicant Selection Form shown in the Appendix is then digitally created and used by each of the participants in the selection process to evaluate and assess each of the applicants. For the case at hand, applicants who met the minimum criteria were then evaluated and a consensus estimate was then reached to determine the most promising candidates for each of the main decision making criteria under consideration (please see the appended Academic Applicant Selection Form) as shown in Exhibit 6.

Exhibit 6 Applicant's Selection Table

	Global Weight	Local Weight	Applicant #	**1**	**3**	**17**	**18**	**21**	**23**	**27**	**30**	**32**	**54**	**55**
Teaching 63.33%	16.68%	26.33%	Education	3	3	3	2	3	3	3	3	3	3	3
	17.80%	28.11%	Teaching Experience	4	3	5	5	5	5	4	5	5	4	3
	5.48%	8.66%	Relevant Business Experience	1	3	5	5	2	2	3	2	3	5	1
	19.84%	31.33%	Students Evaluations	3	3	3	3	3	3	3	3	3	3	3
	3.53%	5.57%	Writing Skills	3	4	5	5	4	3	3	3	3	4	3
	63.33%	**100.00%**	**Teaching**	3.11	3.06	3.85	3.58	3.53	3.48	3.28	3.48	3.56	3.51	2.83
Publications	11.16%	65.90%	**Ref Journal**	2	4	5	5	5	3	5	5	5	5	1
	2.73%	16.12%	**Ref Proceed**	3	2	5	5	5	1	5	5	5	5	1
	1.93%	11.39%	**No Ref Journal**	3	2	5	5	5	1	5	5	5	5	1
	1.12%	6.59%	**Conf Presentation**	3	2	5	5	5	1	5	5	5	5	1
Research 26.05%	16.94%	65.04%	Publications	2.34	3.32	5.00	5.00	5.00	2.32	5.00	5.00	5.00	5.00	1.00
	3.28%	12.60%	Citations	1	1	1	1	1	1	1	1	1	1	1
	3.10%	11.89%	Grants	1	1	3	3	1	1	1	1	1	3	1
	2.73%	10.47%	Honors & Award	1	5	5	3	3	1	1	1	1	3	1
	26.05%	**100.00%**	**Research**	1.87	2.93	4.26	4.05	3.81	1.86	3.60	3.60	3.60	4.05	1.00
Others 10.62%	0.73%	6.91%	Organizational Skills	3	4	3	3	3	2	3	3	3	3	3
	2.11%	19.86%	Quality rating of program	3	4	5	5	3	3	3	3	3	3	3
	3.92%	36.97%	Potential Future research	2	5	2	4	3	2	5	4	5	5	3
	1.75%	16.48%	Commonality with Faculty	3	4	2	2	3	3	2	3	3	3	3
	2.10%	19.77%	Teaching Flexibility	3	5	2	5	3	5	3	5	4	5	3
	10.62%	**100.00%**	**Others**	2.63	4.57	2.67	4.00	3.00	2.96	3.57	3.77	3.94	4.13	3.00
			Overall Score	**2.74**	**3.18**	**3.83**	**3.75**	**3.55**	**3.00**	**3.40**	**3.54**	**3.61**	**3.72**	**2.37**

Using the weights of the selection criterion, graphical representations of the aggregate of the personal preferences of the participants in the selection process are then automatically generated showing for each of the selection criteria the individual scores for each of the applicants as shown in Exhibits 7, 8, and 9.

Exhibit 7 Model Applicants Selection (Teaching scores)

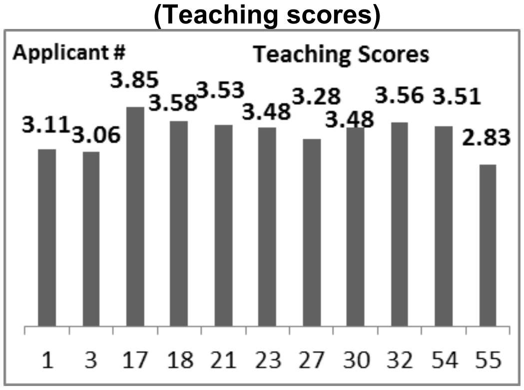


Exhibit 8 Model Applicants Selection (Research scores)

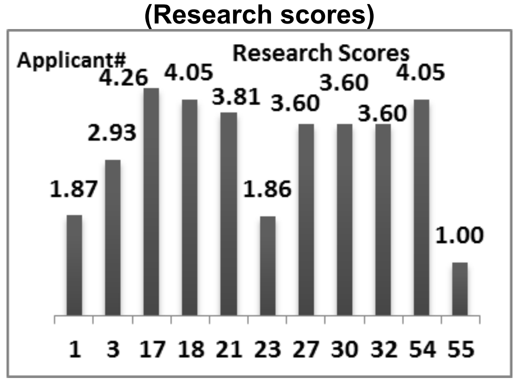
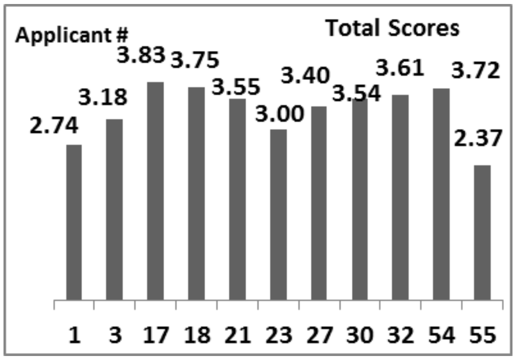


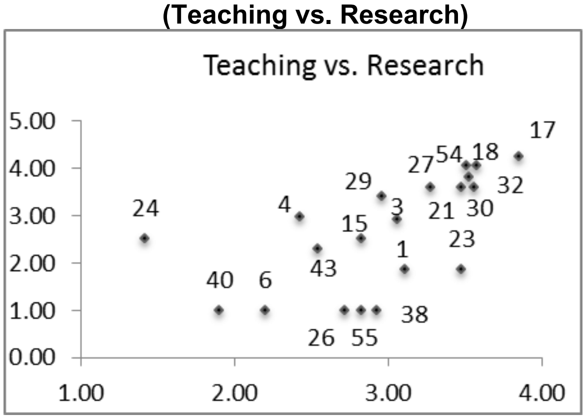
Exhibit 9 Model Applicants Selection (Total scores)



Applicants 17, 18, 32, and 54 received the highest scores (see exhibit 6) and were chosen for a phone interview. Candidates 32 and 17 were then invited for a physical interview, after which an offer was made and accepted by candidate 32.

The framework also allows the participants of the selection process the use of a two dimensional chart to reveal where each of the candidates ranks among his peers in both Teaching and Research selection criteria. The evaluation of many candidates by the selection committee clearly shows candidates 17, 18, 32, and 54 as the leading candidates as shown in Exhibit 10.

Exhibit 10 Model Applicants Selection (Teaching vs. Research)



6. Conclusion, Limitations, and Future Directions

As shown in this paper, the AHP methodology can be a very useful tool in aiding organizations in selecting appropriate candidates to fill open positions. The AHP is by no means a panacea for all the ills of the selection process as it currently exists, but it can significantly increase the structure of the process and reduce subjectivity. If properly designed and implemented, the AHP can assist organizations in meeting many of the goals of the selection process.

The participants of the selection group should insure that only criteria that are related to the performance of the job are included in the AHP. This will increase the likelihood that the chosen candidate will have a strong person-job fit and therefore meet the expectations set out in numerous federal, state, and local laws and regulations governing employment decisions. Most importantly, using only valid, job-related criteria should meet the ultimate goal of the selection process to select the person who will best perform the requirements of the job. Even if only valid, job-related criteria are included in the AHP, time must also be invested at the beginning of the selection process to clearly define each criterion and the degrees of each criterion so that all members of the selection committee who will be ranking the candidates share a common understanding of the definition of each criterion and what is meant by each level of the criterion. If this time is invested, rater subjectivity will be reduced and the ratings across raters (inter-rater reliability) will increase. This more structured approach should better define and streamline the selection process saving time and producing more accurate results.

The numerous benefits that could result from the use of the AHP to select new employees are contingent on whether or not the process is designed and implemented correctly otherwise this process will suffer from the same subjective problems as the currently used selection processes.

7. References

[1] Aczél, J. J., & Saaty, T. L. (1983). Procedures for synthesizing ratio judgments. *Journal of Mathematical Psychology*, 27(1), 93-102

[2] Barron, F. H., & Edwards, W. (1994). SMARTS and SMARTER: Improved simple methods for multi-attribute utility measurement. *Organizational behavior and human decision processes*, *60*(3), 306.

[3] Bhushnan N. (2004). *Strategic Decision Making: Applying the Analytic Hierarchy Process*. Springer Verlag, London.

[4] Brans, J. P., Vincke, P. h., & Mareschal, B. B. (1986). How to select and how to rank projects: The PROMETHEE method. *European Journal of Operational Research*, 24(2), 228-238.

[5] Burke, D. L. (1988). *A New Academic Marketplace*. New York: Greenwood Press.

[6] Charnes, A., Cooper, W.W., and Ferguson, R.O. (1955). Optimal Estimation of Executive Compensation by Linear Programming. *Management Science* 1(2), 138-151

[7] Chatman, J. A. (1989). Improving Interactional Organizational Research: A Model of Person-Organization Fit. *Academy of Management Review*, 14(3), 333-349.

[8] Cole, B. R. (1995). Applying total quality management principles to faculty selection. *Higher Education*, 29(1), 59.

[9] Edwards, J. R. (1991). Person-job fit: A conceptual integration, literature review, and methodological critique. In C. L. Cooper, I. T. Robertson, C. L. Cooper, I. T. Robertson (Eds.) *International review of industrial and organizational psychology*, 1991, Vol. 6 (pp. 283-357). Oxford England: John Wiley & Sons.

[10] Gass, S. I. (2005). Model World: The Great Debate-MAUT versus AHP. *Interfaces*, *35*(4), 308.

[11] Gatewood R.D., Feild H.S., & Barrick M.R. (2008) *Human resource selection*. Cengage Learning.

[12] Ho, W. (2008). Integrated Analytic Hierarchy Process and Its Applications - A literature review. *European Journal of Operational Research* 186(1), 211.

[13] Hwang, C.L., Yoon, K. (1981). *Multiple Attribute Decision Making.* Springer-Verlag, NY

[14] Hwang, C., Lai, Y., & Liu, T. (1993). A new approach for multiple objective decision making. *Computers & Operations Research* 20(8), 889.

[15] Keeney R.L., & Raiffa, H. (1993). *Decisions with Multiple Objectives-Preferences and Value Tradeoffs.* Cambridge University Press, Cambridge & New York.

[16] Kerlinger, F.N. (1986). *Foundations of Behavioral Research.* Harcourt, Brace, Jovanovich College Publishers, Fort Worth, TX.

[17] Kristof, A.L. (1996). Person-organization fit: An integrative review of its conceptualizations, measurement, and implications." *Personnel Psychology, 49(1),* 1.

[18] Kristof-Brown, A.L., Zimmerman, R.D., & Johnson, E.C (2005). Consequences of individuals' fit at work: A meta-analysis of person-job, person-organization, person-group and person-supervisor fit. *Personnel Psychology, 58 (2),* 281.

[19] Mollaghasemi, M., & Pet-Edwards, J. (1997) *Making Multiple-objective Decisions*. IEEE Computer Society Press, Los Alamitos, CA.

[20] Roy, B. (1968). Classement et choix en présence de points de vue multiples (la méthode ELECTRE). *Revue Française d'Informatique et de Recherche Opérationnelle* 8, 57.

[21] Roy, B. (1996). *Multicriteria Methodology for Decision Aiding*. Kluwer Academic Publishers, Dordrecht, the Netherlands.

[22] Saaty, T. L. (1980). *The Analytic Hierarchy Process*. McGraw-Hill Book Company, New York.

[23] Saaty, T. L. (1994). How to make a decision: The Analytic Hierarchy Process. *Interfaces* 24(6), 19.

[24] Savage, L. J. (1954). *The Foundations of Statistics*. John Wiley and Sons, New York.

[25] Vaidya, O.S. and Kumar, S. (2006). Analytic hierarchy process: An Overview of Applications. *European Journal of Operational Research* 169, (1)1.

[26] Verquer, M.L., Beehr, T.A., & Wagner, S.H. (2003). A meta-analysis of relations between person-organization fit and work attitudes. *Journal of Vocational Behavior, 63 (3),* 473.

[27] Von Neumann, J. & Morgenstern, O. (1947). *Theory of Games and Economic Behavior*, 2nd ed. Princeton University Press, Princeton, NJ.

Grading Criteria- Committee Member Name:	Applicants				
Teaching Criteria:	1	2	3	4	5
1.1 Education:					
1- ABD or Masters in a different field					
2- ABD in the field or a PhD in a related field					
3- PhD in the field					
4- PhD in the field from a recognized university tier 3 or more					
5- PhD in the field from a well recognized university tier 1 or 2					
1.2 Teaching experience:					
1- Less than 1 year					
2- 1 year					
3- 2 - 3 years					
4- 4 years					
5- 5 or more years					
1.3 Relevant Business experience:					
1- Less than 1 year					
2- 1 year					
3- 2 - 3 years					
4- 4 years					
1.4 Students Evaluation:					
1- Less than average					
2-					
3- Average					
4-					
5- Excellent					
1.5 Writing Skills (Judged from CV):					
1- Below average					
2-					
3- Average					
4-					
5- Excellent					
Research Criteria:					
2.1-Publications					
2.1.1 Referred Journal (Over the last 5 years) Use the following Scale					
1- No Cabell indexed journal publication					
2- One Cabell indexed journal publication					
3- Two Cabell indexed journal publications					
4- Three Cabell indexed journal publications					
5- Four or more indexed journal publications					
2.1.2 Referred Proceedings (Over the last 5 years) Scale 1-5					
2.1.3 Non-referred Journal publications (Over the last 5 years) Scale 1-5					
2.1.4 Conference Presentations (Over the last 5 years) Scale 1-5					
2.2- Citation: (Scale 1-5)					
1- The applicant has not been cited					
2-5 Depends on the number of citations					
2.3-Grants: (Scale 1-5)					
1- The applicant did not receive any funding or grants					
2-5 Depends on the funding/Grants value					
2.4-Honors & Awards: (Scale 1-5)					
1- None					
2-5 Such as scholarship or any type-					
Others Criteria:					
3.1-Organizational Skills (Scale 1-5)					
3.2- Quality rating of the program the applicant's graduated from (Scale 1-5)					
3.3-Applicant's potential of future research (Scale 1-5)					
3.4-Applicant's commonanility with existing faculty (Scale 1-5)					
3.5-Applicant's teaching flexibility (Scale 1-5)					

Academic Applicant Selection Form

Inverse Correlated Gamma Variables

Pierre Ngnepieba and Dennis Ridley
School of Business and Industry, Florida A&M University, Tallahassee, Florida, 32307, USA
Pierre.Ngnepieba@famu.edu, dridley@fsu.edu

Abstract

The correlation between a gamma distributed random variable and its pth power is simulated for negative and positive values of p. As expected the correlation is positive for positive p. However, for negative p, the correlation is negative. Furthermore, the correlation approaches minus one as p approaches zero from the left. This is entirely counter intuitive. It provides a method for eliminating bias in fitted values obtained from any regression model.

1. Introduction

Data analysis has a variety of applications. For example, regression models, forecasting models and statistical process control charts. All such applications are adversely affected by bias in estimated model parameters. For example, a statistical process control chart requires that the data from which it is constructed be independent. Unfortunately, over eighty percent of manufacturing and other process variables are not independent (see Alwan and Roberts [1] and Roberts [2] on approaches to control charts for correlated data). Wardell, et. al. [3] discussed applying statistical process control charts to both the correlated and the random components.

Combining antithetic variables provides a method for eliminating bias in fitted values obtained from any autoregressive time series model. By extension, combining antithetic forecasts provides a method for eliminating bias from forecast values. Antithetic combining was applied to a wide range of data distributions by Ridley [4]. The methodology for optimizing weights for antithetic combining was demonstrated by Ridley [5]. In addition to eliminating bias in the forecast, antithetic combining eliminates the effect of changing the forecast origin. For a demonstration of how antithetic combining desensitizes the forecast origin, see Ridley [6]. The first proof of the existence of inversely correlated random variables (X, X^p) for $p\to0^-$ was presented by Ridley [7]. Inversely correlated random variables obtained in this way were referred to there as antithetic random variables. The proof that the limiting value of the correlation between X and X^p is equal to -1 as $p\to0^-$ was for the special case when X is lognormally distributed.

In this paper we consider the more general case when X is gamma distributed. Since the gamma distribution can be generalized to represent not only the lognormal distribution, but many other distributions, the demonstration of antithetic random variables can be extended to all such distributions. Likewise, the application of antithetic random variables can be extended to data that follow all such distributions.

The purpose of this paper is to investigate the relationship between a gamma distributed random variable X and its pth power X^p. In particular, we are interested in the correlation between X and X^p as $p\to0^-$. As can be seen from Figure 1, this correlation is counterintuitive. As expected, when p is positive, the correlation is positive. When p=1, the correlation is exactly plus one. As the exponent p approaches zero from the right, the correlation moves away from plus one and moves toward zero. However, as p approached zero from the left, there is an inverse correlation between X and X^p. It does not move toward zero. Instead, the correlation moves towards -1. These two results (for p positive and for p negative) are in stark contrast, hence the counterintuitive nature of the correlation. We will demonstrate that the limit of the correlation as p approaches zero from the left, inside a delta neighborhood of zero, but not zero, is -1.

The paper is organized as follows. In section 2 we review the gamma distribution. In section 3 we use Matlab [8] to compute estimated correlations ($\hat{\rho}$) for a wide range of values generated from the gamma distribution. Section 4 shows the results of an empirical case study. Section 5 contains suggestions for future research.

2. The gamma distribution

The Gamma distribution is very important for technical reasons since it is the parent of the exponential distribution and can explain many other distributions. The gamma probability density function (pdf) is (See Hogg and Ledolter [9]):

$$f(X;\alpha,\beta) = \begin{cases} \frac{1}{\beta^{\alpha}\Gamma(\alpha)} X^{\alpha-1} e^{-\frac{X}{\beta}}, if\ X \geq 0 \\ 0, \qquad if\ X < 0 \end{cases} \tag{1}$$

where the parameter $\alpha > 0$ is called the shape parameter and $\beta > 0$ represents the scale parameter. The gamma function is defined as

$$\Gamma(\alpha) = \int_0^{\infty} X^{\alpha-1} e^{-X} dX \tag{2}$$

Graphs of the gamma probability density function for β= 0.6 and various values of α=1.1; 3; 5; 9; and 11 are shown in Figure 2.

3. Correlation versus p

In order to demonstrate the effect of p on the correlation, the correlation is estimated from the sample correlation coefficient ($\hat{\rho}$) for a set of n values x_k, k=1,2,3,…,n of X as follows.

$$\hat{\rho} = \frac{\sum_{k=1}^{n}(x_k - \bar{x})(x_k^p - \overline{x^p})}{\sqrt{\sum_{k=1}^{n}(x_k - \bar{x})^2 \sum_{k=1}^{n}\left(x_k^p - \overline{x^p}\right)^2}},$$

or, in easier computational form

$$\hat{\rho} = \frac{\sum_{k=1}^{n} x_k^{p+1} - n\bar{x}\,\overline{x^p}}{\sqrt{\left(\sum_{k=1}^{n} x_k^2 - n\bar{x}^2\right)\left(\sum_{k=1}^{n} x_k^{2p} - n\overline{x^p}^2\right)}}$$

where

$$\bar{x} = \sum_{k=1}^{n} \frac{x_k}{n}\ and\ \overline{x^p} = \sum_{k=1}^{n} \frac{x_k^p}{n}.$$

Reversal of the correlation can be facilitated by adding a constant λ to x_k before computing the correlation coefficient as follows:

$$\hat{\rho} = \frac{\sum_{k=1}^{n} z_k^{p+1} - n\bar{z}\,\overline{z^p}}{\sqrt{\left(\sum_{k=1}^{n} z_k^2 - n\bar{z}^2\right)\left(\sum_{k=1}^{n} z_k^{2p} - n\overline{z^p}^2\right)}}, \tag{3}$$

where $z_k = x_k + \lambda$, k = 1 , 2 , 3 , . . , n
and

$$\bar{z} = \sum_{k=1}^{n} \frac{z_k}{n}\ and\ \overline{z^p} = \sum_{k=1}^{n} \frac{z_k^p}{n}.$$

The Matlab random generator GAMRND(α, β, n) is used to generate n random numbers from the gamma distribution with parameters α, β. In practice, the data may include relatively few observations. To investigate the small sample correlation coefficient, the correlation coefficient is calculated from equation 3, for $p \to 0^-$, n=100, $\lambda = 2.0\bar{x}$, β =0.5 and for various values of α = 5, 10, 15, 20, 25. The results are shown in Table 1.

For all values of α, the correlation coefficients are negative. The correlation coefficients get closer to -1 as α increases from 5 to 25. From Figure 2, smaller values of α are for more asymmetrical distributions and larger values are for more symmetrical distributions. In practice the value of α cannot be modified. It will be that for the actual data under study. However, it can be said that the effect of reversing the correlation is greatest for symmetrical distributions.

