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Predicting Corrugated Box Compression Strength Using an Artificial Neural Network

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Abstract McKee formula has been widely used to predict the compression strength of corrugated boxes. An experimental verification, published in early 2015, showed the inaccuracy of the formula. McKee formula left out several important factors, including box height, temperature, and humidity. An artificial neural network, CBU-BOX1, was developed based on 74 cases of cubical RSC single-wall corrugated boxes from 3"x3"x3" to 36"x36"x36". Box height, temperature and humidity data were included in the network development. CBU-BOX1 performance ranged from 0% to 26.3% error with an average error of 6.9% while McKee formula performance ranged from 0.6% to 149.3% error with an average error of 28.7%. However, CBU-BOX1 performance dropped significantly when it was used for rectangular boxes. Out from twelve test cases of rectangular boxes, the formula resulted in an average error of 25.7% while CBU-BOX1 resulted in 34.8%. Thus, the network is unacceptable for rectangular boxes. In this study, 67 more cases were added to the previous 74 cases. Out of 141 cases, 43 were rectangular boxes. CBU-BOX2 significantly outperformed McKee formula with an average error of 9.21% versus 30.79%.

Keywords *Artificial Neural Network; Compression Strength; McKee Formula; Corrugated Boxes*

1. Introduction

McKee formula has been widely used to predict the compression strength of corrugated boxes. An experimental verification [1] showed the inaccuracy of the formula, which left out several important factors, including box height, temperature, and humidity.

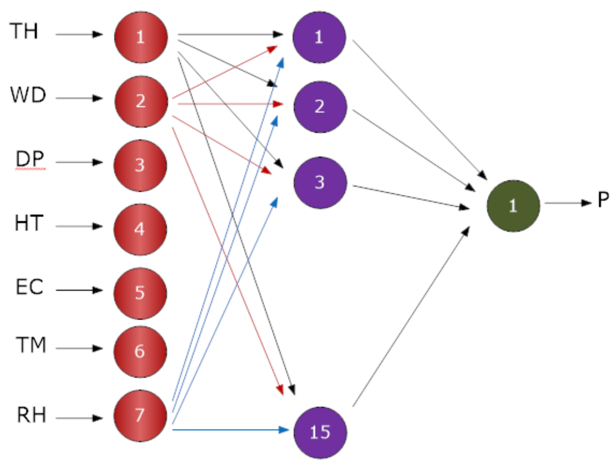
An artificial neural network is software capable of learning from examples. It has been successfully used in transport packaging [2]. The first version of the box compression strength neural network [3], CBU-BOX1, was developed based on data of 74 cases of cubical RSC single-wall corrugated boxes. This neural network outperformed McKee formula with an error range of 0% - 26.3% versus 0.6% - 149.3% with an average error of 6.9% versus 28.7%. However, when CBU-BOX1 was applied to rectangular boxes, its performance was worse than that of McKee formula [4].

In this study additional cubical and rectangular boxes at different temperature and humidity were added. The second version of box compression strength neural network, CBU-BOX2, was developed.

2. Materials and Methods

Twenty-four cubical boxes were added to the previous 74 cases, which gave a total of 98 cubical boxes. Forty-three rectangular boxes were also added. Thus, a total of 141 cases of RSC single-wall corrugated boxes were included in this study. An ECT test was performed for each box compressed. Some boxes were placed in a temperature/humidity chamber at different combinations of temperature and humidity, while some boxes were placed at room condition, which was about the standard test environment of 73°F and 50% RH. Box dimensions (width/depth/height) ranged from 3” to 36” with a temperature range from 66°F to 104°F, and a humidity range from 48% to 80%.

A feed-forward fully- connected Backpropagation neural network shown in Figure 1 was used. The numbers of input and out neurons were controlled by the collected data, i.e., seven input parameters and one output parameter. The number of hidden neurons was arbitrary and was chosen as 15 in this work. Other training parameters were shown in Figure 2. The sigmoid function, $y = \frac{1}{1+e^{-x}}$, was used to generate an output (y) of each hidden and output cell from a weighted sum of connection weight and input vectors (x). NeuroShell2 [5] was used to train CBU-BOX2 neural network. Figure 3 shows some features of NeuroShell2 software. Once training reached a satisfactory performance, a generic source code was generated for software application development in any programming language. Fourteen samples out of 141 cases of training data are shown in Table 1. In the “Mark” column, “T” was used for 114 training cases and “V” for validation for 27 cases.



Input	Output
Wall Thickness (in) - TH Box Width (in) – WD Box Depth (in) – DP Box Height (in) – HT ECT (lb/in) – EC Temperature (°F) – TM Relative Humidity (%) - RH	Maximum Load (lb) - P

Figure 1: *CBU-BOX2 Neural Network Configuration*