To investigate the theoretical population correlation coefficient, a large sample of n=10,000 is used. The correlation coefficient is calculated from equation 3, for $p \to 0^-$, $\beta=0.5$, and for various values of $\lambda=0.0\bar{x}$, $0.5\bar{x}$, $1.0\bar{x}$, $1.5\bar{x}$, $2.0\bar{x}$ and α = 5, 10, 25. The results are shown in Tables 2, 3 and 4. The trends are consistent with those in Table 1. Moreover they show that the shifting constant λ is effective in facilitating convergence of the correlation coefficient to -1.

This completes the primary objective of power transformation and inverse correlation. See the appendix on how inverse correlation can be used to eliminate bias.

4. Results from an empirical case study

For a comparative benchmark, consider the case of electric heater sales analyzed by Chatfield and Prothero [10] (includes the data). The 77 months of data are plotted in Figure 4. The time series is comprised of trend, multiple growth cycles and multiplicative error components. As it turns out, due to this mixture, a seemingly regular time series is actually challenging to forecast. A histogram is plotted in Figure 3. Like the gamma distribution, the data distribution is skewed to the right, and with adjustments to the shape and shift parameters, the data can be approximated by the gamma distribution.

The Chatfield and Prothero paper was read at a meeting of the Royal Statistical Society. After an extensive exchange between the author and the discussants, the following autoregressive integrated moving average (ARIMA) model was identified for fitting the data and forecasting sales:

ARIMA Model$(1+.37\mathcal{B})\nabla\nabla_{12}x_t^{.34} = (1-.79\mathcal{B}^{12})a_t$,

where x_t are data, ∇ is the differencing operator, $\mathcal{B}$ is the backward shift operator, and a_t are random errors. The model fitting period is January 1965 to April 1968. The forecast period is from May 1968 to May 1971.

In this paper we fit a twelfth order autoregressive model

$$\text{AR12: } x_t = \sum_{l=1}^{12} \Phi_l \, x_{t-l} + e_t$$

to the data. The combining procedure described in the appendix is then applied to the fitted and forecast values (the calculations were performed using the computer program FOURCAST [11]). The model parameter estimates are $\hat{\Phi}_1 = .123, \hat{\Phi}_2 = .025, \hat{\Phi}_3 = -.055, \hat{\Phi}_4 = .019, \hat{\Phi}_5 = .005, \hat{\Phi}_6 = .007, \hat{\Phi}_7 = -.012, \hat{\Phi}_8 = -.010, \hat{\Phi}_9 = .004, \hat{\Phi}_{10} = .039, \hat{\Phi}_{11} = -.007, \hat{\Phi}_{12} = .884$

.

The combining model parameters are ω=1.172895, λ=431.973. The original fitted mse = 2.226. The combined fitted mse = 1.906. The reduction due to combining is 14.4%. The measure of forecast error used is the root mean square error (rmse). The results are shown in Figure 4. The combined model rmse is (100(91.3-51.2)/91.3) % = 43.9% smaller than that for the ARIMA model.

The ARIMA model forecasts diverge. This is clear evidence that they are biased. The combined forecasts follow the actual data very well, suggesting that they are unbiased.

5. Conclusion

It was successfully demonstrated by computer simulations that the correlation between a gamma distributed random variable and its pth power approaches minus one as p approaches zero from the left. This counterintuitive result extends previous findings of the same result for lognormally distributed random variables. Antithetic random variables can be applied to eliminate bias in fitted values and forecasts from an autoregressive time series model when the time series variable follows not only a lognormal distribution but follows many other distributions. Suggestions for future research include the derivation of a theoretical function for the correlation between X and X^p, when X is gamma distributed, and a limiting value of the correlation as p approaches zero from the left, not including zero.

6. Appendix

We have shown that $z_k = \hat{x}_k + \lambda$ and z_k^p are nearly perfectly correlated, albeit negatively, so we can express z_k^p in the original units of z_k, by means of the linear regression of z_k on z_k^p as follows:

$$z_k = c_0 + c_1 z_k^p + \varepsilon_k, \qquad (A1)$$

where the least squares estimators for c_0 and c_1 are

$$c_0 = \bar{z} \text{ and } c_1 = \frac{\sum_{k=1}^{n}(z_k - \bar{z})(z_k^p - \overline{z^p})}{\sum_{k=1}^{n}\left(z_k^p - \overline{z^p}\right)^2},$$

and ε_k is an error term.

As p approached zero from the left, near perfect correlation between z_k and z_k^p ensures that the error term becomes negligible, and a near perfect estimate is obtained from

$$z_k' = c_0 + c_1 z_k^p. \qquad (A2)$$

Now, suppose that

$$z_k = f(z_{k-1}) + \epsilon_k, \text{ k=2,…,n}$$

is a time series model for which the errors ϵ_k are serially correlated. The estimated parameters of this model will be biased. That is unavoidable. Therefore, any estimate $\hat{z}_k$ of z_k from this model will also be biased. To remove this bias, we power transform $\hat{z}_k$ to obtain $\hat{x}_k^p$. Then, we use equation (A2) to convert $\hat{x}_k^p$ back to the original units of z_k. Hence

$$\hat{z}_k' = c_0 + c_1 \hat{x}_k^p.$$

Both estimates $\hat{z}_k$ and $\hat{z}_k'$ contain errors. These errors contain two components. One component is purely random and one component is bias. Combining the estimates cancels the bias components, leaving only the purely random component. The combined estimate $\hat{z}_{c,k}$ is obtained from

$$\hat{z}_{c,k} = \omega \hat{z}_k + (1-\omega)\hat{z}_k',$$

where $-\infty \le \omega \le \infty$, and the value of ω is chosen so as to minimize the mean square error.

$$\sum_{k=1}^{n}\left(z_k - \hat{z}_{c,k}\right)^2/(n-1).$$

Likewise, the unbiased combined estimate of a future value at time τ is obtained from

$$\hat{z}_{c,n}(\tau) = \omega\ \hat{z}_n(\tau) + (1-\omega)\hat{z}_n'(\tau),$$

$$\text{and } \hat{x}_{c,n}(\tau) = \hat{z}_{c,n}(\tau) - \lambda.$$

7. References

[1] L. C. Alwan, and D. Radson, “Implementation issues of time-series based statistical process control,” *Production and Operations Management*, Vol. 4,1995, pp. 263-276.

[2] S. W. Roberts, “Control chart tests based on geometric moving averages,” *Technometrics,* vol. 1, 1959, pp. 239-250.

[3] D. G. Wardell, H. Moskowitz, and R. D. Plante, “Control charts in the presence of data correlations,” *Management Science*, vol. 38, 1992, pp. 1084-1105.

[4] A. D. Ridley, "Combining Global Antithetic Forecasts", *International Transactions in Operational Research,* Vol. 2, No.4, 1995, pp. 387-398.

[5] A. D. Ridley, "Optimal Weights for Combining Antithetic Forecasts", *Computers & Industrial Engineering*, Vol. 32, No. 2,1997, pp. 371-381.

[6] Ridley, A., Desensitizing the forecast origin in: Process Control: Problems, Techniques and Applications, Editor: Samuel P. Werther, ISBN 978-1-6-61209-567-7, Nova Science, Publishers, Inc., Chapter 8, 2011.

[7] A. D. Ridley, "Optimal Antithetic Weights for Lognormal Time Series Forecasting", *Computers and Operations Research*, Vol. 26, No.3, 1999, pp. 189-209.

[8] MATLAB: *Application Program Interface Reference, Version 8*, The MathWorks, Inc., 2008.

[9] Hogg, R. V. and J. Ledolter. Applied Statistics for Engineers and Physical Scientists. 3rd Edition, Prentice Hall, p 174, 2010.

[10] Chatfield, C. and D. L. Prothero. "Box-Jenkins seasonal forecasting: problems in a case study," *Journal of the Royal Statistical Society: Series A*, vol.136, 1973, pp. 275-336.

[11] FOURCAST: Application program, EMC, Inc., Version 2010.12, http://www.fourcast.net/fourcast. File: CompanyX.zip. (2010).

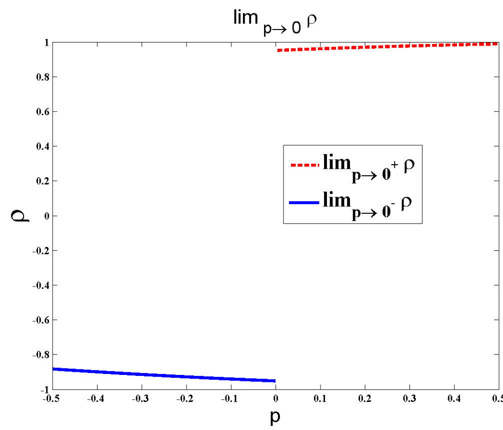


Figure 1. Behavior of correlation coefficient as p→0.

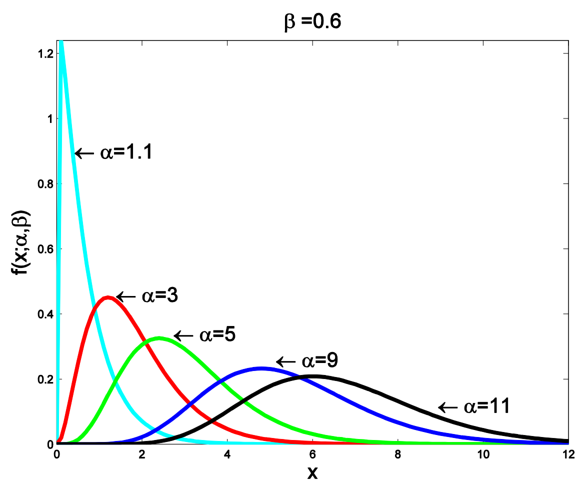


Figure 2. Gamma distribution for β= 0.6 and various values of α.

Table 1. Values of $\hat{\rho}$ for $p \to 0^-$, n=100, $\lambda = 2.0\bar{x}$, β=0.5 and various values of α.

p	α=5	α=10	α=15	α=20	α=25
-0.5000	-0.9894	-0.9946	-0.9962	-0.9972	-0.9978
-0.4500	-0.9901	-0.9953	-0.9966	-0.9976	-0.9981
-0.3500	-0.9914	-0.9956	-0.9969	-0.9977	-0.9982
-0.3000	-0.9920	-0.9960	-0.9971	-0.9979	-0.9984
-0.2500	-0.9926	-0.9963	-0.9973	-0.9981	-0.9985
-0.2000	-0.9931	-0.9965	-0.9975	-0.9982	-0.9986
-0.1500	-0.9937	-0.9968	-0.9977	-0.9983	-0.9987
-0.1000	-0.9942	-0.9971	-0.9979	-0.9985	-0.9988
-0.0500	-0.9947	-0.9973	-0.9981	-0.9986	-0.9989
-0.0001	-0.9952	-0.9976	-0.9983	-0.9987	-0.9990

Table 2. Values of $\hat{p}$ for $p \rightarrow 0^-$, n=10,000, β=0.5, α=5 and various values of λ .

p ↓ λ →	0.0$\bar{x}$	0.5$\bar{x}$	1.0$\bar{x}$	1.5$\bar{x}$	2.0$\bar{x}$
-0.5000	-0.8825	-0.9582	-0.9764	-0.9844	-0.9888
-0.4500	-0.8989	-0.9634	-0.9793	-0.9863	-0.9902
-0.3500	-0.9066	-0.9659	-0.9806	-0.9872	-0.9908
-0.3000	-0.9139	-0.9683	-0.9820	-0.9881	-0.9915
-0.2500	-0.9209	-0.9706	-0.9833	-0.9890	-0.9921
-0.2000	-0.9275	-0.9728	-0.9846	-0.9898	-0.9927
-0.1500	-0.9339	-0.9750	-0.9858	-0.9906	-0.9933
-0.1000	-0.9399	-0.9770	-0.9869	-0.9914	-0.9938
-0.0500	-0.9455	-0.9790	-0.9881	-0.9921	-0.9943
-0.0001	-0.9508	-0.9809	-0.9891	-0.9928	-0.9948

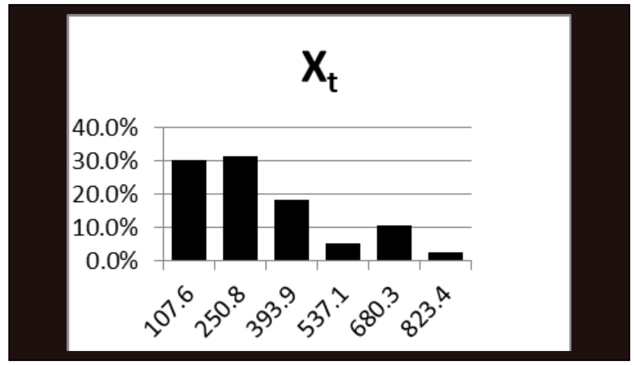


Figure 3. Histrogram of sales data.

Table 3. Values of $\hat{p}$ for $p \rightarrow 0^-$, n=10,000, β=0.5, α=10 and various values of λ .

p ↓ λ →	0.0$\bar{x}$	0.5$\bar{x}$	1.0$\bar{x}$	1.5$\bar{x}$	2.0$\bar{x}$
-0.5000	-0.9424	-0.9772	-0.9872	-0.9917	-0.9941
-0.4500	-0.9501	-0.9801	-0.9888	-0.9927	-0.9948
-0.3500	-0.9538	-0.9814	-0.9895	-0.9932	-0.9952
-0.3000	-0.9572	-0.9828	-0.9903	-0.9937	-0.9955
-0.2500	-0.9606	-0.9840	-0.9910	-0.9942	-0.9959
-0.2000	-0.9638	-0.9853	-0.9917	-0.9946	-0.9962
-0.1500	-0.9668	-0.9865	-0.9924	-0.9951	-0.9965
-0.1000	-0.9697	-0.9876	-0.9930	-0.9955	-0.9968
-0.0500	-0.9725	-0.9887	-0.9936	-0.9959	-0.9971
-0.0001	-0.9751	-0.9897	-0.9942	-0.9962	-0.9973

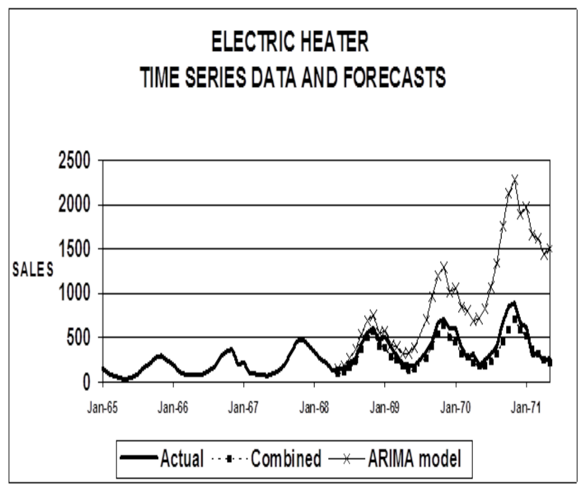


Figure 4. Electric Heater sales forecasts for May 1968 to May 1971.

Table 4. Values of $\hat{p}$ for $p \rightarrow 0^-$, n=10,000, β=0.5, α=25 and various values of λ .

p ↓ λ →	0.0$\bar{x}$	0.5$\bar{x}$	1.0$\bar{x}$	1.5$\bar{x}$	2.0$\bar{x}$
-0.5000	-0.9772	-0.9904	-0.9946	-0.9965	-0.9976
-0.4500	-0.9802	-0.9916	-0.9953	-0.9970	-0.9979
-0.3500	-0.9816	-0.9922	-0.9956	-0.9972	-0.9980
-0.3000	-0.9830	-0.9927	-0.9959	-0.9974	-0.9982
-0.2500	-0.9843	-0.9933	-0.9962	-0.9976	-0.9983
-0.2000	-0.9855	-0.9938	-0.9965	-0.9978	-0.9984
-0.1500	-0.9867	-0.9943	-0.9968	-0.9979	-0.9986
-0.1000	-0.9879	-0.9948	-0.9971	-0.9981	-0.9987
-0.0500	-0.9890	-0.9953	-0.9973	-0.9983	-0.9988
-0.0001	-0.9900	-0.9957	-0.9976	-0.9984	-0.9990

HYDRA: High Yield Display-wall for Research Activity

Sean Sovine, Devon Albrecht and Paulus Wahjudi
Weisberg Division of Engineering and Computer Science, Marshall University, Huntington, WV 25755
sovine5@marshall.edu, albrecht4@marshall.edu, wahjudi@marshall.edu

Abstract

Marshall University has formed the Computational Research and Education (CoRE-NET) group to promote undergraduate research in computer science. One of the first projects of CoRE-NET has been to research display wall technology with the goals of discovering an effective and affordable display wall implementation and of discovering research, government, and business applications for this technology. It was discovered that these applications include visualizing scientific and engineering data, use in planning activities, and facilitating group management and decision-making activities. CoRE-NET arrived at a display wall solution called the High Yield Display-wall for Research Activity (HYDRA), which uses commodity desktop computers with LCD monitors, the Ubuntu distribution of Linux, and the Scalable Adaptive Graphics Environment (SAGE). HYDRA uses only free software that is publicly available, and requires no high-performance hardware. The HYDRA implementation process was documented in detail as a guide for others who wish to use the HYDRA display wall. The HYDRA project demonstrated the effectiveness of CoRE-NET as a learning tool, showing that undergraduates can benefit from a research experience focused on new technology. Future plans for HYDRA include developing an integrated installer and exploring educational and research applications.

Background

In the constantly evolving field of computer science, universities are pressured to provide degree program infrastructures that support research activity as well as classroom learning. In the current economy, where budget cuts are prevalent, it is especially difficult for small programs to gain the funding to provide the needed infrastructure to keep pace with the growth of technology. Further, undergraduate research experience is becoming more important in preparing students for graduate school and for research jobs after graduation, while at the same time, undergraduates in many universities are considered low priority under graduate students when distributing resources for research opportunities.

As an effort to provide this structure for student development, Marshall has founded the Computational Research and Education for New and Emerging Technologies (CoRE-NET) group. CoRE-NET is a research group for undergraduates that is intended to expose students to the field of computer science research. The Computing Technology Farm (CTF) initiative, which is housed within CoRE-NET, is a framework in which students are able to pursue research projects outside the normal curriculum that facilitate a more in-depth, hands-on, and collaborative learning experience.

One of the first projects of the CTF initiative was the High Yield Display Wall for Research Activity (HYDRA) project, which set out to create a versatile, scalable display wall using open source software and standard desktop hardware. A display wall project was chosen because it was a good fit for the computing resources available to CoRE-NET, and because display wall technology is an active, interesting area of research and development that has applications in diverse fields.

Introduction

Due to the large amounts of data that scientist, engineers, civil planners and other professionals are able to collect, store, and analyze using modern computing technology, large-scale visualization has become a useful tool for interacting with data. Large-scale visualization allows individuals to images at high resolutions, preserving both the local detail of a portion of an image and the global context of that portion within the larger image.

There are many visualization tasks that go beyond what is suited to multi-screen desktop visual environments and large single-screen displays. Multi-screen desktop environments provide detail, but not enough visual space to gain the context of a significant portion of an image. Standard display solutions using large screens or projectors do not provide the resolution needed to view adequate detail in an image. A tiled display walls provides a solution to both of these problems.

The CoRE-NET display wall project set out to implement a large-scale visualization wall, searching for the most flexible and affordable implementation, and to discover research and business applications for this technology. This research arrived at the HYDRA display wall, which is described in detail below, along with applications and proposed research goals for HYDRA.

CoRE-NET also planned to document the process of implementing a visualization wall in a way that can be easily followed by others with a minimum amount of technical background. This documentation was realized in the form a concise, but fully detailed manual for implementing the HYDRA display wall. Applications of display wall technology are presented first in this paper in order to motivate the decisions described in the implementation section.

Applications of tiled display walls

Scientific visualization and engineering

Continuous improvements in computer processor and data storage technology in recent years have led to the rapid development of applications of computer technology for scientific data collection and analysis [12]. In many areas of science and engineering, visualization of data has become a necessity, providing the only effective means for interpreting large amounts of data obtained from instrumentation, experimentation, and simulation [13]. Scientific visualization is the field of computer science that centers on the visualization of scientific data sets in order to reveal patterns and gain insight into the natures of data sets or parts of data sets. Research in this field focuses on the development of algorithms and tools that assist in the comprehension of these data sets [10].

Large-scale tiled display walls are one of the most useful and creative ways to present large, high-resolution images [13]. Due to the needs of scientific visualization and other data intensive fields, display wall technology is becoming increasingly more common. Large-scale tiled displays also allow researchers to view large, high-resolution images while creating juxtapositions of important data that are vital to the understanding of research data [4].

Collaboration

Display walls can be used to facilitate collaboration among scientific researchers, engineers, civil planners, and other professionals at one location or multiple remote locations. Large-scale display walls allow users to share a single high-resolution workspace while preserving visual contact with one another. This shared workspace also enables collaborators to bring together different sets of relevant data [17]. These capabilities facilitate discussion and collaborative decision-making and lead to a drastic improvement of the quality of human interaction, while aiding in the comprehension of data used in collaboration [16].

Implementation of a tiled display wall

Tiled display wall hardware solutions

In terms of display hardware, the two most common tiled display wall solutions are those utilizing tiled projectors and those utilizing tiled LCD monitors. There are several advantages to tiled LCD displays that make them preferable over projector-based solutions in many cases.

LCD display walls can be implemented significantly more cheaply than comparable projector-based display walls. LCD display tiles can withstand years of consistent use without needing to be replaced, while projector bulbs need replaced after an average of 2000 hours of use [9]. Further, projector-based display walls take up significantly more space than tiled display walls, consume more power, and generate significantly more heat [2].

The display surface of an LCD display wall has mullions resulting from the plastic cases that surround the individual displays. Experience has shown that the human eye tends to look past the mullions of a tiled LCD, viewing them as “window panes” [1]. These mullions also act to minimize the effects of misalignment of the individual display screens to the eye of a viewer. In contrast, projector based tiled displays offer seamless display, but require precise alignment in order to display an image that appears correct to the viewer [1]. This alignment must often be performed by a professional, and can entail a high annual cost. For some projects, the seamless display offered by projectors could be the deciding factor, despite the cost and other disadvantages of these types of display, but for many applications LCD displays provide all the necessary functionality.

Tiled display wall software solutions

Both commercial and open-source software solutions exist for the creation of a large-scale tiled display wall. For this project only open-source solutions were considered, due to the funding constraints of the project and the price of commercial solutions, as well as the fact that commercial solutions are generally closed-source, “black box” products. This proprietary aspect of commercial solutions is counterproductive to a display wall research project, as it prohibits students from gaining a detailed understanding of the implementation of a solution and can also prohibit extending the functionality of that solution.

Among the existing open source software solutions for tiled display walls, three were found to potentially satisfy the goals of the CoRE-NET project. These are Xdmx, Chromium, and the Scalable Adaptive Graphics Environment (SAGE).

Xdmx is a proxy X server that, when coupled with Xinerama, allows for multiple displays attached to different machines to function as a single, multihead display. Xdmx lacks compatibility with many 3D applications due to a lack of support for recent versions of OpenGL. Xdmx also scales poorly to large displays due to a large network communication overhead inherent to the X protocol [1].

Chromium is a system for the distributed rendering and display of OpenGL graphics on computing clusters. The major drawback of Chromium is that it sends rendering information across the network, which consumes a high amount of bandwidth, especially for applications with a large amount of geometry and texture information. Also, Chromium lacks compatibility with applications using newer versions of OpenGL (beyond 1.5) [1][2].

The Scalable Adaptive Graphics Environment (SAGE) is a middleware that allows data, high-resolution graphics, and very high-resolution images to be streamed in real-time from remotely distributed rendering and storage clusters to tiled display walls over high-speed networks [3]. SAGE acts as a windowing environment and window manager that allows image, video, document, and application windows to be moved, resized, and overlapped on the display space of a display wall [3]. In addition, SAGE features an OpenGL wrapper that can capture pixel streams from existing OpenGL applications and display them on the display wall without modifying the source code of these applications.

Figure 1. Display wall software comparison

Solution	Positive	Negative
Xdmx	Shared desktop; integration with X-server.	Lack of support documentation; No support for recent OpenGL versions.
Chromium	Distributed OpenGL rendering;	No support for recent OpenGL versions; Inefficient for some tasks;
SAGE	Windowing; Built-in functionality; Extensibility.	Somewhat difficult to locate documentation.

High Yield Display Wall for Research Activities (HYDRA)

After researching software and hardware solutions for a tiled display wall, CoRE-NET arrived at the High Yield Display Wall for Research Activities (HYDRA). HYDRA is a two-by-four tiled display wall constructed from 17” LCD monitors, each connected to a Dell desktop computer. HYDRA is able to display one or more images, videos, documents, and OpenGL programs, such as Google Earth, simultaneously on its display surface using the SAGE software. HYDRA uses all open source software and standard desktop hardware, plus commercially available monitor stands. The HYDRA architecture supports a highly scalable number of display tiles. Figure 2 shows the hardware configuration for HYDRA.

Hardware configuration

CoRE-NET was able to obtain nine identical machines for the creation of the HYDRA display wall. These are each compact Dell desktop machines, each with Intel Pentium D820 2.80 GHz processors, 2.00 GB RAM, ATi Radeon X600 SE video cards, 120 GB Hard disk drives, and 17” LCD monitors. Each machine is also equipped with a gigabit Ethernet interface. Initially, eight machines were to be used for the display wall and the ninth machine was to be the rendering and control node for the wall.

Later, it was decided that more processing power was needed for the rendering node, so this machine was replaced with a Dell imaging workstation. This machine is a 5-year-old Dell Precision workstation equipped with an Intel Xeon quad-core processor and an Nvidia Quadro video card. A new, standard desktop with an upgraded video card also has enough computing power to perform as a rendering node for HYDRA. This further demonstrates that commodity hardware is sufficient for a HYDRA display wall.

For the configuration of the HYDRA display wall, two commercially available mounting frames were purchased over the Internet to mount the eight LCD monitor tiles in side-by-side two-by-two configurations, creating a single two-by-four display wall.

The SAGE software requires that the rendering and wall control computer be connected via network to each of the display computers. For this network, it was discovered experimentally that in order to effectively display streaming video on the full two-by-four wall using SAGE, a network bandwidth at least equivalent to gigabit Ethernet is necessary between the rendering and control node and the display nodes. For full (1080p) high-definition video playback on eight displays with this configuration, there is still a small amount of video lag. Network analysis shows that network activity is near capacity during this playback, yet system resources on the render and control node and display nodes are only moderately utilized, so it is assumed that the primary cause of this video performance deficit is the bandwidth limitation between the rendering node and display nodes. However, for lower resolutions, such as 720p, video playback performance is beyond acceptable. To implement this gigabit connection, a 16-port, unmanaged Cisco switch was utilized, costing approximately $300.

During the configuration process of the SAGE software, it was discovered that no fully functional OpenGL or equivalent drivers were available for the ATI graphics cards factory installed in the display node desktop machines.

Affordable, basic Nvidia graphics cards were purchased for these machines, solving this compatibility issue. These basic video cards performed adequately for all tasks tested on HYDRA.

Software configuration

Each HYDRA machine runs the Ubuntu 10.04 distribution of the Linux operating system and uses the open-source SAGE version 3.0 software to operate and manage the display wall. As part of this configuration, SAGE is installed on each machine.

The primary steps for installing SAGE include first setting appropriate SAGE environment variables in the SAGE user's .bashrc script, downloading and installing required packages, unpacking the SAGE binaries, and running the 'make' script in the SAGE folder. Instructions are currently available from the SAGE homepage, however, as a part of the HYDRA project, a document has been created that includes these instructions for the software installation process.

Some difficulty was encountered in the initial configuration of SAGE. This difficulty was primarily caused by compatibility issues with drivers for the display machines' ATI graphics cards. The solution to this problem was replacement of the existing ATI graphics cards with Nvidia graphics cards with functioning OpenGL drivers, as mentioned above. Once these cards were installed, obtaining the appropriate drivers was as simple as using the Ubuntu Hardware Drivers applet.

Each HYDRA machine needs Internet connectivity to download files and updates during the installation and configuration process. All machines of the HYDRA wall are on a private network that allows the rendering and control node to communicate efficiently with the display nodes. To provide Internet connectivity to the display nodes, a shared connection can be created from the control node to the display nodes. This is accomplished by the installation of a second network interface card (NIC) in the control node. Then, using the Network Manager applet and modifying configuration files, a static IP / hostname configuration can be created for each machine in the shared network, which allows for much easier configuration of SAGE. This Internet sharing configuration saves the expense of purchasing additional NICs for each display node machine.

During the configuration of the HYDRA display wall, there are several steps that require a solid understanding of Linux tools and configuration procedures. Secure shell (SSH) is used extensively by the SAGE application, as well as being an extremely useful tool for configuring and troubleshooting networked Linux machines. For SAGE, each machine must allow password-less SSH access to each other machine. This requires some knowledge of the SSH configuration files and of the encryption key system used by SSH. Proper firewall configuration is also necessary to allow SAGE to communicate between the rendering and control node and the display nodes.

Some shell scripts were written for HYDRA to automate basic tasks in the operation of SAGE. For example, a BASH shell script was written to synchronize the display manager configuration file for SAGE on all machines. Another script was written to shut down each machine in the display wall with a single command.

On the HYDRA display node machines, a free, open-source mouse and keyboard sharing software called Synergy was used to assist configuration and maintenance. This software is available in the Ubuntu 10.04 software repository. Synergy uses a client-server architecture in which a mouse and keyboard are physically attached to one computer, which acts as a server, sharing this mouse and keyboard with client machines. Synergy was configured on display node machines to start automatically with GNOME before user login. This was accomplished by modifying GNOME startup scripts. This process is described in detail in the HYDRA documentation.

Many steps in configuring the software used for HYDRA required the assistance of other users and sometimes developers via online forums. The use of forums for software support is a common feature of the open-source software experience.

As stated above, one goal of the HYDRA project is to gather information together and present it in a user-friendly way. There are some websites by organizations and individuals that have already done this quite well for some steps of the configuration process used for HYDRA, and these sites were of great assistance during the research phase of HYDRA.

Affordability

The HYDRA display wall uses only free, open source software, so the entire price of HYDRA is in its hardware. A HYDRA display wall could be built using new Dell OptiPlex 390 Desktop machines. These new desktop computers have significantly more computing power than the older machines CoRE-NET used to power the original HYDRA display wall. These machines feature Intel Core i3 processors, 2.00 GB RAM, AMD Radeon HD 6350 video cards, 250 GB SATA hard drives, and 23" Dell LCD monitors with low-profile cases. These OptiPlex 390 machines cost $903 each. Two Ergotech Quad 2 Over 2 monitor stands would each cost $298. This would result in a HYDRA display wall with 81.6 by 22.56 inches of display area, which is 1,841 square inches, and a total resolution of 7680 by 2160 pixels. This yields a total cost of $8,723, which is $4.74 per square inch, or .053 cents per pixel.

The commercial display wall provider Pixell offers an 87.2 by 49 inch tiled display wall with a resolution of 3840 by 1080 pixels for a cost of $67,000. This is $15.68 per square inch, or 1.62 cents per pixel. Pixell's 174.4 by 49 inch display wall has a resolution of 7860 by 2160 pixels, similar to HYDRA. This model costs $117,000, which is $13.69 per square inch, or .69 cents per pixel.

Solution	Cost-per-inch	Cost-per-pixel
Pixell 87.2" x 49" (2 x 2)	$15.68/in.	$0.0162/in.
Pixell 174.4" x 49" (4 x 2)	$13.69/in.	$0.0069/in.
HYDRA	$4.74/in.	$0.00053/in.

Figure 3. HYDRA cost comparison

Most commercial display wall solutions consist of a tiled display wall that is powered by a video processor, which receives multiple input sources and distributes these sources across multiple output screens. These devices generally consist of a single high-performance computer with slots for several specialized video cards. These video processors provide a high level of performance. However, given the price of these video processors, a display wall similar to HYDRA can be built using higher-performance computing hardware than the Dell OptiPlex machines mentioned above and still cost significantly less than a commercial display wall solution.

Functionalities

HYDRA is able to display images, videos, and documents using the SAGE software, as shown in Figure 4. HYDRA can also be configured using SAGE to intercept and display graphics from OpenGL programs without modification of those programs' source code. This aspect alone makes the HYDRA wall using SAGE a very flexible tool. HYDRA can be easily paired with the Google Earth application to provide interactive, large-scale map visualization. By this same method, HYDRA can also display output from the open-source scientific visualization and analysis program ParaView.

The hardware configuration of the HYDRA wall can also be easily adapted to other display wall software solutions, such as Chromium, though it has been the experience of HYDRA researchers that SAGE provides equivalent functionality and has many advantages over the other software solutions.

Future goals and plans

For HYDRA, several plans are on the table for future research and development. One of these plans is the creation of an integrated installer that will be in the format of a disk image that can be burned to a CD or DVD or mounted to a flash drive. This integrated installer will accomplish the complete configuration and installation of the HYDRA tiled display wall automatically, requiring only some basic input from the user. It will be designed so that a single disk can be used to install the render and control node and the display nodes. Further, if more displays or display nodes need to be added or removed from the display wall, the integrated installer will automate this task. This installer would provide a display wall solution that practically any user could have access to, without having to study extensively how to use and configure a wide array of software tools, operating system configuration files, and applications.

Another plan for HYDRA is the creation of a GUI utility that will manage the tile configuration for SAGE, so that the number and layout of tiles to be utilized for the SAGE display area can be configured graphically. Using this utility, users will be able to easily run SAGE on any rectangular configuration of contiguous monitors. This will aid in the analysis of the performance of the display wall in different configurations.

CoRE-NET plans to explore parallel rendering applications using the SAGE Application Interface Library (SAIL). Parallel applications using software such as Equalizer or CUDA GPU technology will be explored, allowing a separate cluster of nodes to process data that will be visualized and displayed on HYDRA using SAGE. These applications can also be used as example applications in a parallel processing class. HYDRA may also be used in graphics courses that are a part of the Marshall University computer science program.

The software ParaView is an open source application that can be used to visualize data sets from many sources in many formats, using many parameters. Scientists in many fields currently use ParaView for its powerful visualization capabilities. A display wall such as HYDRA is very well suited to this type of application, and makes this type of visualization more accessible to many scientific organizations, thanks to the affordability of HYDRA. For example, engineers use ParaView to visualize aerodynamics data and materials stress data. Economists can use ParaView to visualize and analyze the huge data sets they often work with. The ParaView software can also be used as a powerful tool to explore data mining sets.

There are several programs at Marshall that can benefit from use of the HYDRA display wall as a part of their research and education activities. These include a numerical relativity project that simulates black holes and black hole collisions and a civil engineering program that can use the HYDRA wall in its visualization of traffic simulations and models. A project suitable for undergraduate students would be to work with faculty performing research on numerical relativity simulations and adapt the visualization of their data to display on HYDRA.

Conclusion

Large-scale visualization is a growing field of computer science that allows users to interact with large sets of data more efficiently and creatively than traditional methods of visualization. Tiled display walls are large grids of traditional LCD or projector displays. For most applications, LCD display walls are the most cost effective solution and require the least maintenance.

Members of CoRE-NET were able to construct an adaptable, configurable display wall on a limited budget using open source software, including Ubuntu Linux and SAGE, and standard DELL desktop computers with LCD monitors. This display wall solution was called the High Yield Display-wall for Research Activity (HYDRA). A wall similar to HYDRA can be implemented at a cost of only .053 cents per pixel, as compared to .69 cents per pixel for a commercial display wall with comparable resolution.

HYDRA has been a successful demonstration of the CoRE-NET Computing Technology Farm project. The HYDRA project enabled a small group of undergraduate students to gain significant knowledge of a specialized area of computing technology and to gain hands-on experience in researching and implementing new computing technology.

The HYDRA implementation process has been documented concisely and in full detail, enabling others to implement a HYDRA display wall with only a limited amount of technical background.

Future plans for HYDRA include the creation of an installer and GUI utility to facilitate setup and use of the HYDRA display wall, as well as the application of HYDRA as a research and education tool. Future projects for HYDRA include using SAIL to develop applications that can be used as demonstrations in parallel computing and computer graphics classes and collaborating with researchers in physics, engineering, economics, data mining, and other fields to use HYDRA as a tool to visualize and understand research data.

References

[1] Navrátil, P., Westing, B., Johnson, G., Athalye, A., Carreno, J., Rojas, F.: A Practical Guide to Large Tiled Displays. ISVC '09 Proceedings of the 5th International Symposium on Advances in Visual Computing: Part II (2009)

[2] Visualization Clusters using Commodity Hardware. Dell Computers (2010)

[3] Jeong, B., Renambot, L., Jagodik, R., Singh, R., Aguilera, J., Johnson, A., Leigh, J.: High-Performance Dynamic Graphics Streaming for Scalable Adaptive Graphics Environment. SC 2006 Conference, Proceedings of the ACM/IEEE (2006)

[4] SAGE: http://www.sagecommons.org/ (2011)

[5] VisWall, Inc.: http://www.visbox.com/main.html (2010)

[6] Rajlich, Paul: miniWall. National Center for Super Computing Applications: http://archive.ncsa.illinois.edu/prajlich/miniWall/ (2003)

[7] Burris, Gavin: LionEyes Display Wall. Penn State: http://rcc.its.psu.edu/viz/facilities/displaywall/ (2007)

[8] High Resolution Tiled Display Walls. IEEE eScience 2010: http://vizwall.wordpress.com/2010/12/14/escience2010/ (2010)

[9] Pojector Lamp Life. Projector Lamp Source: http://www.projectorlampsource.com/projector_lamp_life.html (2011)

[10] Scientific Visualization. The Scientific Computing and Imaging Institute, University of Utah: http://www.sci.utah.edu/research/visualization.html (2010)

[11] NASA Goddard Space Flight Center, Scientific Visualization Studio: http://svs.gsfc.nasa.gov/projects/index.html (2007)

[12] Wallace, G., Anshus, O., Bi, P., Chen, H., Chen, Y., Clark, D., Cook, P., Finkelstein, A., Funkhouser, T., Gupta, A., Hibbs, M., Li, K., Liu, Z., Samanta, R., Sukthankar, R., Troyanskaya, O.: Tools and Applications for Large-Scale Display Walls. IEEE Computer Graphics and Applications (2005)

[13] Pieper, G., Leigh, J., Renambot, L., Verlo, A., Long, L., Brown, M., Sandin, D., Vishwanath, V., Kooima, R., Girado, J., Jeong, B., DeFanti, T., Liu, Q., Katz, M., Papadopoulos, P., Keefe, J., Hidley, G., Dawe, G., Kaufman, I., Glogowski, B., Doerr, K., et al: Visualizing Science: The OptiPuter Project. SciDAC Review, Issue 12 (2009)

[14] LambdaVision. Electronic Visualization Laboratory, University of Illinois-Chicago: http://www.evl.uic.edu/cavern/lambdavision/ (2005)

[15] Immersive Media Systems: Scalable Display Wall. Princeton University: http://www.cs.princeton.edu/omnimedia/index.html (2008)

[16] On the Same Page: Georgia Tech's CoVE Takes a Collaborative Approach to Design Analysis and Decision-making. Georgia Tech Research News: http://gtresearchnews.gatech.edu/georgia-tech-cove/

(2007)

[17] Renambot, L., Jeong, B., Jagodic, R., Johnson, A., Leigh, J., Aguilera, J.: Collaborative Visualization using High-Resolution Tiled Displays. CHI 06 Workshop on Information Visualization and Interaction Techniques for Collaboration Across Multiple Displays, Montreal, Canada (2006)

[18] DMX Homepage: http://dmx.sourceforge.net/ (2004)

[19] Main Page - OptiPortal:http://wiki.optiputer.net/ optiportal/index.php/Main_Page (2010)

[20] Chromium Homepage: http://chromium.sourceforge.net/ (2006)

Additional Figures

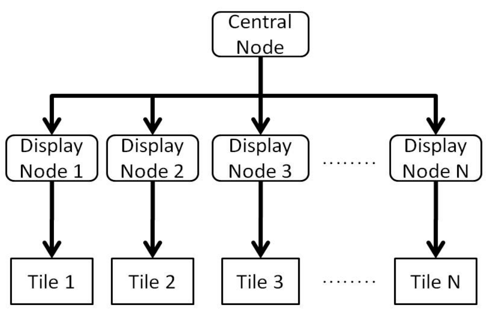


Figure 2. HYDRA architecture

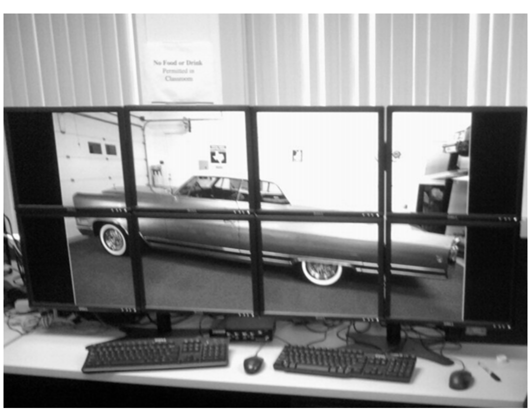


Figure 4. HYDRA functionalities

Conditional Indirect Effects of Corporate Social Responsibility Packaging Cues on Purchase Intentions

Scott D. Swain
College of Business Administration, Northeastern University, Boston, MA 02115, USA
s.swain@neu.edu
B. Andrew Cudmore
Nathan M. Bisk College of Business, Florida Institute of Technology, Melbourne, Florida 32901, USA
acudmore@fit.edu

Abstract

This research examines the complex interplay of corporate social responsibility (CSR) cues with consumers' brand attitudes and purchase intentions. Focusing on fair trade logos, we find that CSR cues can enhance purchase intentions but that this effect is mediated by brand attitudes. Drawing on cue utilization theory, we make the novel prediction that adding a second CSR cue (e.g., a charitable donation logo) to a fair trade logo disrupts the mediation process by pinning brand attitudes at a relatively high level, thereby minimizing variance in brand attitudes. This moderated mediation pattern of effects was observed even after controlling for differences in consumers' perceptions of the importance of CSR and differences in consumers' aesthetic evaluations of the logos. We discuss the implications of the research for the study of CSR as well as the management of CSR portfolios in a multiple-stakeholder context.

1. Introduction and background

More than 2 billion cups of coffee are consumed around the world each day, including over 400 million cups in the U.S. alone [1]. Fifty-six percent all American adults drink coffee daily and consumption among younger consumers continues to trend upward [1, 2]. This pattern represents an opportunity for firms to capture new customers and strengthen their relationship with existing customers.

But the coffee industry is highly competitive and consumers have more choices than ever before. In turn, producers have begun to explore newer, more sustainable bases for differentiating their products. One such basis is the adoption of fair trade practices and use of a fair trade logo on coffee packaging. Briefly, importers who participate in fair trade agree to buy coffee from farmers in developing countries on terms that are more favorable than commercial terms, and then market it in developed countries at a premium [3, 4]. To use the fair trade logo, importers must meet specific requirements such as buying only from certified small coffee farmers directly, offering long-term contracts, paying a premium price, and offering pre-financing. Coffee farmers must be small family farmers, organized into independent, democratic associations, and they must pursue specified environmental and ecological goals [5].

On the primary demand side of the equation, it is clear that some consumers will purchase fair trade coffee at a premium price [6, 7]. Thus, it is surprising that virtually no research to date has examined whether or how brand responses play a role in this behavior [8]. For marketers, the question of whether fair trade is a potential tool for brand differentiation or simply a cost-sharing effort between producers and consumers is critical – particularly in an increasingly competitive environment [9, 10].

We empirically address this issue by conducting an experiment in which we hold prices constant and orthogonally manipulate the presence or absence of a fair trade logo on coffee packages. Additionally, we examine two competing explanations for the effects of fair trade logos – consumers' general perceptions of the importance of companies' social responsibility and consumers' aesthetic appraisals of packages that carry a fair trade logo. Our basic thesis is that brand attitudes mediate the impact of fair trade logos on purchase intentions. That is, fair trade logos do not merely serve as reminders to consumers who want to "do their part" [11, 12, 13] or as visually pleasing badges but rather they serve as part of the value proposition and thus enhance perceptions of the brand itself [14, 15].

Going a step further, we also ask the question of whether the impact of fair trade logos on brand attitudes is impacted by the presence of other corporate social responsibility (CSR) cues [16]. In broad terms, CSR refers to the process of assessing the firm's impact on society and evaluating its responsibilities with respect to all stakeholders. CSR can be a powerful tool for building goodwill among consumers, shareholders, employees and the greater community [17, 18]. One way companies attempt to leverage their CSR platform is by promoting their CSR activities and associating CSR cues with selected brands. Unlike fair trade logos, CSR information or cues may only be loosely (or not at all) connected to the production or meaning of the brand. This often results in low consumer awareness [19] or, worse, skepticism or cynicism about the company's motives [20, 21, 22]. However, when consumers perceive a CSR activity as credible and desirable, they often form positive attitudes towards the company through a process of social identification (perceiving overlap between the company's values and their own values). This is an important outcome, as consumers who identify with a company tend to hold more favorable product attitudes and tend to be more loyal over time [23].

To better understand the possible interplay between fair trade logos and other CSR communications, we examine the common case where a producer places a logo on a package to indicate a sales-based charitable donation program. Consistent with prior research on consumer attitude formation, we propose that the presence of additional CSR initiatives undermines the mediation process that links fair trade logos to purchase intentions by serving as an alternative input to brand attitude. We elaborate on this effect in the development of the conceptual model.

2. Cue utilization theory

Consumers routinely face the need to evaluate the quality of one or more brands in the service of other decisions such as whether to buy, what to buy, or how many to buy. When information about intrinsic or integral product attributes is readily available and easy to evaluate, such information tends to dominate brand attitudes [24, 25]. However, brands are often difficult to evaluate because information about intrinsic attributes may be missing, unobservable, or difficult or impossible to evaluate. As a result consumers often face significant uncertainty regarding brands. Further, this uncertainty is frequently exacerbated by chronic or contextual deficits in consumers' motivation, opportunity, or ability to process information.

"Cue utilization theory" holds that consumers often cope with brand uncertainty by attending to extrinsic "cues" that are not integral to the product but that they believe are indicative of brand quality [26, 27, 28, 29, 30]. Prior research has uncovered a number of such cues, including "price" [e.g., 31], "brand name" [32], "store name" [33, 34], and "country of origin" [35]. Similarly, logos indicating that the brand practices Fair trade principles may serve as extrinsic cues to brand quality. That is, consumers may infer that companies that make good decisions in the value domain also tend to make good decisions in the brand domain [9]. Indeed, there is a close connection or "fit" between the concept of fair trade and the product category, thereby increasing the chances that consumers will utilize fair trade logo cues [20].

In the absence of similar cues, fair trade logos provide unique information about a brand. Thus, variance in brand attitudes that is due to fair trade logos is likely to contribute to the explained variance in purchase intentions. However, when fair trade logos are in the presence of other, similar cues they are likely to be jointly evaluated and thus subjected to consumers' rules for information integration. Prior research suggests that the most likely form of integration under these conditions is a linear averaging rule [26, 29]. Thus, we do not expect fair trade logos to impact brand attitudes when charity logos are present. This occurs not because fair trade logos become inert but rather charity logos are also capable of elevating brand attitudes. Extending this logic, if brand attitudes do, in fact, mediate the effects of fair trade logos on purchase intentions then the mediation effect should be reduced or eliminated when charity logos are present (versus absent). From an analytical perspective, the preceding conceptualization can be described as "moderated mediation" [36]. That is, we generally expect brand attitudes to mediate (explain) the effect of fair trade logos on purchase intentions – however, this mediation process is only expected when charity logos are absent. Accordingly, we offer the conceptual model in Figure 1. Next, we report the results of an empirical test of the model.

3. Study

3.1 Participants, design, and procedure

One hundred and seven coffee drinkers participated in the study. Of these, 52.3% are female and 86% consume 1-2 cups of coffee in a typical day. Participants' ages ranged from 18 to 67, with a mean of 25.1 years (standard deviation = 10.5). In terms of gross income, 60.7% indicated < $15,000/year, 11.2% indicated $15,000-$21,999, 10.3% indicted $22,000-$29,999, 7.5% indicated $30,000-$55,999, and 10.3% indicated $56,000 or more. Among participants reporting their ethnicity, 77% indicated Caucasian, 9% African American, 8% Hispanic, 1% Asian, 1% American Indian, and 4% Other.

Participants were randomly assigned to view one of four packages, each containing the same brand of ground coffee and each priced at $7.44. The price level was determined by the average of 284 actual local prices in the product category at the time of the study. When the fair trade logo was present the package indicated that fair trade refers to giving farmers in developing countries more money for their coffee beans. When the charity logo was present the package indicated that 3% of sales would be donated to charity.

The package stimuli were developed according to a 2 (fair trade logo: absent, present) × 2 (charity logo: absent, present) between-subjects balanced experimental design. Each package was depicted as a brown bag with the word "Coffee" printed on the front in the top-center location. Below the word Coffee was a graphic showing a world map with the continents made out of coffee beans. Below this graphic were two aquamarine squares placed side-by-side. In the "no logos" condition, the squares remained empty. In the "both logos" condition, the fair trade logo was placed in one square and the charity logo in the other (left-right orientation was rotated). In the fair trade logo only condition the logo was placed in one of the squares while the other square remained empty (left-right orientation of the logo was rotated). The same procedure was used when only the charity logo was shown. Participants then completed the dependent measures and were debriefed .

3.2 Measures

The key dependent variables were brand attitude and purchase intentions. Brand attitude was measured with three 7-point bipolar items. The question stem was "My attitude toward this coffee is___" and the anchors were negative / positive, bad / good, and unfavorable / favorable (Cronbach's α = .90). Purchase intention was measured using a 7-point bipolar item anchored with very unlikely / very likely.

As potential controls, we measured participants' perceptions of corporate social responsibility (7-point bipolar item: "I believe that corporate responsibility is_____ Not Important / Important") as well as their evaluations of the package design itself (three 7-point bipolar items anchored with unappealing / appealing, boring / exciting, unpleasant / pleasant). Cronbach's α for the package design evaluations was .81. We also included gender, age, income, and ethnicity as controls, as prior research suggests that these factors may be associated with differences in the level of support for specific CSR activities [37]. We excluded consumption level (cups consumed per day) due to low variance.

The success of the manipulations was checked by assessing how accurately participants recalled their exposure (or non-exposure) to the logos.

3.3. Manipulation and confound checks

Of the participants who were exposed to the fair trade logo, 86.5% correctly recalled the exposure. Similarly, 72.7% of the participants who were not exposed to the fair trade logo correctly indicated a lack of exposure. For the charity logo conditions, the corresponding accuracies were 94.2% and 74.1%. Z-tests confirmed that all accuracy percentages were significantly greater than the chance level of 50% ($p < .05$).

3.4. Results of moderated mediation analysis

Consistent with the analytical framework of [28], we empirically assessed our conceptual model relating fair trade logos to purchase intentions using three models: a direct effect model (see Table 1), a mediator variable model (see Table 2), and a dependent variable model (see Table 3). The use of fair trade and charity logos was dummy-coded (0 = logo/info absent, 1 = logo/info present). Gender was dummy-coded

(Male = 0, Female =1). Due to low cell counts, Income and Ethnicity were also dummy-coded (Incomes < \$15,000 = 0, otherwise = 1; Caucasian = 0, otherwise = 1).

Purchase intentions were greater when a fair trade logo was present (fair trade = 1) than when it was absent (fair trade = 0) even when controlling for the effects of CSR attitude, package evaluations, gender, age, income, and ethnicity ($\beta_{\text{fair trade}} = .71$, $t = 2.22$, $p = .028$). In order to understand how fair trade logos impact purchase intentions, we consider the conditional indirect effects tested by the mediation and dependent variable models.

In the mediator variable model (Table 2), the key result is that the interaction between fair trade and charity logos had a significant effect on brand attitudes ($\beta_{\text{fair trade} \times \text{charity}} = -1.25$, $t = -2.58$, $p = .011$). To interpret this effect, we plot the corresponding means in Figure 2 and observe that brand attitudes in the three logo-present conditions ($M_{\text{fair trade only}} = 5.16$, $M_{\text{charity only}} = 5.18$, $M_{\text{fair trade and charity}} = 5.12$) did not significantly differ from each other but were significantly greater than the no-logo condition ($M_{\text{no logo}} = 4.03$). Thus, the impact of fair trade logos on brand attitude depends on whether or not charity logo is present. When a charity logo is present, a fair trade logo neither enhances nor reduces brand attitude. When the charity logo is absent, fair trade logos significantly enhance brand attitude.

To assess whether the differential effects of fair trade logos on the brand attitudes account for the impact of fair trade logos on purchase intentions we turn to the dependent variable model (Table 3).

As shown in Table 3, in the presence of the proposed mediator (brand attitude), the interaction between fair trade and charity logos on purchase intentions becomes non-significant ($t = .73$, $p = .470$). Further, the effect of brand attitude on purchase intention is significant ($t = 5.96$, $p < .001$).

Using the approach advocated by Preacher, Rucker, and Hayes [36], we find that there is a significant conditional indirect effect of fair trade logos on purchase intentions when charity logos are absent (Indirect effect = .947, $Z = 2.93$, $p =.003$). However, when charity logos are present, the conditional indirect effect of fair trade logos on purchase intentions becomes non-significant (Indirect effect = -.054, $Z = -.26$, $p =.793$). Thus, the conceptual model (depicted in Figure 1) is fully supported. To assess the robustness of this conclusion, we conducted a bootstrap analysis (5000 samples) and found that the bias corrected 95% confidence intervals for the two conditional indirect effects did not overlap.

4. Discussion, limitations, future research

We found that fair trade logos enhance purchase intentions by enhancing brand attitudes. This effect was observed even after analytically controlling for differences in consumers' perceptions of the importance of CSR and differences in consumers' aesthetic evaluations of the logos. However, as predicted by cue utilization theory, this indirect (mediated) effect was conditional on the status of a charity logo: when the logo was absent, the mediation process was significant but when the logo was present, the mediation did not occur.

These findings hold important implications as companies increasingly deploy a portfolio of CSR activities in order to pursue value creation for multiple, and often diverse, stakeholders [38]. In particular, we find that a single CSR cue is as effective as multiple CSR cues and that using multiple CSR cues can make it difficult to parse the effects of CSR on branding. In the present research both CSR cues had positive implications for the brand. Prior research suggests that different patterns of effects can be expected when cues hold conflicting implications [26, 29]. Future research should examine more closely the broader issue of selecting a strategy for managing multiple CSR activities within an integrated marketing communication plan.

This research, like all research, is not without limitations. While the experimental stimuli were highly realistic, participants did not face a real purchase decision. Additionally, it is noteworthy that we intentionally left the name of the charity unspecified in the charity experimental conditions. While this provided some level of protection against a process in which participants simply retrieved prior, idiosyncratic attitudes rather than processing the experimental manipulations, it does raise the interesting question of how to study and perhaps model respondent heterogeneity in CSR communication studies. Finally, though the purpose of the research was to examine patterns of basic judgment processes, applied researchers may wish to assess the generalizability of the effects across product categories, populations, and contexts.

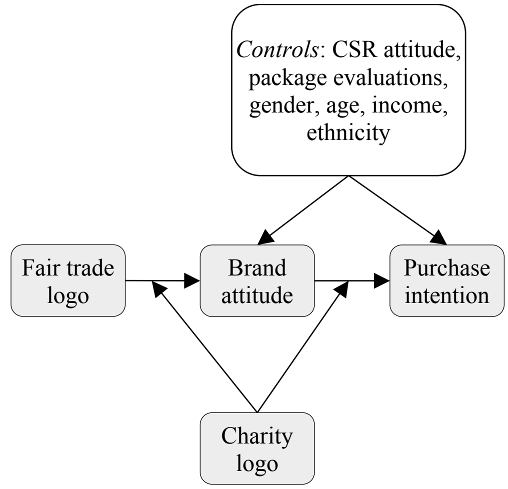


Figure 1. Conceptual model of conditional indirect effects of fair trade logos

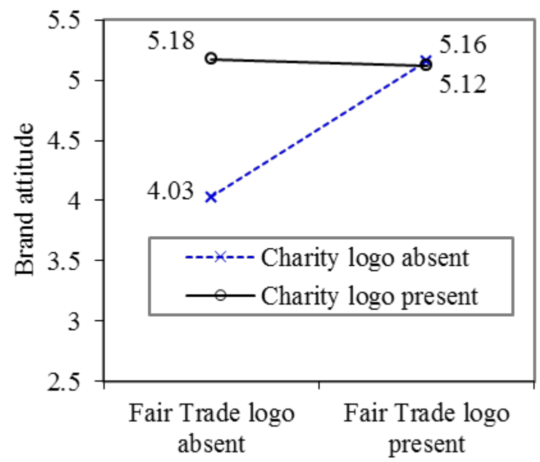


Figure 2. Interaction effect of fair trade and charity logos on brand attitude

Table 1. Direct effect of a fair trade logo on purchase intention

	Coef	*SE*	*t*	*P* >|*t*|
Constant	2.66	.70	3.78	< .001
Controls				
CSR attitude	.08	.11	.69	.489
Package evaluation	.23	.10	2.35	.021
Gender	-.35	.31	-1.11	.264
Age	-.01	.02	-.47	.642
Income	.44	.37	1.20	.235
Ethnicity	-.54	.37	-1.43	.156
Fair trade	**.71**	**.32**	**2.22**	**.028**

Table 2. Effect of fair trade logo on mediator (brand attitude) is moderated by charity logo

	Coef	*SE*	*t*	*P* >|*t*|
Constant	1.25	.59	2.12	.037
Controls				
CSR attitude	.17	.09	2.01	.048
Package evaluation	.33	.09	4.28	<.001
Gender	.26	.25	1.06	.290
Age	.01	.01	1.04	.301
Income	-.09	.29	-.31	.754
Ethnicity	-.09	.29	-.29	.770
Fair trade	1.14	.33	3.41	< .001
Charity	1.18	.33	3.55	< .001
Fair trade×Charity	**-1.25**	**.48**	**-2.58**	**.011**

Table 3. Direct effect of fair trade logo on purchase intention is eliminated when mediator (brand attitude) is included in model

	Coef	*SE*	*t*	*P* >|*t*|
Constant	.76	.75	1.01	.317
Controls				
CSR attitude	-.05	.09	-.50	.621
Package evaluation	-.00	.09	-.03	.977
Gender	-.39	.27	-1.47	.146
Age	-.02	.01	-1.03	.304
Income	.49	.31	1.58	.117
Ethnicity	-.49	.31	-1.58	.117
Fair trade	.09	.39	.24	.813
Charity	1.24	.92	1.34	.181
Fair trade×Charity	**.40**	**.55**	**.73**	**.470**
Brand attitude	**.83**	**.14**	**5.96**	**< .001**
Charity×Brand attitude	-.28	.19	-1.47	.144

5. References

[1] D. Bolton, "Coffee Industry Shifts under Tough Economy," Specialty Coffee Retailer, posted. 07/27/2009, http://www.specialty-coffee.com

[2] G. Dicum and N. Luttinger, "Fair to the Last Drop?," Boston Globe, (October 26, 2006).

[3] P. D. Pelsmacker, L. Driesen, and G. Rayp, "Do Consumers Care about Ethics? Willingness to Pay for Fair-Trade Coffee," The Journal of Consumer Affairs, 39, (2), (2005), pp. 363-385.

[4] K. Utting, "Assessing the Impact of Fair Trade Coffee: Towards an Integrative Framework," Journal of Business Ethics, 86, (2009), pp. 127-149.

[5] S. Lyon, "Fair Trade Coffee and Human Rights in Guatemala," Journal of Consumer Policy, 30 (3), (2007), pp. 241-261.

[6] M. Boström, "Regulatory Credibility and Authority through Inclusiveness: Standardization Organizations in Cases of Eco-Labeling, 13, (3), (May 2006), pp. 345-368.

[7] J. Sneddon, J. A. Lee, and G. N. Soutar, "An Exploration of Ethical Consumers' Response to 'Animal Friendly' Apparel Labeling," Journal of Research for Consumers, 18, (2010), pp. 1-5.

[8] C. Obermiller, C. Burke, E. Talbott, and G. P. Green "Taste Great or More Fulfilling: The Effect of Brand Reputation on Consumer Social Responsibility Advertising for Fair Trade Coffee," Corporate Reputation Review, 12, (2), (2009), pp. 159–176.

[9] S. Castaldo, F. Perrini, N. Misani, and A. Tencati, "The Missing Link between Corporate Social Responsibility and Consumer Trust: The Case of Fair Trade Products," Journal of Business Ethics, 84 (1) (2009), pp. 1-15.

[10] J. Hainmueller, M. J. Hiscox, and S. Sequeira, "Consumer Demand for the Fair Trade Label: Evidence from a Field Experiment," (working paper), pp. 1-43.

[11] R. Chomvilailuk, and K. Butcher, "Enhancing brand preference through corporate social responsibility initiatives in the Thai banking sector," Asia Pacific Journal of Marketing and Logistics, 22, (3), (2010), pp. 397-420.

[12] J. J. C. Hietbrink, G. Berens, and J. V. Rekom , "Corporate Social Responsibility in a Business Purchasing Context: The Role of CSR Type and Supplier Product Share Size, " Corporate Reputation Review, 13, (4), (2010), pp. 284-301.

[13] I. Castelló, and J. M. Lozano, "Searching for New Forms of Legitimacy Through Corporate Responsibility Rhetoric," Journal of Business Ethics, 100, (1), (2011), pp. 11-29.

[14] P. Jones, D. Comfort, and D. Hillier, "Marketing and corporate social responsibility within food stores," British Food Journal, 109, (8), (2007), pp. 582-595.

[15] X. Nan, and K. Heo, "Consumer responses to corporate social responsibility (CSR) initiatives," Journal of Advertising, 36, (2), (2007), pp. 63-74.

[16] Maignan, I. and Ferrell, O.C. , "Corporate social responsibility and marketing: an integrative framework," Journal of the Academy of Marketing Science, 32 (1),(2004), pp. 3-19.

[17] D. H. Dean, "Consumer Perceptions of Corporate Donations: Effects of Company Reputation for," Journal of Advertising, 32, (4), (Winter 2003/2004), pp. 91-103.

[18] J. L. Holcomb, R. S. Upchruch and F. Okumus, "Corporate Social Responsibility: What are Top Hotel Companies Reporting?," International Journal of Contemporary Hospitality Management, 19, (6), (2007), pp. 461-475.

[19] K. Fukukawa and Y. Teramoto, "Understanding Japanese CSR: The Reflections of Managers in the Field of Global Operations," Journal of Business Ethics, 85, (2009), pp. 133–146.

[20] K. L. Becker-Olsen, B. A. Cudmore and R. P. Hill, "The Impact of Perceived Corporate Social Responsibility on Consumer Behavior," Journal of Business Research, 59, (2006), pp. 46-53.

[21] P. S. Ellen, D. J. Webb, and L. A. Mohr, "Building Corporate Associations: Consumer Attributions for Corporate Socially Responsible Programs," Journal of the Academy of Marketing Science, 34, (2), (2006), pp. 147-158.

[22] S. O. Idowu, and I. Papasolomou, "Are the Corporate Social Responsibility Matters Based on Good Intentions or False Pretenses? An empirical study of the motivations behind the issuing of CSR reports by UK companies," Corporate Governance, 7, (2), (2007), pp. 136-149.

[23] C. B. Bhattacharya and S. Sen, "Consumer-Company Identification: A Framework for Understanding Consumers' Relationships with Companies," Journal of Marketing, 67, (April 2003), pp. 76-88.

[24] Purohit, Devavrat and Joydeep Srivastava, Effects of Manufacturer Reputation, Retailer Reputation, and Product Warranty on Consumer Judgments of Product Quality: A Cue Diagnosticity Framework, Journal of Consumer Psychology, 10 (3), (2001), pp. 123-134.

[25] Rao, Akshay R. and Kent B. Monroe, The Moderating Effect of Prior Knowledge on Cue Utilization in Product Evaluations, Journal of Consumer Research, 15 (September), (1988), pp. 253-264.

[26] C. M. Troutman and J. Shanteau, "Do Consumers Evaluate Products by Adding or Averaging Attribute Information?," Journal of

Consumer Research, 3, (September), (1976), pp. 101-106.

[27] P. Richardson and A. S. Dick and A. K. Jain, "Extrinsic Cue Effects on Perceptions of Store Brand Quality," Journal of Marketing, 58, (October 1994), pp. 28-36.

[28] P. Richardson, "Cue Effects on Evaluations of National and Private Label Brands," American Marketing Association Winter Educators Conference, AMA Chicago, (1994), pp. 165-171.

[29] A. Miyazaki, D. Grewal and R. Goldstein, "The Effect of Multiple Extrinsic Cues on Quality Perceptions: A Matter of Consistency," Journal of Consumer Research, 32, (1), (June 2005), pp. 146-153.

[30] D. F. Cox, "The Sorting Rule Model of the Consumer Product Evaluation Process," Risk Taking and Information Handling in Consumer Behavior, Ed. By D. F. Cox, Harvard University: Boston, (1967), pp. 324-369.

[31] B. P. Shapiro, "Price Reliance: Existence and Sources," Journal of Marketing Research, 10, (1973), pp. 286-294.

[32] J. C. Olson J. and Jacoby, "Cue Utilization in the Quality Perception Process," in M. Venkatesan (Ed.), Proceedings of the Third Annual Conference of the Association for Consumer Research, Association for Consumer Research, (1972), pp. 167-179.

[33] W. B. Dodds, "In Search of Value: How Price and Store Name Information Influence Buyers' Product Perceptions, Journal of Consumer Marketing, 28, (1991) pp. 307-319.

[34] W. B. Dodds, "Market Cues Effect on Consumers' Product Evaluations," Journal of Marketing Theory & Practice, 3, (1995), pp. 50-63.

[35] G. R. Elliot and R. C. Cameron, "Consumer Perception of Product Quality and the Country-of Origin Effect," Journal of International Marketing, 2, (2), (1994), pp. 49-62.

[36] K. J. Preacher, D. D. Rucker, and A. F. Hayes, "Assessing Moderated Mediation Hypotheses: Theory, Methods, and Prescriptions," Multivariate Behavioral Research, 42, (2007), pp. 185-227.

[37] P. Arlow, "Personal Characteristics in College Students' Evaluations of Business Ethics and Corporate Social Responsibility," Journal of Business Ethics, 10, (1991), pp. 63-69.

[38] D. Korschun, C.B. Bhattacharya, and S. D. Swain, When and How Does Corporate Social Responsibility Encourage Customer Orientation?," European School of Management and Technology, ESMT Working paper, (2011), #11-05.

A Novel Method to Determine Limb Length Discrepancy Using the F-Scan System

Ha Van Vo and R. Radharamanan
School of Engineering, Mercer University, Macon GA 31207, USA
vo_hv@mercer.edu,radharaman_r@mercer.edu

Abstract

The purpose of this study is to investigate the effects of Limb Length Discrepancy (LLD) on the human gait using F-Scan system (Tekscan Inc.). The F-Scan interprets the gait cycle by analyzing plantar pressure during normal ambulation. There are several factors that can be observed in ambulatory gait and plantar pressure analysis of bilateral feet that would indicate a difference in limb length between right and left legs of the candidates. There are three main factors that can be experimental: the discrepancy in acceleration between legs when comparing the duration of the swing phases of each leg; early reduction of heel pressure for the shorter limb; and increased metatarsal pressure concentrating in the metatarsal head of the shorter limb. For this study, one candidate was randomly selected and two trials were conducted. On the average, there are 15 lb-f difference in heel strike reaction force and 20 lb-f difference in toe-off reaction force of the two feet with the right leg is longer and experiences higher reaction load than the left. This data correlates with the 0.45 inches LLD in physical measurement by a physician.

1. Introduction

LLD is one of the major concerns in orthopedic biomechanics analysis and it is a required topic in teaching biomechanics at Mercer University. LLD is the difference between the upper and/or lower leg of the lower extremity. The prevalence of LLD is common and can be found in approximately 60 percent (less than or equal 2.0 cm LLD) of the population. As a result, the normal gait may be adversely affected, having the subject exert abnormal pressure and stance to accommodate the difference in weight balance between the two sides of the body. This compensation for the offset center of gravity experienced in individuals that have LLD may lead to poor biomechanics that can cause scoliosis and back pain. Measurable factors that signify LLD are time difference of heel lift increase in submetatarsal pressure of the shorter limb, and difference in acceleration between the two limbs [1].

The purpose of this study is to analyze F-Scan data to investigate the effects of the lower leg's limb length discrepancy on the human gait. The F-Scan interprets the gait cycle by analyzing plantar pressure during normal ambulation [2]. There are several factors that can be observed in plantar pressure gait analysis that would indicate a difference in limb length between right and left legs [3]. These factors include the discrepancy in acceleration between legs when comparing the duration of the swing phases of each leg, the early reduction of heel pressure for the shorter limb, the increased submetatarsal pressure on the shorter limb (especially noticeable below the 1st metatarsal head) [4]. Lower extremity limb length discrepancy is the difference between the upper and/or lower leg [5-6]. The LLD identification factors are the early heel lift, the increased acceleration, and the increased metatarsal pressure [7-8]. This paper investigates the correlation between varying limb lengths and includes the factors such as the time of early heel lift, increased acceleration, and average peak plantar pressure.

2. Materials and Methods

This study uses the F-Scan system made by Tekscan to analyze plantar pressure during ambulation. The sensor insert is first cut to fit the appropriate foot size of the subject. These inserts are then placed within the shoes of the subject and connected via wired cables to the computer. The sensors are calibrated prior to each trial in order to allow the raw data to be converted to pressure values that can be interpreted by the user. The information that is used to identify the subject includes: name, age, weight, and actual limb length. Figure 1 shows an image depicting the F-Scan sensor that is used for the experiment.

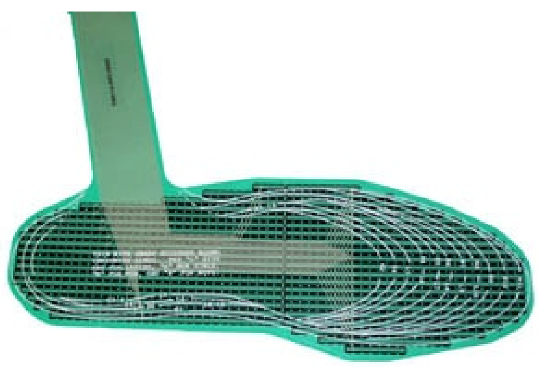


Figure 1. The F-scan sensor used to profile plantar pressure during ambulation [9-11]

The sensor pad that is used with the F-Scan system for the experiment consists of 960 sensors and responds to force application by a change in resistance [12-13]. The recordings for each trial were made by taking 400 frames per trial at a sampling frequency of 50 Hz. This corresponds to a total recording time of 8 seconds per trial. Each trial consisted of approximately 6-7 steps per leg. The data were isolated such that the beginning and the end of each recording was truncated from the results. Only the 2nd - 5th steps/stances were analyzed for statistical correlation due to their consistency since they were samples from the middle of the walk. The distance traveled by the subject during each gait analysis/recorded trial was approximately 20 feet. The trials were conducted along a straight path that is available in the Biomechanics/Gait Analysis laboratory. This path is shown in Figure 2.

Figure 2. Walkway used to conduct LLD trials in the Gait Analysis Lab at Mercer University

The experiment to analyze induced limb length discrepancy required that platforms of varying thicknesses be affixed to the bottom of the subject's shoes. In order to simulate the natural gait pattern of individuals with LLD, the choice of materials to use as a platform had to be relatively incompressible but pliable enough that the subject's act of gait propulsion is not hindered by the stiffness of the material. Therefore, incompressible foam and rubber were used to simulate LLD in 0.25 inch increments for each trial. The foam is 0.5 inch thick and is cut into three pieces that are the shape of the subject's shoe plantar profile. The rubber is 0.125 inch thick and is similarly cut to the shape of the subjects shoe plantar profile, however, only two pieces are cut and stacked to create the 0.25 inch increment. When taped to the shoe, the platforms cover the entire plantar aspect of the shoe. The configuration of the shoe with the height of the shoe adjusted to simulate LLD for 0.25 inch and 0.50 inch are shown in Figure 3.

Figure 3. 0.25 inch LLD (left) and 0.5 inch LLD (right)

The height of the shoe is adjusted using rubber and foam as depicted in Figure 3. All components used to simulate LLD are shown in Figure 4.

Figure 4. Shoe (left), 0.125 in rubber platform (center), 0.50 in foam platform (right).

In order to measure and differentiate between the normal versus the induced LLD gait, a subject was chosen and verified not to have a significant LLD (less than 0.125 inch). Prior to running the trials, the subject's limb length measurements were taken using a tape measure. The method for this measurement is palpation to find the anterior superior iliac spine and measuring from this point to the subject's medial mallaelus with the subject laying in supine in the neutral position. This measurement procedure is used to determine the total length of both limbs. The result is that the subject has a measured limb length of 33.5 inches on each limb and does not appear to have any limb length discrepancy.

The trials are executed to analyze induced LLD in increments of 0.25 inch, starting from 0 to a maximum of 1.5 inches discrepancy between the left and the right leg. The right leg of the subject is chosen to apply the induced LLD arbitrarily by the subject’s preference. All trials of induced LLD were conducted by varying the length of the right leg. A total of seven trials were conducted to observe the effects of induced LLD on the subject's gait. The first trial investigates the subject's normal gait and acts as the control for the following trials.

When all trials were completed, the data were statistically analyzed to determine the correlation coefficient in order to find the degree of correlation between each of the limb length factors and the change of length that was induced [14].

3. Results and Discussions

The peak pressure figure illustrates the 3 dimensional contour images that depict the level of pressure values recorded by the sensors across the plantar surface of the foot during a trial. The image represents the average values of the stances during the each gait trial recording (excluding the first and last stances for consistency). Observation from these images enables identification of the distribution of peak forces within the left and right foot.

Figure 5 displays the 2D view of the plantar pressure forces applied during the subject’s normal gait trial. The general regions are identified and the forces averaged over the stances. As expected, the normal gait's distribution of forces is reasonably symmetric between the left and right foot. It is interesting to note the additional peak force near the lateral calcaneous area. This could be due to the subject's unique anatomical deformity. Although the general regions and force structure can be shown, 2D contour graphs are not able to identify which regions have higher forces due to the limited levels of resolution (only 13 levels of pressure can be differentiated by color). Thus, a more detailed depiction can be observed from the 3D contour graphs of the plantar forces.

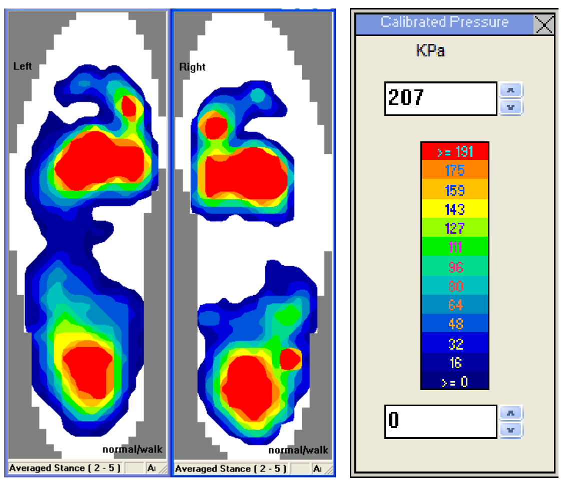


Figure 5. 2D Contour of Peak Pressure (Normal Gait)

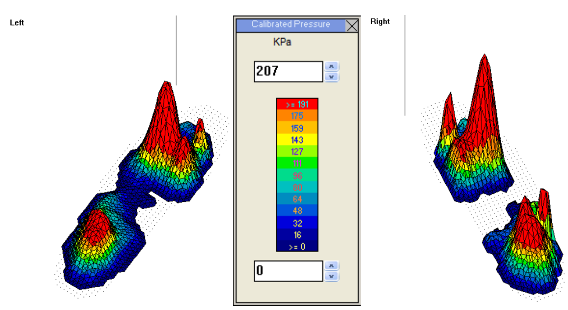


Figure 6. 3D Contour of Peak Pressure (Normal Gait)

Figure 6 displays 3D contour representation of the forces recorded during the subject's normal gait trial. It can be seen that the natural gait of the subject has highest peak forces near the lateral metatarsals, with overall higher peak forces in the right foot in comparison to the left foot. From this image, the three main regions of peak forces can be identified to which one can track for comparison, changes, and data correlation. The three main regions are: 1st Metatarsal, 2nd – 5th Metatarsal, and Calcaneous. Using F-Scan's "add-box" function of the 2D contour figures, the regional peak force was determined for each of the induced LLD trials (0, 0.25, 0.5, 1.0, 1.25, and 1.5 inch induced LLD). The next few graphs show correlation data between LLD lengths and regional peak forces. In addition, the linear regression lines were also included in order to show the linear correlated best fit line for each region.

From Figure 7, it can be seen that the left leg has a slight positive correlation between Calcaneous increase in pressure with respect to increase in LLD. However, there is a slight negative correlation between the metatarsal pressures with increase in LLD. Table 1 presents the correlation coefficient of these regression lines.

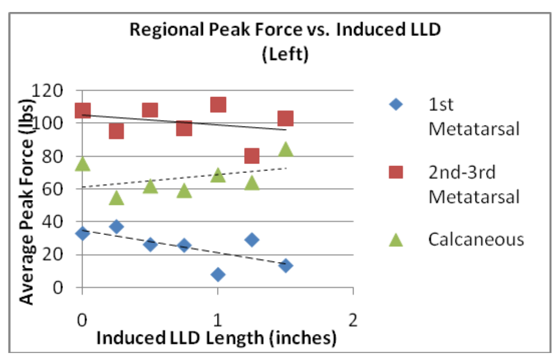


Figure 7. Regional peak force vs. induced LLD (Left)

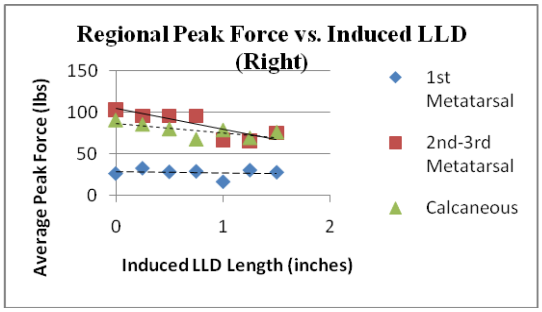


Figure 8. Regional peak force vs. induced LLD (Right)

Figure 8 shows a negative correlation between all three regions of the plantar surface with respect to an increase in LLD. However, the second and third metatarsal pressures show a stronger correlation coefficient of 0.85 (Table 1) to the change in length. The greater slope indicates a greater change in plantar pressure than the other two regions. The right leg in Table 1 is subjected to LLD while the left leg length remains constant.

Figure 9 shows the correlation between the regional peak force difference (right – left) and the induced LLD for the 1st metatarsal (positive: 0.865), 2nd-3rd metatarsal (negative: - 0.631), and Calcaneous (negative: - 0.828).

Table 1. Correlation Analysis of Regional Peak Force vs. Induced LLD

Left Leg Peak Force (lbs) Averaging Stance			
LLD (inches)	1st Metatarsal	2nd-3rd Metatarsal	Calcaneous
0	33.1	107.9	75.7
0.25	37.3	95.3	54.8
0.5	26.3	108.4	61.9
0.75	25.8	97.2	59.3
1	7.8	111.8	68.8
1.25	29.2	80.3	64.1
1.5	13.3	103.2	84.7
Mean	24.68571429	100.5857143	67.0428571
STDEV	10.55863447	10.78632291	10.2855655
Variance	111.4847619	116.3447619	105.792857
Cor. vs. LLD	**-0.68758632**	**-0.291116185**	**0.39380071**

Right Leg Peak Force (lbs) Averaging Stance			
LLD (inches)	1st Metatarsal	2nd-3rd Metatarsal	Calcaneous
0	26.4	103.4	90.5
0.25	32.8	95.7	85.3
0.5	28.5	95.8	79.7
0.75	29	96	67.2
1	16.6	67	78.5
1.25	30.5	65.3	69
1.5	28	75.2	75.9
Mean	27.4	85.48571429	78.0142857
STDEV	5.172684667	15.79645831	8.31392979
Variance	26.75666667	249.5280952	69.1214286
Cor. vs. LLD	**-0.17450795**	**-0.850812348**	**-0.7201131**

Difference (Right-Left)			
LLD (inches)	1st Metatarsal	2nd-3rd Metatarsal	Calcaneous
0	-6.7	-4.5	14.8
0.25	-4.5	0.4	30.5
0.5	2.2	-12.6	17.8
0.75	3.2	-1.2	7.9
1	8.8	-44.8	9.7
1.25	1.3	-15	4.9
1.5	14.7	-28	-8.8
Mean	2.714285714	-15.1	10.97142857
STDEV	7.346978647	16.33289115	12.12074177
Variance	53.97809524	266.7633333	146.912381
Correlation vs. LLD	**0.865294201**	**-0.63061393**	**-0.82812035**

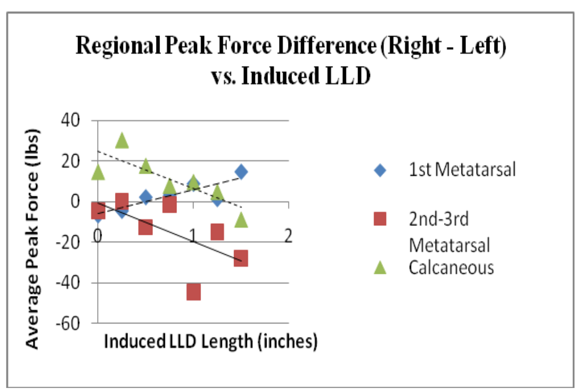


Figure 9. Regional peak force difference (Right - Left) vs. induced LLD

The Force vs. Time (Figure 10) plots the peak forces applied to the plantar surface versus time during the gait trial. From this graph, one can identify two factors that are commonly used to detect LLD. The first factor is an increase in shorter leg acceleration due to the subject's natural modification of posture and gait to compensate for the longer side. The shorter leg acceleration is represented by a shorter swing phase of the leg in the air during walking. Ideally, with no LLD, the swing phase time of each leg should be equal.

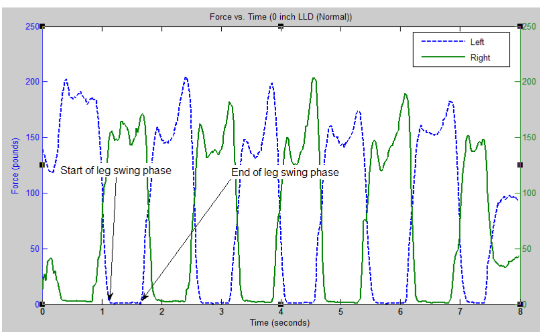


Figure 10. Force vs. Time (0 inch LLD (Normal))

Statistical analyses were performed to identify the correlation between the induce LLD trials to average swing phase of each leg, as well as to the difference between their lengths. As a result, there was no statistical significance between the induced LLD to the individual average swing phase. However, there was a statistical significance to the difference in time of the right leg's (induced LLD) swing phase compared to the left. This signifies a correlation between the difference in left and right leg swing phase duration with respect to induced LLD lengths (Table 2).

Figure 11 shows the correlation plot of differences in right and left leg swing phases for different lengths of LLD on the right leg. The leg swing phase of the middle three stances of each trial was averaged to obtain each data point. The linear regression line indicates that there is a slight positive correlation with the different in right leg over the left leg as the LLD length was increased. This indicates that as LLD is increased, so does the right leg's swing phase duration, and thus, indicating that it is the leg with slower acceleration.

Figures 12 through 18 illustrate the average stance effects due to increased LLD. As the length of the right limb increases, the expected result is an early heel lift and decrease in metatarsal pressure. Table 1 identifies some strong correlation factors that can be observed in LLD subjects. These factors include the decrease in shorter limb's 1st metatarsal pressure, increase in longer limb's 2nd-5th metatarsal pressures, and decrease in longer limb's calcaneous pressures. Figure 12 shows the results of averaging four of the middle stances during walking with the right leg unmodified. Figures 13 through 18 show the stances due to incremental changes in the right limb's length in order to simulate LLD.

Table 2. Correlation analysis of swing phase

LLD (inches)	Avg. Leg Swing Phase (Left)	Avg. Leg Swing Phase (Right)	Average Time Difference
0	0.615	0.5	-0.125
0.25	0.44	0.46	0.02
0.5	0.45	0.475	0.025
0.75	0.5	0.4	-0.035
1	0.44	0.5	0.045
1.25	0.48	0.42	-0.065
1.5	0.4	0.445	-0.05
Mean	0.475	0.4571429	-0.026429
STDEV	0.06946	0.0382815	0.0601882
Variance	0.004825	0.0014655	0.0036226
Correlation	-0.63865	0.2037014	0.151645

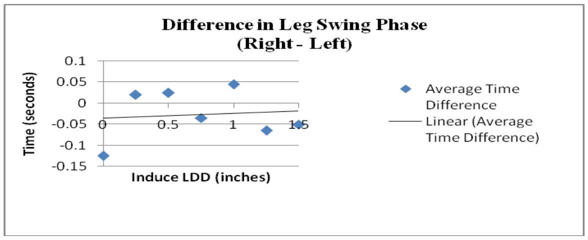


Figure 11. Difference in leg swing phase

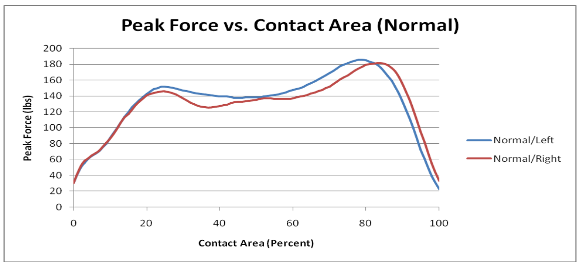


Figure 12. Peak force vs. contact area (Normal)

For the normal gait, it can be seen that the heel lift is approximately at the same time while metatarsal pressures are approximately equal. This is expected since the subject chosen has equal limb lengths.

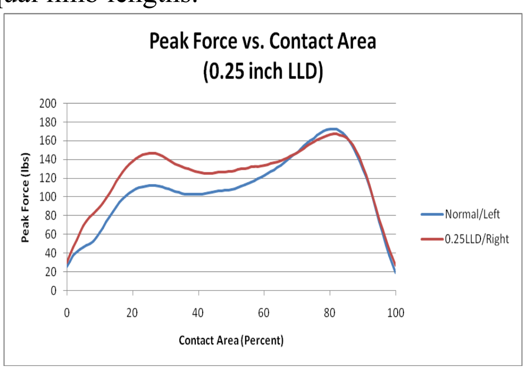


Figure 13. Peak force vs. contact area (0.25" LLD), decrease in calcaneous pressure of the shorter limb represented by the lower curve.

With an increased limb length of 0.25 inch to the right leg, the shorter limb's calcaneous pressures have started to decrease (Figure 13). This is consistent with the results presented in Table 1's correlation of a decrease in calcaneous pressures of the shorter limb with an increase in LLD.

Figures 14-18 show an increasing trend of early heel lift as LLD is increased. Additionally, the rise of the metatarsal pressures near 70 % signifies the drastic pressure increase in the 2nd-5th metatarsals. However, the main defining feature that can be determined is the early heel lift of the shorter limb caused by LLD, especially when compared to the longer limb.

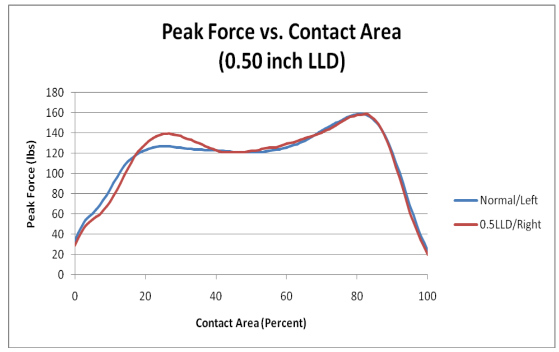


Figure 14. Peak force vs. contact area (0.5 inch LLD)

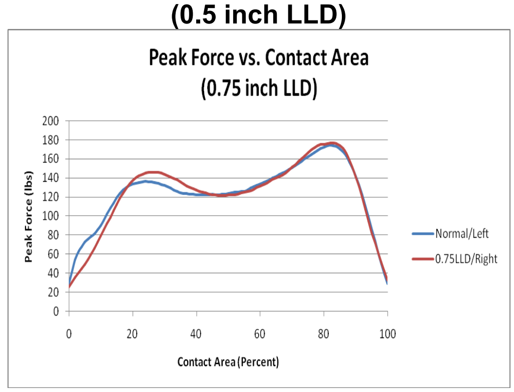


Figure 15. Peak force vs. contact area (0.75 inch LLD)

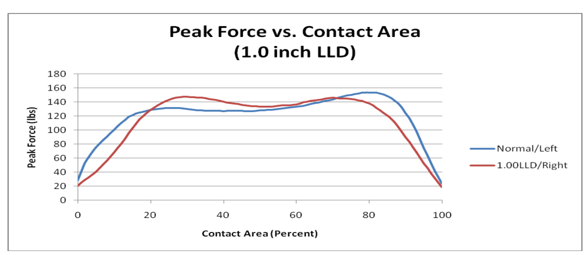


Figure 16. Peak force vs. contact area (1.0 inch LLD)

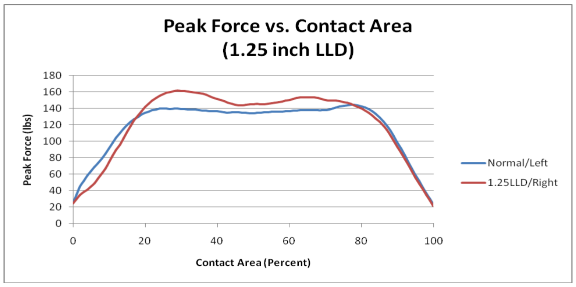


Figure 17. Peak force vs. contact area (1.25 inch LLD)

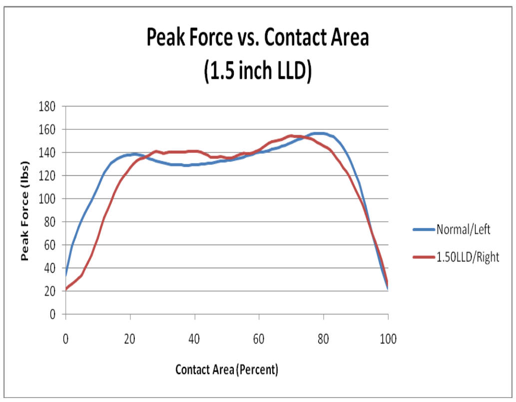


Figure 18. Peak force vs. contact area (1.5 inch LLD)

4. Future work

It would be instructional to repeat the experiment outlined in this paper with a greater number of trials to increase the confidence of the data collected. Conducting the same experiment on multiple individuals would also provide evidence of LLD factors correlation with change in limb length and may be used to model a given population's prevalence of LLD in quantifiable terms.

An additional test may be devised to take plantar pressure profiles in the same fashion as this experiment; however, instead of using a subject without LLD, conduct the experiment using a subject that has 1.50 inches LLD and adjust the length of the shorter limb in 0.25 inch increments until the two limbs are of even length. Such a test may quantitatively highlight the benefits of LLD correction when using shoe inserts or reveal deficiencies in this type of treatment.

5. Conclusions

Based on the experimentation and statistical analysis in this study, it has been shown that there is correlation between change in limb length with respect to increase in metatarsal pressures, early heel lift, and increased shorter limb acceleration (smaller swing phase for the shorter limb). In addition, it was found that there is a more significant correlation to decrease in the 1st metatarsal pressure of the shorter limb and a significant increase in the 2nd-5th metatarsal pressure in the longer limb when LLD is increased. Quantitative analysis of the plantar pressure with respect to LLD changes can prove to be valuable when considering and investigating relevant gait factors. Conducting statistical analysis can increase reliability and confidence of results gained through experimentation. This study can be further investigated in combination with the pressure plate analysis to determine the correlation between the limb length verse the plantar peak pressure of the patient on ambulation. The study would generalize more solid results and relationships between LLD and plantar pressures of the foot if more samples and testing trials are involved.

6. References

[1] Leg-Length Discrepancies: Diagnosis and Treatment by Séamus Kennedy, BEng (Mech), CPed., The O&P Edge 08, 2005.

[2] Tekscan, Inc. - F-Scan In-Shoe Pressure Measurement SystemThe Engineering Toolbar and DesignInfo are service marks of GlobalSpec, Inc. 1999-2011.

[3] Sabharwal, S., et al, "Computed Radiographic Measurement of Limb-Length Discrepancy", Investigation performed at the University of Medicine and Dentistry of New Jersey, New Jersey

Medical School, Newark, New Jersey, 2006 The Journal of Bone and Joint Surgery.

[4] Knutson, G. A., Anatomic and Functional Leg-Length Inequality: A Review and Recommendation for Clinical Decision-Making. Part II, the Functional or Unloaded Leg-Length Asymmetry, Journal of Chiropractic & Osteopathy, Vol. 13, July 2005.

[5] Fish, D. J., and Nielsen P. J., Clinical Assessment of The Human Gait, Journal of Orthotics & Prosthetics, Academy Bookstore 1993, Vol. 5, Num 5, pp. 39-48.

[6] Bogey, R., and Caillliet R., Gait Analysis, Web MD Professional, Medscape Oct 29, 2009.1993.

[7] Podiatry Arena, "General Biomechanics, Sports and Foot Orthoses", Leg Length Discrepancy: How Do You Measure Clinically? 2007.

[8] American Heeler, What is Limb Length Discrepancies? Shoe Modification, 2009.

[9] BTS Bioengineering Company, Pressure Analysis, F-scan, Nov 23, 2010.

[10] William, B. E., Detecting Limb Length Difference with Pressure Mapping, Tekscan 2011, Merrillville, IN

[11] Wheeless, C. R. III, Limb Length Inequalities & Growth Deformities. Wheeler Textbook of Orthopedic September 13, 2011.

[12] Caselli, M. A., and Rzonca, E. C., Detecting and Treating Leg length Discrepancies, Journal of Podiatry Today, Volume 15, Issue 12 pp 65-68, December 2002.

[13] Gurney, B., et al, Effects of Limb-Length Discrepancy on Gait Economy and Lower-Extremity Muscle Activity in Older Adults, The Journal of Bone & Joint Surgery, Volume 83, Issue 6, June 2011.

[14] Nolan, D., and Kennedy, N., Effects of Low-Dye Taping on Plantar Pressure Pre and Post Exercise: An Exploratory Study, BMC Musculoskeletal Disorders, 2009.

! " " # $ % &

! " # " "

$ % & " % & ' (% &

' $ ($$ $) ' ' !
* ' $ $ $ $ $! +) ! ! $ '
$! $!) $! ! $)) ! , $ $) (! ,
$)) $! ! $ $! -) ! '. $ ( )) ! $) ,
$ $! $ $ $!)! & ! / $ 0
$ $!) & $! -) ! '
. ! $ $ 1 $! $$ $! !)
! $ $)) ($! $ $ -) ! '. $ / $ ' $!
) & ! $)

! "

$ $ ') !
$ / $ ' ' $ $
$, ($ $! '
$! $ ($
$! $$ '
$ $ 2 3 $ & $
$ $ +) $ ($

!

$! $ $ $ $! ,
$ $) & ! $ $
! $ $! ! $!)
$ $ $) $! $ '
$ $ 0 $!
! ! $ $
$) $ ($! '
$ $ $! $)
($ $! ' ,
$ $!
$ $, ') $,
$! $) ' !
! ,) ! ( ) & $ (
($ ($$
$)) ( ) $
) $ $
($ $! ($

$ $ $ $ $ (
' $ $ $! $
$! ! $) $! 0
! ! $ $ $! $ $
! $ '
$!% $ $
$ ' ! $!
) ! ($!
($! $! $ ($
! $! $ $

! "

! , $ $ '
) $ $) $
+ ! $ '$ $ $
$) ! $ $
$!

$!! !
!) ($ $
) $$,243 $) $
, , !)
$! +) $
) !$) $$)) ! '
$ ( ) $
) 5) ! $$$!) & ! $
$ $$ (($
!) $! $) '!
(($ $ $!
$) $$ $ ' $'
) $$ $ ' ($
$) $!) & ! $ $
! $ $ $') & !
$ +) ! $
$ 6 7$ ' $! $) $
$ $! !' $!)' & !
) $$ $ ' $$ $
$ $) ,) $$($
+)) 5) ! $$ $
$) $$! $ '
$ $! $
$7 $ $!
! $ $ + $
( ) $$)) ! $$ $
($ ')) (
$ +! $ $7 ! $ $ $
(+! ! $ $! !
( ) $$ $(
) $ $!) & ! $ $ (
!!) $!) & !
) $ $ $ '
!!)) & ! ! $ $
,) $$))' $!
) & ! $! 8 $ '
* !, ' $ $ (,
) & ! 8 ') & !) $
' $ ' $)$ (
$ $) & ! ! (
$ $ $)$ $ $
) $$ ' $!) & ! $ $

+) $!! ! $!,
$! $

#!#

($ $!) $ $! $
($!
! $)9
+) $ *)
.
") !
") ! '
" !

$ $! $! $
$! ! $ $
$ $! !! $2:3+) $
*) $ ('$ '
$) $
+) $ *) $! (
$ *) 1$$,
$ ($
) ! 1$$!
$ *) !) $! !
! $ $ '* !, ' *)
$ $,))
) (
) ! $ *) $ $
) $$ $ $
$!
. $ $ ('$
$$ (! $ $!))
! ($ $
$ $! ! $! $ $
)) $ ((! $
$ $! $ ") '$
$) ($!
! $ $)
") ! $! $! !
$ $! $ ' '
!! ;$< $!) & ! $
" $!) & ! $! '
$) ! *) $) & ! $

$) ! ! $!) & ! $ (+) ! $!$!
$! $ $)) $! $ $ $ 2 > 3 $
/ $ $! $ $) $ $ $) $) $ $ (
! $ $ $ $ $!) & ! $ $ $
") ! ' $ ' $ " $$ ($ $ $) $
)) +) ") ! ' $ $ $ $ $$
(!) $ $ $ +) $ $ $ $ $) $
$! $ $)) $ ($! , $) $ $
) $! (' $ ' $! ‼
) $ $; $) $ $ $ + ! (!) $) $
$) ! $ $) !) < ! ! $! & $) ! $
(+) $$ $!) & ! $ $! $)) $
" ! $)) $) $ $!) ! ' '
$ $$! $ (' (' $ $
$! $ $)) + ' !
$ $ $!) & ! $ $) $ $! ' $ 1 $
! ! 8 ' $: ?
, $ $ % 0 $# + ! ' $)$ $ '
$! ') !) $! $ $!) $
$) ! & ! $ $ $. $! $)
$! $ $! $$! $ $ $! $ ' $ $
$ $! $! !) $ (, $! !) $
) & ! $ $ $ $, ($ $ $ ' (' $
$) + ! $ $) & ! $) $ + !
! $ $ $! 5 ! $) * $
!) $ ($! $ $! $) $ (
!) $ $ $ $!) $ $ " $ '
) = $ ($ $ $! ! $ (, $)
' ! $ $! (! $ $! ! $ $
$) $! ! $ $ $$! ') $ 0 !) $ $
$ 6 ($ $ ($)
$ $ $!
! $ $ $ $ $!
$ $ ($ $) $$!
$! . $ $ $ $! ! $ $) $ (' $
($!) $$! 2 3 $ $ $
$ $ (! * $ 1 $! $! $! $
! ! $ ') $$
! $ " ! $ $! $ 0 2 3
$!) $) $ @ $ $) ' $ $ '
$ $, $ $ *
$!) $) $ $ $ $ $ (

) $) !
! ' $) ! $ (
$ / $ $') !,
$! $
$! $ (!
($

%!&

$ / $ '1$) "! !
) $ '( )
$! ' $
$!) !)
$! !) $ $
' ! ! (!
$! '
% ($ ((!
-) ! '. ;- .<((
$$) $)) $
$$ $ ($ $
$ $
$!! ' - . ($!
(! $) & !
$ (($) $)!
$ $ $!
$) $ $ $
! $) - . $$
$ $ $$) $)$ $
$ / $ -) "! !
)) $ (
$ ' - . $) & !
$$) & ! $! $ * $$$
) ($ $ $ '
$) & ! $) ' (8
, ($ $! $ $
(($ - .
! $ - . ' +)
(! $
!) $! ! ! $($
! ' ($
! $$! ! $ $($) ,
! $ ($
$ $ $ '!

! $$! $ +)
') & ! $ ($! $
$!($ (!
! ((! (, $ '
! $ (( ) & ! $
! ')) $ $
' $ ($8
)) ! $$ ' $) '
$ 0 ( ) & ! $ (
/5-@ " ':
1$ $) $
) & !($$$) % (
$!) ! $
) $$ $ A$) & ! $
(!)$ ( )) $ $
$($! $ $ $
$! $! ($ $
$ $ $) & ! $ '! ! $
(,
%) & ! $) ! $!$ $
(($ $!) $
($$!
$ $ '(!)
$ A $($)
$ $ $, * $ %
* $ ($ $,) $(
$ $(($) $$ (
(((+) !
$ $ - .
$ $ $
-) ! ' . $
$ $! $
! $!) $! !
! ! 2B3 ') ' $, ! $
$ $) , $
! $$ $) $ $
$ $ $)$ $ '
, $!)$!
. $$ $, ! $
$ $ - . !) !
$ ( ) & ! $,
$ $. ! $ $ $

$ ( ) & ! $! ! $
$ ') $ $
$! $ $ $ - .
$ - . $) & ! * $
$ $ $, $ $
) & ! $ $ ' $
+) ! $ - . ($ $
$ + $ ' ! ( ) & !
($ - . $
$ $! $) $)
$ $ $
! $ $ $ $ $
- . $(($ $ $ ' (
) $ $ $ (((,
(' !) %
)+) ! $ $ $
- . $
$A C % $ ' $! $ 8
' $! % (,
) & ! $. !
) $ $) ' !
$ $ $ $ ($ $ $
(' ( ) $!)) ! $
! $) $ ((
! ! (
$ $ $ ($ (
! ! $ $
$! (
% $) ! $ $ $
(- . 1 $ ($ + !
, ($ $ ($ $ (,
) & ! $ $ (- .
' ! (
% $ $! (,) & !
' $ $ (
$ $ $ $ ' $ '
$ $$
$ ($ (,) & ! $
! !) $ $$) '
! $ $ $! $
(,)) & ! $! $ 5

! (') $ $) & ! $
% $ $ $ $
! $) & ! ' (, (,
- . ! $ $ (,
) & ! $ $ $
$) & ! $ ' '
' $ $! $
) & ! $! $! $
) & ! $) $
) & ! $ $) $ $ ' ! ! !
$ $! $ ')
$ ' !) !
+ $) & ! $) & ! $ $
) - . ($!)$ $
, ($! ! $
$! (, ! $
) & ! $ $ $ '
) $ $ $! $ $
' (& ' ($
! $ ( ) & ! $ $
$ $ $) & !
$! !
) & ! !) $ $ $,
) & ! $) $
($ ($ $
!)) & ! $
$) & ! $
$, $ $!) !
+ $) $ $!) $) ! ! $
) & !6 $ $ (
! ! ($ $)! ! ! $
$) & ! $) $ $
(') & ! !
$ $ $) & !
+ $) $ $! $ $
$!
$) & ! ($ * $ $
*) ($) $!)
$ $) (' D ! $
$ $! $!
) & ! $!)

$ $! $ $) !
$! $ $ $ $)
) ! (- . $ $ $
) $)$ ($ $!
) & ! $$ $ *) $
$)$ $! ! * (
7 $ $) $ $
! $ ('
$! 2 E 3
+ $) $ (,!
!) & ! $ $
) ' $!) & !
! , $! $ $!
))) $) & !) $ $
$ $ ')) !
$ $! ($$ $ $
(, (, , ! $ $
$! !) $ $ &
) ! $ $) ! $ $
) $ ' $ $! $ $ '
! $ $ $) " '
$ ($ $ $ '
$) !) $ $
") $ $
(,

) ! *

% ' $ $ (
$ (+) $
($ (, $
-) ! ' . (
)) $) & ! $ '
) ! $ / $ '

) !

!) ! $! ,
$! !) $! ! % $$
! !) (
$!) ! $ = $ (
! ($ $) & !
= ($!
)) ! $ $!) ! $

$ $ +) (
$! ($!
D (! $. ((,
) ' $! '
! $)
! ! $ = $ $ $! $
; <$ $(! $
$ $, $
$ $! $ $ (
$,= $) 5 !) $
$) (' ' ! 1 $
!) ! $ $ %$ $ $
($$ $) $! $ $ $
@ - = ($ $
) (, $! $ ') $
(! $
$ - $ ($! # ' !
! !))
) ! $ $! $ $ $
) & ! $ ' - . $
($ $) !)
!)

) ! # + , -

! $ $ + ' $
- . 1 $ $) $ ($ $)
) & != 1 $ ') ($
$ $, (
) $) & !(- .
) & ! ! $ & $ ' $
)) ! $ $ +
) & ! (6 F @
6 F @ 1 $6 F $) '(
@ $! ! $ < !) ($ $) '
$! '
$ 0) & ! G - $! '
$ $ ' $ $
) ! ! !
(, % $ $ '
$ 6 F @ 1 $) $
$ $ +) $

$$ $) ') !
$ $ (
! , = 6 F @ ($ $!
! $ 5 !$ $) ('
! ' ! ! $
! $ 6 F @ 8 !
! $ $) '
$ ($ $
! (' 5 ! $
" $ ( ) $
$ (6 F @ 1)$ ($
) 5 $!)) ! ' ! ' " =
; " !) =) ! $ <
" = $ $ ' $ $
($)) ! $)
! (, $ (A +) $
G - ($)) $# = $ $
($ $ 2 H 3
$(
( ) 5 $!
)) ! A $) $ (
! ($) ! %
) $ $ (!' + $
! * ! , +
!) (($ $,
! -))
!) $) 5 $!
$ (' $ $))
) ((!
! $ $)) ! !
$ (* $A $! $
(! $) ! ' $ $ ($)
$!)) ! ! $ $))
($ ($ $
) $ $ (((
(, 6 F @ ! $,
$ $! ($ $
' ! ! $ $ $ '
! $ $ '
) ' +) ! $ $
! $ ((! ($

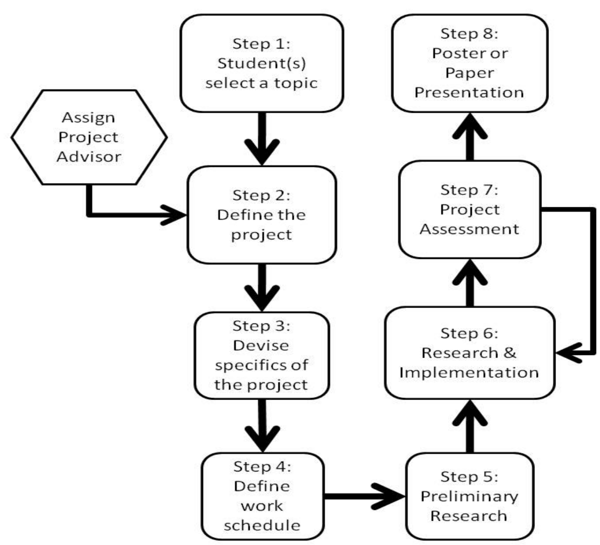
$ ') ! '
$ $! $

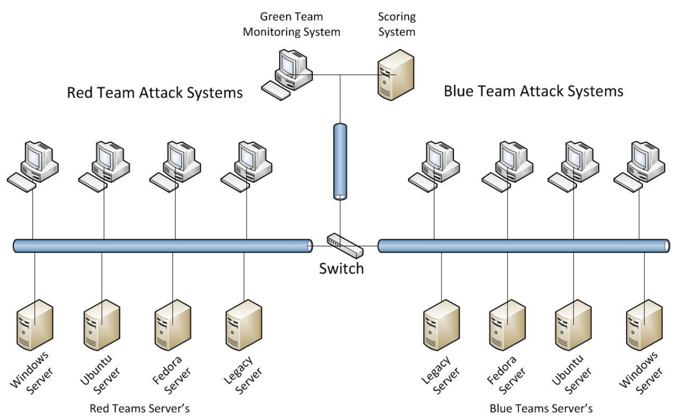
) ! $. / 0

- @ " - ' 5 $! @ $!
! " ' $ $) & ! ($
!) - . $) & !
$, $! $ ' - @ " $
$ $ $ +($ $
$! ! $) ' $ $'
$! ' ! * $! '
($ ' ! $!
((
($) $ $ (# - @ " 1 $
(, 0 $ **$** $ $! $
! $ (, ! ($ $ $
! $ $ $! $ $
- @ " ($ $ +) !
! , ,) ! $ +) ! '
$! $ $
! $)) $ $
' (,) ! ! ' $! '
$ &

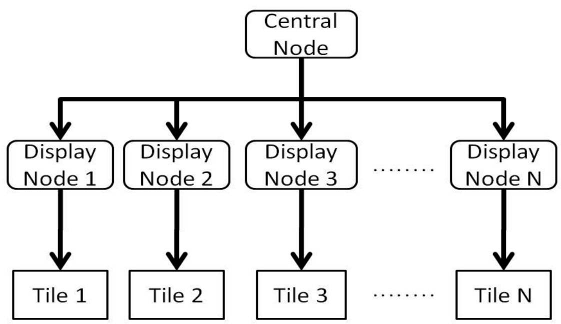
) ! % $

' : ; ' ! < $ $ (
$ $ $) :' $ $
$! $ $ ' : $ $!
! -) $) ' $ $
: ($! $ 7
) $) ! - $! $ >
$$) !
+) ! $ $ '
($ $ $: $ 0
) $ $
+))) ! ' : (
) ! ! $)
$ $ $ $(! $
! $ $ (


Assign Project Advisor
Step 1: Student(s) select a topic
Step 2: Define the project
Step 3: Devise specifics of the project
Step 4: Define work schedule
Step 5: Preliminary Research
Step 6: Research & Implementation
Step 7: Project Assessment
Step 8: Poster or Paper Presentation


Green Team
Monitoring System
Scoring
System
Red Team Attack Systems
Blue Team Attack Systems
Switch
Windows
Server
Ubuntu
Server
Fedora
Server
Legacy
Server
Red Teams Server's
Legacy
Server
Fedora
Server
Ubuntu
Server
Windows
Server
Blue Teams Server's

!


Central
Node
Display
Node 1
Display
Node 2
Display
Node 3
....
Display
Node N
Tile 1
Tile 2
Tile 3
....
Tile N

& # $ %

Strategic Pioneering Challenges of an E-Titan: Promise and Peril

James Yao and John Wang
MIS Department, Montclair State University, 1 Normal Avenue, Montclair, NJ 07043, USA
yaoj@mail.montclair.edu, j.john.wang@gmail.com
Jeffrey Hsu
Information Systems and Decision Sciences Department, Fairleigh Dickinson University, 285 Madison Avenue, Madison, NJ 07940, USA
jeff@fdu.edu

Abstract

eBay provides online marketplaces for the sale of goods and services, online payments, and online communication offerings. As the one of the top ten largest global online retailers, eBay's mission is to pioneer new communities around the world built on commerce, sustained by trust and inspired by opportunity. Its ability to maintain or enhance this position will depend on its ability to adapt to new technologies while facing increased competition and anticipating customers' needs. This paper will address its management's philosophies, the corporate business model, its challenges, network relationships, and its corporate growth to date, as well as future horizons. Particular focus is given to the role of acquisitions, particularly that of Skype, and also the role of trust.

1. Organization Background

1.1. History

The beginnings of eBay can be linked to its founder, who co-founded two previous firms, which were innovative online businesses, and later were bought out by Microsoft [9].

Subsequently, the founder brainstormed the idea of an online auction where people would be able to trade with each other. In 1995, he co-founded an online auction service with the concept of serving people on the Web, and his partner provided the business experience to turn the concept into a business [3]. The company incorporated in 1996, and with the rapid growth of the company recognized the need for additional capital in the spring of 1997.

During the 1990's, as a result of Silicon Valley's successes, there was a tremendous amount of venture capital available for internet start-ups. The online auction site's person-to-person online trading business was provided its initial funding of $5 million from a major venture capital firm, Benchmark Capital.

In September, 1997 the company formally adopted the name eBay, and began to post banner ads on selected sites and ad placement in certain publications. By year's end, eBay's revenues were over $300 million and boasted over 800,000 registered users [2].

1.2. Management

The search for a new chief executive in March, 1998 resulted in the recruitment of a new CEO for the firm. As the former General Manager of the $600 million Preschool Division of Hasbro, the CEO had strong "brand-building" experience [3].

Most of eBay's key executives who were first recruited came from the managerial ranks of traditional business: Hasbro; McKinsey & Company; Kenetech Corporation, Pepsi-Cola.

1.3. Going Public

During Fall 1998, there was eBay's Initial Public Offering. Despite the market jitters at the time, the firm's IPO resulted in the sale of over 4 million shares of stock for net proceeds of more than $65 million. During the first day of after-market trading, the price per share rose from $18 to $54 before settling back to close at $48. Nine months after the IPO, the share price reached $234. Clearly, the word was out that the firm had bright prospects for the future.

1.4. The Business Model

Mike Malone, editor of Forbes, believes that eBay's success is the result of two key decisions: (1) To let anybody sell anything and (2) To take a hands-off approach to user transactions [3]. This philosophy was motivated by the founders' instincts, and gave their business model infinite potential in terms of scale. The following sections examine their philosophy as it was applied to each of the business segments.

1.4.1. Marketplace: eBay calls itself "the world's personal trading community" [7]. The users of eBay grew from roughly two million users at the end of 1998 to more than 180 million through 2005, with online bidders forming goal-driven, experiential, focused, and opportunistic groups based on their bidding behaviors in C2C private value auctions [14]. eBay's marketplace rationalizes the sale and purchase of used goods [31]. Buyers enjoy a broad base of goods and services while sellers are rewarded with high conversion rates. With over 2 billion searches per month, the company offers selection, value, convenience and also entertainment for its buyers. Sellers are afforded the opportunity of maximizing sales and profits.

Placement and success fees are paid by the seller. eBay does not certify the sellers or the quality of their products - it operates on the principle of *caveat emptor* – or "let the buyer beware." However, in recognizing the critical importance of trust between buyer and seller, eBay developed marketplace services designed to increase the user's comfort level in dealing with relatively unknown partners in cyberspace. These services are discussed further in the "Trust Factor" section. Additionally, online classified sites which are associated with and owned by eBay enhanced the marketplace platform and helped situate eBay as the leader in C2C classified websites worldwide. They currently service over three hundred cities in over thirty countries.

1.4.2. Payments: In 2002, eBay acquired PayPal, Inc. in order to provide more satisfying online experiences by eliminating online payment obstacles such as lengthy processing times, inconvenience, and the costs and fees associated with traditional methods. Initially, PayPal offered its account-based system in close to 40 English speaking countries. Today, it is a global leader in online payment solutions in over 50 markets with at least 100 million total accounts, which include over 20 million business accounts and more than 70 million personal accounts with anticipated revenues for 2006 of over $200 million. .

1.4. Business Climate

Online sales for the third quarter of 2005 totaled over $40 billion, representing a 22% year-over-year increase [15]. Based on projected future sales growth, it was concluded that online sales will enjoy a 14% compound annual growth rate over the next five years, resulting in sales growth from $172 billion in 2005 to $239 billion in 2010 [16].

With the growth experienced to date and together with anticipated future growth, online buying and selling has become a highly competitive market. eBay has successfully captured 14% of that market in 2005. To remain competitive, eBay will need to expend resources in technology and marketing, which will be expensive and may reduce profit margins.

2. Setting the Stage

Initially, eBay developed and used proprietary software, which later evolved into a system capable of handling all aspects of the auction process. The system also managed various notifications for sellers and buyers, including daily status updates, bid and outbid notices, registration confirmations, account change notices, billing notices, and end-of-auction notices. User registration information, billing accounts, current item listings, and historical listings are maintained and archived for record-keeping and analysis purposes. A search engine regularly updates the titles and descriptions of items, as well as pricing and bidding activity [9]. The seller's billing account is updated every time an item is listed, a feature is selected, or an auction closes with a bid in excess of the seller-specified minimum bid.

According to Lin, Tanyavutti, and Jindrapacha [20], eBay's computer systems use of these cutting-edge technologies provide faster data transmission and the ability to handle larger volumes of business transactions which aided eBay to pave its way towards strong growth potential.

3. Case Description

3.1. Unparallel Success

Who would have thought that a small start-up auction company in the 1990's would have emerged to have a market capitalization of over $34 billion? In fact, eBay does not even hold any inventory or buy/sell any products directly [4]. This potential is amazing, if one is to capitalize on this concept and extend it to other areas of business [27]. eBay members use a rating system to post transactions in which this information is kept centralized, and further developments may result in a "peer to peer exchange" which is a decentralized environment in which trust management can be taken advantage of at its best [1, 23].

3.2 The Trust Factor

A big part of eBay's success has been built on trust. An important reason that trust is critical is due to the fact that those who transacting business do not know each other, however on eBay the emphasis is on an open environment in which everyone has something to contribute. With this mutual understanding, buyers and sellers alike are more trusting, and more inclined to do business with complete strangers that they have never dealt with before. The philosophy of eBay has ensured that these values are enforced by every buyer and seller, by allowing its users to leave feedback regarding transactions that have occurred. To make users more comfortable dealing with strangers, and to conduct transactions over the Internet, certain features have been put into place. A forum for feedback allows users to comment on other eBay users and set profiles with ratings. A seller's feedback ratings, reported by other eBay users, can have a measurable effect on his/her auction prices and volume of business [24]. There is also a "safe harbor" Program (3 Areas: Investigations, Fraud Prevention and Community Watch) in place that establishes guidelines for trading and ways to resolve disputes, and reports of misuse are responded to appropriately. A purchase protection program and also a buyer protection program have been added [30].

The Review of Economics and Statistics is a study that examined how important one's reputation was in selling and buying using an online auction. The results that supported the theory that reputation was very important in people's buying decisions. If the seller had only a few positive reports, the chances of a sale were increased greatly over those who had no reports or a negative report [21]. Negative feedback ratings have a much greater effect on diminishing sales than positive feedback ratings did on improving them [24]. Another study showed that "while impulsive buyers consistently pay high premiums, analytical buyers pay greatly different premiums depending on a sellers' reputation" [18]. Of course, there are those who will dispute the effectiveness of eBay's feedback forum, and those who will argue that honest repeated buyers and sellers will benefit as intended, but there is no legal framework of feedback intermediaries to resolve matters that involves fraud [29]. In short, it often comes down to whom you are buying it from which matters to the customer.

Although eBay lives and thrives by their culture of trust, buyers have found that there still is risk, and reasons to beware. Consumers should beware, and companies need to protect their image from those who are deceitful. The case of a major jewelry firm's experience with eBay involved listings that were not genuine. The solution which was tried was to block false listings, and one effort, and this effort, done over a 5 month period, resulted in a finding of 73% which were not genuine.

Is eBay legally and/or ethically responsible for the products traded through their site? The debate is an ongoing one. Legally, eBay has both won and lost lawsuits brought upon by companies and industries suing eBay for counterfeit products sold on its site. However, the sheer volume of products traded makes it difficult for eBay to monitor every product sold and police every infraction.

Patent infringement lawsuits also are likely to have an effect on trust. Recently this year, the Supreme Court ruled unanimously that the federal courts must consider other factors before making an automatic injunction against a patent infringer. The ruling was that traditional principles of equity should be taken into account. At the time, a U.S. District Court had almost forced eBay to shut down, however noted that a competitor would not be harmed if eBay continued to design around the patent in question. The fixed price buying option on their eBay's website was at stake, and these stem back to when the tiny company from Virginia, had won millions by suing eBay for previous infringement infractions [13].

3.3. Growth Check

A careful analysis provides some insight into why eBay has grown successfully. Over the past few years eBay has made dramatic moves into areas which are different from when they first began as an online auction market for collectibles [30]. They acquired PayPal in 2002, which put them in the online payment services category, competing effectively with credit card companies. In fact, many have predicted PayPal to be a key driver of future growth for eBay. eBay made acquisitions overseas to establish a presence outside the United States. In 2005, eBay acquired a major shopping site to gain a stake in the online shopping comparison service market. Their acquisition of Skype, the free voice-over-internet (VoIP) company, was noteworthy and controversial, but Google, Microsoft and Yahoo all have started to offer avenues of buyers and sellers to communicate with one another online [19].

eBay has also introduced a fixed price sales option, which allows for fixed price transactions instead of using an auction format. company, eBay also was accused of interfering with sellers, when they wanted to make price increases [30]. Changes to the rating systems for buyers, and also problems associated with the selling of bogus or counterfeit items, have also affected eBay's credibility and reputation. In general, it could be said that although investors and members may have widely diverging and conflicting viewpoints, their concerns should always be taken seriously.

Another area of expansion was eBay's position in China. There are more than 300 million middle class Chinese, which by itself is larger than the entire population of the United States

In 2003, eBay acquired a Chinese company with the intention of bringing their P2P swap meet to the Far East. By 2006, they had failed while their biggest competitor (a major Chinese online consumer trading site) was seeing record sales. Their competitor was a Chinese company with intimate knowledge of its customers, which led it to include a communication system unforeseen by eBay [8]. This Chinese firm also has an internal C2C network that allows users to see and search online users. The importance of these features should not be underestimated. In the Chinese context, it is critical that buyers be in a position to trust sellers before engaging in transactions.

Also, in line with [12], eBay has once before made a purchase of a large minority stake in an Asian company. It has a fifty percent stake in a Chinese mobile Internet company. This firm is very similar to Skype, the Internet voice communication that eBay bought back in 2005. eBay wants to eventually buy large enough of a stake to attempt to control as much as it could and potentially take over the firm. eBay has to watch how it goes about its acquisitions and related ventures because they have had some legal trouble concerning their way of going about each minority stake. Conflicts with a major classified ad listing firm, Craigslist, for example, took eBay to court and said eBay made a hostile bid to change their minority stake into a much more extensive acquisition.

3.4. The Hype about Skype

The acquisition of Skype by eBay was widely discussed and controversial, since there were debates and opinions given as to whether it was a wise acquisition. In short, the acquisition, announced in September 2005, had eBay acquiring Skype for the price of $2.6 billion, including the provision for an additional $1.5 billion earn out of profit targets were met in 2008 [33].

This came after a period of "hype" over rumors over which firm might acquire Skype, given the state of VoIP market penetration by Vonage [17a] and firms including Yahoo! And Google was mentioned as one of the possible interested parties. The preference of one of the founders, Niklas Zennestrom, for an acquisition where Skype could function as a stand-alone company was consider highly desirable [32].

There were a number of advantages for eBay to acquire Skype, as cited by the management of eBay. In general terms, aside from the goals of running two successful, yet separate businesses, there also were hopes for synergies that could benefit both firms. The benefits could include both positive volume and network effects. These included the development of a larger user base, the positive aspects of cross marketing, reducing "e-commerce friction," and also offering additional features, including "pay per call" and others [33].

Both eBay and Skype claim large user bases that have established them as the leaders in their respective business areas. One of the expected benefits of joining the firms was that the user bases of both could be shared or merged. This seemed like a good opportunity, since there was, before the acquisition, only a 1% overlap between the two user bases [33].

In terms of cross marketing, the goal was to help eBay gain access to the users which Skype had. This, coupled with the desire for eBay to expand into international markets, had made the Skype acquisition seem attractive. At the time, 87% of Skype's users were located outside of the United States. These all would help bring about cross-marketing opportunities for eBay [33].

Another goal would be to help reduce e-commerce friction. This can be generally described as the psychological resistance to a given element of your sales process that causes aggravation, fatigue or confusion. The main premise of this in relation to the eBay and Skype deal is the fact that having phone calling facilities over the Internet would assist in the auction process and provide a more seamless experience. Originally, for example, potential buyers of e-Bay needed to use the listings provided by the sellers and could use the text messaging feature in order to communicate with sellers. This worked sufficiently, but may be less desirable in the case of more complex and higher priced goods being sold. There was a desire to expand auctions in the areas of art and antiques, and perhaps to automobiles and other "high-end" products. Certainly a buyer may have questions and need clarification on the information provided. The availability of VoIP services seems like an ideal solution, and this could be integrated into the eBay site to provide easier access to sellers [33].

The third perceived benefit was in line with the second. It involved not only with the availability of calling features to eBay users, but also helped integrate a more direct link between buyer and seller (included the link between the two when using a search engine), whereby the buyer could click on a link to invoke a call from the seller, and using the "pay-per-call" model would be billed for the call to the potential buyer. As an intermediary, the seller would not have access to the buyer's phone number, which could help protect buyer privacy. The benefits of Skype's services could also be extended to classified advertising, sales lead and other applications, since eBay had invested in businesses including craigslist, rent.com, and shopping.com [33].

Also, more generally, there seemed to be a type of similarity in the development and growth of these two firms, which seemed to indicate some kinds of parallels in terms of development [10a]. Parallels were also drawn to eBay's acquisition of PayPal, and opinions were expressed about the synergistic effect of the payment processing approach as benefiting both parties; and in this case the positive effects of VoIP and communications serviced on eBay auction capabilities [11].

However, numerous options were voiced, both positive and negative, about the viability of this acquisition. Some expressed ideas that it would be a positive, citing the fact that it would be a worthwhile investment. Others articulated the opinion that Skype "lacked a sustainable advantage in communications" [10a]. Aside from eBay shares falling after the announcement, and concern over the perceived high price, there was a reaction that Skype's offerings were somewhat remote from the core business of auctions and that the fit was not that good [10a].

Part of the concern came from the perception that while PayPal came about from the needs of users in conducting and participating in auctions, Skype did not fit in the same way [10a]. eBay's acquisition of Skype was heralded by the company as being a smart acquisition that helped expand the capabilities of the auction company to other services, and also could help make for a better online auction experience. Unfortunately, things did not go as smoothly as expected for the marriage of the firms. In particular, the integration of the firm's technology offerings did not proceed as well as planned [10a].

By October 2007, an evaluation of the company showed that things perhaps were not as positive as originally hoped. The earn-outs turned out to be only a third of the maximum payout negotiated. Zennstrom announced his plans to leave the company. Despite integration of Skype into the eBay marketplace, eBay was scheduled to have its first unprofitable quarter in eight years [28a, 33]. As an eBay subsidiary, Skype's user base grew, especially with the various options and promotions including free SkypeOut calls for a limited time, video conferencing, many-to-many video calls, and features for SMS text messaging. A software worm a month previous to this showed the vulnerabilities inherent in the Skype system in terms of security. Offering other kinds of calling features and packages for businesses were also part of an approach to help improve revenue [28b, 33].

Problems occurred in terms of integration between eBay and Skype. Touted as the "Power of Three," it included integration of Skype both with Paypal, and the eBay Marketplace. Both of these efforts were delayed, starting with PayPal, and followed by a delayed integration with all aspects of the eBay marketplace. In the latter case, the resistance and lack of enthusiasm on the part of sellers to use voice features aided in slowing down the integration process. This was one reason for the diminishing enthusiasm and optimism for the Skype acquisition on the part of the eBay management [28b, 33].

By 2009, eBay finally announced that it was selling Skype for $2.75 billion to an investor group which included firms run by Marc Andressen and Joltid Ltd, started by one of Skype's founders [33]. Following sale, the original founders of Skype sued eBay over the rights to their original P2P technology, therefore splitting up the ownership of Skype between the investment group, eBay, and the founders [33]. In summary, while the acquisition was originally thought of as a "perfect fit" for eBay, numerous challenges and difficulties, in particular the less than well-received reaction from users, slowed and troubled the integration of Skype features into eBay's main businesses, especially its core auction business. The supposed good match in terms of capabilities and proposed visions for the future did not materialize, and both a lack of user acceptance and the uncertain results of blending businesses and technologies resulted in outcomes different from that expected and projected.

3.5. The Missing Link in the Value Chain

eBay and Google have worked very closely together over the years. However eBay is beginning to realize the potential of search engine giant Google as a serious threat. In fact, eBay was one of the first customers to have advertised on Google. Now, to combat this threat eBay had approached Yahoo! and Microsoft to form strategic alliances. A warning signal came when Google started a classified advertising service which was a direct competitor to eBay's online auctions. One way for eBay to work with Yahoo! and Microsoft would be to agree on exchanging and sharing access to data that had been collected on their consumers. Another way would be to share technical aspects of their systems to help promote their businesses jointly [10].

In value cluster analysis, activities are grouped together into a value cluster. For eBay these can include the auction database, monitoring the auction process, payment processing, and online community services. What is more to be considered are those activities of the traditional business model (shipments, payments, fraud protection, banking services, etc.). It is the network relationships which will link the two together. From a strategist's standpoint, eBay must understand their relationship between all the elements in this system to be able to understand how those activities will affect the system overall, and what the responses will be from other members. Therefore, eBay is "part of a competitive system that produces its own change" [4]. eBay and e-commerce have developed a kind of "value web" which has given a totally different approach from the traditional "value added" concept. eBay has taken cooperative advantage to a different level by building trust between the merchant and the customer in its virtual marketplace [5].

According to Guth & Mangalindan [10], eBay is in an interesting position in view of the fact that Google's search technology is a good fit in terms of compatibility with eBay. Majestic Research has estimated that eBay has almost doubled its volume of advertising on Google compared with other search engines simply because of the fact that Google is known to carry approximately triple the traffic compared with other search engines. A question to ask is if it is better to form closer ties with Google, which should help eBay's business in the short run or to reduce, or eliminate their ties with Google given that Google is likely to be one of the biggest threats to eBay in the future. Various offers have emerged from Yahoo!, Microsoft, and even Google to collaborate with eBay, beyond advertising. As a result of any arrangement, the company with the best offer may be able to post their clients' advertisements on eBay's auction pages. In return, whoever eBay accepts should also be able to run eBay's advertisements on their sites. This should enable eBay to evolve into one of the largest advertisers on the Web.

4. Challenges Facing eBay

In 1997, a director of Internet research for Donaldson, Lufkin & Jenrette, began following eBay when it was still a small private company, as he was impressed with eBay's business model. Though the company was small, it represented a great opportunity to combine the scalability of Amazon's model, the ability to grow revenues at a very rapid pace, and also enjoy profitability like that enjoyed by Yahoo! [3].

However, eBay developed strategies to help preserve and expand from its lofty beginnings. Outsourcing and partnering strategies focused on customer oriented issues and market opportunities; minimizing investments on fixed assets, and having a small and agile organizational structure [24]. Since its inception, eBay has had to deal with some serious systems challenges: scaling up to meet exploding demand, the need to upgrade based on technological advancements, and dealing with service outages. eBay needed to continually improve its systems to manage increasing levels of activity, and required new features and services [25]. As Min, Caltagirone, & Serpico [28] pointed out and supported by Kayhan, McCart, & Bhattacherjee [17], advancements in Internet technology are continuing to revolutionize today's business practices, and it has become increasingly apparent that the Internet has become an integral part of our daily lives and routine.

References

[1] Aberer, K., and Z. Despotovic, (2001). "Managing Trust in a Peer-2-Peer Information System", *Proceedings of the Tenth International Conference on Information and Knowledge Management (CIKM01)*, pp. 310-317. New York: ACM Press.

[2] Baltic, A.P. (2009). "Addressing the Technology Challenge", Public *Manager*, Vol. 38, No. 1, pp. 81-86.

[2a] Berr, J. (2005). "Big eBay users shun Skype," *The Street*, 10/25/05.

[3] Bunnell, D. (2001). *The eBay Phenomenon, 1st Ed*. New York: John Wiley & Sons, Inc.

[4] Cartwright, S., and R. Oliver, (2000). "Untangling the Value Web", *The Journal of Business Strategy,* Vol. 21, No. 1, pp. 22-27.

[4] Cartwright, S., and R. Oliver, (2000). "Untangling the Value Web", *The Journal of Business Strategy,* Vol. 21, No. 1, pp. 22-27.

[5] Cass, J. (2006). "What Culture Does A Company Need to Adapt to Use Cooperative Marketing Effectively?" *Backbone Media.* March 2. Retrieved Dec. 27, 2009, from http://blogsurvey.backbonemedia.com

[6] Claburn, T. (2006). "eBay's Growth Strategy; Community, Not Acquisitions", *Information Week*, No. 1094, pp. 26.

[7] Crowe, M. (1999, May 21). "eBay Inc.: Going, Going, Gone!", *The Business Journal,* Vol. 17, No. 4, B4.

[8] Davison, R.M. (2009). "Why eBay Lost in China: The Global Advantage", *Communications of the ACM,* Vol. 52, No. 1, pp. 145-148.

[9] eBay. (2005). *Annual Report to Shareholders,* Retrieved Dec. 27, 2009, from http://investor.eBay.com/annual.cfm

[10] Guth, R., and M. Mangalindan, (2006, April 21). "'Behemoths' Dance: eBay Talks to Microsoft, Yahoo about a Common Foe: Google", *The Wall Street Journal*, (eastern), A1.

[10a] Hagel, J. (2005). "eBay and Skype," *Edgeperspectives*, Sep 2009.

[11] Hof, R. (2005). "No Head-Scratching at eBay about Skype's Potential", Business Week Online, Retrieved Dec. 27, 2009, from http://www.businessweek.com

[12] Holahan, C. (2008). "eBay Steps up Asian Expansion", *Business Week*, Vol. 9, August 14.

[13] Holzer, J. (2006). "Supreme Court Buries Patent Trolls", *Forbes*, May 16, pp. 67-68.

[14] Hou, J., and C. Rego, (2007). "A Classification of Online Bidders in a Private Value Auction: Evidence from eBay", *International Journal of Electronic Marketing and Retailing Issue,* Vol. 1, No. 4, November, pp. 322-338.

[15] Johnson, C. (2005a). "Q3 2005 Online Sales: Weak, But Not a Trend for Q4", *Forrester Research*, Vol. 1, November 2, 2005.

[16] Johnson, C. (2005b). "US eCommerce: 2005 to 2010: A Five-Year Forecast and Analysis of US Online Retail Sales", *Forrester Research*, Vol. 1, September 14, 2005.

[17] Kayhan, V.O., J.A. McCart, and A. Bhattacherjee, (2009). "An Empirical Study of Cross-Listing in Online Auctions", *The Journal of Computer Information Systems*, Vol. 49, No. 3, pp. 76-80.

[17a] Kewney, G. (2005). "Who will buy Skype?" the Register, 08/08/05.

[18] Kim, Y. (2005). "The Effects of Buyer and Product Traits with Seller Reputation on Price Premiums in E-Auction", *The Journal of Computer Information Systems,* Vol. 46, No. 1, pp. 79-92.

[19] Lashinsky, A., and D. Roth, (2005). "The Net's New Odd Couple", *Fortune*, Vol. 152, No. 7, October 3.

[20] Lin, L.H., A. Tanyavutti, and S. Jindrapacha, (2007). "Analyzing eBay Platform Strategies: An Application of Meyer's Product Platform Strategy Model", *Management of Engineering and Technology*, August, pp. 125-142.

[21] Livingston, J. (2005). "How Valuable Is A Good Reputation? A Sample Selection Model of Internet Auctions", *The Review of Economics and Statistics,* Vol. 87, No. 3, pp. 453-465.

[23] Lo, A. (2009). "The Opportunities Brought to You by Distress", *MIT Sloan Management Review,* Vol. 50, No. 3, p. 53.

[24] Lucking-Reiley, D., D. Bryan, N. Prasad, and D. Reeves, (2007). "Pennies from eBay: The Determinants of Price in Online Auctions", *Journal*

*of Industrial Economics,*Vol. 55, No. 2, June, pp. 223-233.

[25] MacInnes, I., Y. Li, and W. Yurcik, (2005). “Reputation and Dispute in eBay Transactions”, *International Journal of Electronic Commerce,* Vol. 10, No. 1, pp. 27-54.

[26] Mangalindan, M. (2005). “eBay Aims Two New Services at Merchants Looking Elsewhere”, *Wall Street Journal* (Eastern Edition), June 24, B.3.

[27] Marketing Science Institute. (2006). “Featured Academic of John D. C. Little”, Retrieved Dec. 27, 2009, from http://www.msi.org/

[28] Min, H., J. Caltagirone, and A. Serpico, (2008). “Life after a Dot-Com Bubble”, *International Journal of Information Technology and Management,* Vol. 7, No. 1, pp. 21-35.

[28a] Musich, P. (2007). “Skype co-founder Zennestrom bows out,” eweek, 11/15/07.

[28b] Reardon, M. (2007). “eBay: what to do with Skype?,” *CNET*, 10/30/2007.

[29] Rietjens, B. (2006). “Trust and Reputation on Ebay: Towards a Legal Framework for Feedback Intermediaries”, *Information & Communications Technology Law,* Vol. 15, No. 1, p. 56.

[30] Savitz, E. (2005). “Time to Bid on: eBay”, *Barron's,* Vol. 85, No. 23, June 6, pp. 25-27.

[31] Sinclair, J. T. (2007). *eBay the Smart Way: Selling, Buying, and Profiting on The Web's #1 Auction Site*. New York: Amacom.

[32] Steinberg. D.H. (2006). Web 2.0- after dinner with Niklas Zennestrom, *O'Reilly Network*, 12/13.

[33] Vitzthum, S and B. Konsynski. (2009). “eBay's Acquisition of Skype SA: Valuing the Voice of the Buyer, *Communications of the AIS*, 24, 6, 89-104.

! "# $

! "
$ % & & % # $ % &

% & % & & & $ &(') % * &)
)) +,) &)) &) - &
& . - / - &))) . - / & * 0) & $ 1
& * * &) & 2 & &
-)) $))) & 0 &) &) $
%)) $ (0 - 0 $ & * & & 3 0
&

& % * &
& * % &4
) & %$ & 5 ,
&) $& 0 & +,) &
) &) 76 8 9
-) & %*) %
% &) % , &
* " 7 : 9
3 $ & * %
$ &) % & &
&) & &
% % & &)
% % & &
% 0&) &
* % & &)
* 2) &
*) ;
0 & '
,) ( ) *
% &)
&)) &) & &) &
& % ,) &

$ 1 & % &) 0
1 & * & $ 3
3 & +))
* 0 & % 0
) % & &
& & &))) & 8
) & 0 0 & *
0 3 +*
; &) & % %
& $ 0 $
& & ' < &

! "

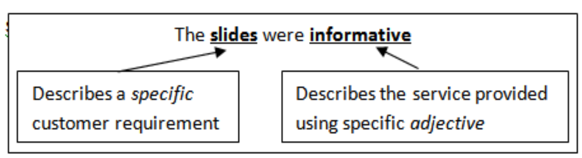
% 5 & *)
) &))
)) & $
& 3 76 9 %) &
& & $ 1 & %
))
& * & $ = ' >
7 ? 95 4 ' 0 $
% * % * % & 6
(& * %

% & % & &) &
%) % * & &)# & && $
& ; 8 - 2 & $ ')
. - 2 / % 4 0 & &) $) & &)
- 2 % 0))
% 7 9 &
% $ & $ %) &))
& & $) &)) '
& & - $ & +) 7 @ 9) $)
) @ A @ & &) $ & &))) &)
$ & & 7 9) % % &
. D / * %)
& & & & * 0 $, & ,
&$ B 7 A 9 & $ 0 &
) & & &) &) & &) $
0) %) & ,
& * & & 0 @ 0) &
& & $ & ,) &) $ @ 0 B
$) & & & $ % & & % . / , $ $
$ %) & &1 & % & $ & %
7 9) & & & & & ,)
& 3$ D 0 & &
& ') &$ 0
& $ $ 0
& 3 $ (') & ' & $
) * &) & * &)) $) 0
) & %$ & C & & $ 0
7 9)) 1 $) &
&) % * & & $)) $
*) @ & & %& 7 9
& & & $ & 3) % % $ & $
) &) & &) , & &)))
@& & & * $ % & & $
$ & '
* & $
&) % & * + $
& * & $ %
& &))) . - / & * & % & & " 7 8 9
3* %,) % & - & * & & 3
)) % 3 % $+1 & %) $
) & ' & 7 9 & $) $) &
-) & 0 & % % %) $ % 0 &
% %& & % & & $

- What did you like most about the presentation?
- What did you like least about the presentation?
- In what ways would you like the presentation to be improved?

The slides were informative but the design of the slides was distracting.

- The slides were informative
- The design of the slides was distracting



& $ &
0 B

Critical Incidents
The slides were informative
The slides were explanatory
The slides had appealing colors.

→

Satisfaction Item
The slides were well prepared.

& 0 $
8 & $) &
& 0 B <

Satisfaction Items
- The slides were well prepared
- The slides were too crowded
- There was no connection between slides
- The slides were informative

→

Student Requirement
Organization and Content of Slides

! "
" #

% * 0 $
* & & &
& % &) %
*

$ % & "

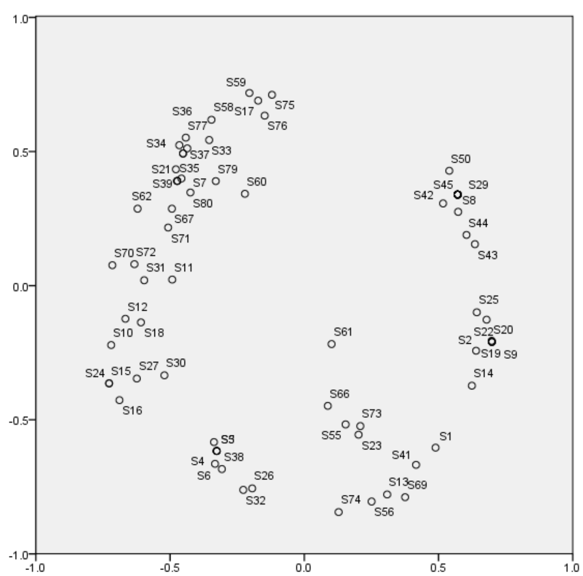
S.no	Student's Requirements
1	Organization and Content of Slides
2	Use of Figures and Graphics
3	Use of Examples
4	Clarity of Speech
5	Ability to Finish on Time
6	Ability to Answer Questions
7	Team Cooperation

%
B 0 % ;)) &
& $ &' & 7 9
A 0
) $) & & &) &
,)
0 B ?

(19) Graphs and charts were appealing to the audiences
(7) There was no clarity in speech
(5) Presenters were able to answer all questions

' &( )

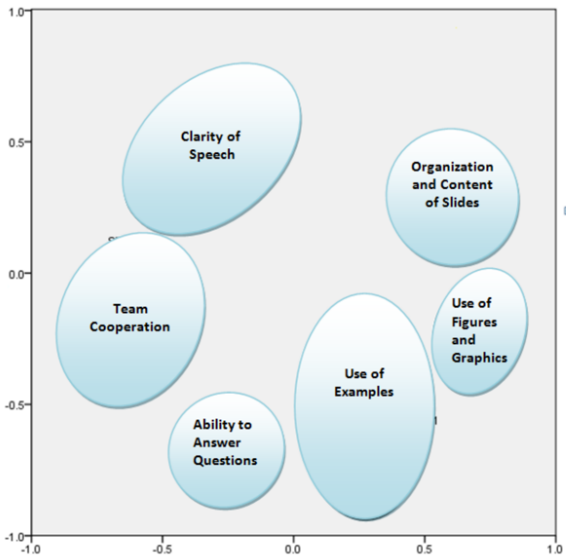
0 $ 0)
&
& %) &) &
0 %) &' 0 &' A
& 0 &
))) $
&) 0 % $
, & & $
0 & $,
0 &0 3)
& G : 7 < 9 D
0) 0 B :
0 &))
)) & & &
& $)
)



* & $ +

,
))) $
&)
& & % 0
3 G :

, & 0 $ $
& & 0
, % $ $ &
B A 0) &
) &)
D



- &

& '

1 & 0
& &)) &) 0
0) % 0
E + E $ + $,)
) &
&&) , 0 %
0 0 &
& &) $
0) *
$ &
$ & &
&)) & %
%
$ &)
< & & & 0))
A & &))) -
& & % %

) &) &)
) 0 &)
(- 0 &
% %) &)
$ &
&) 3
& $+ C 0 % $
& $
& & $
$ % 3 $
&)))
, & % $
, $ 3 &)
0 & & &
3 ,) &
& &))) & 0 -
& &
* 0 -) % &
& & $
*) & %
) * 0))
) - %
* 0 - ,
* ,
% * $
5 $ B 6 $ 0
& 0 & $
E -) + E (3
+ B A $,) $
& $ 0 *

(
-) -
' ' 0
& * 0
) $)
& & -)) $)))
& 0 &) &)
$ %))
$ (0 - 0 $ & *
& &) & 0 &

0) $ &
) & & %* C '
$ & &)
) $) &)))
&) 1
& +) &
, * D
& * %& *
$1 & %
& & $ 3
))) 0 &
&

)

7 9 ! C 5 &
& % &
6 0 ' # & H
4- 4 G :
7 9 C I 0 5 * %) &
& % G6 G & :<
A)) <?8;<:<
7 8 9 D " 5)) & &
& & H
& * 6 &
? :.?/)) ; <A
7 9 D = & - I ' 5 & &
& & * % & & 6
% 2& & @@ :. /)) ?<;A
7<9! G & @G & @@A
)HJJ000) & J 0 J & J
7?9= '> 52 $ %
* % &!6% C - H
A?

7:9 ! " 5 *K
& $ '6 .< / &" 0;
C H

7A9 - B 5 - & &
& * G6 & !& < < . /
)) 8 :L<A
7 9= &' # & 5- &)
)) %)) &
) ; % * 6
(3 2 & @@<))
8@:L88?
7 @9 - $ & 5- &)
& 6G & '<
?.8/)) :;88
7 92 G 5 ;
- $ & M &) 6
- 2 & . /)) 8A ;8
7 92 = 5( )
) % 6)) &
@@? 88. /)) @<; <
7 89 N G > I I
! 5D % 4 % & H &
- ,) & G &) 60
O 'H B G @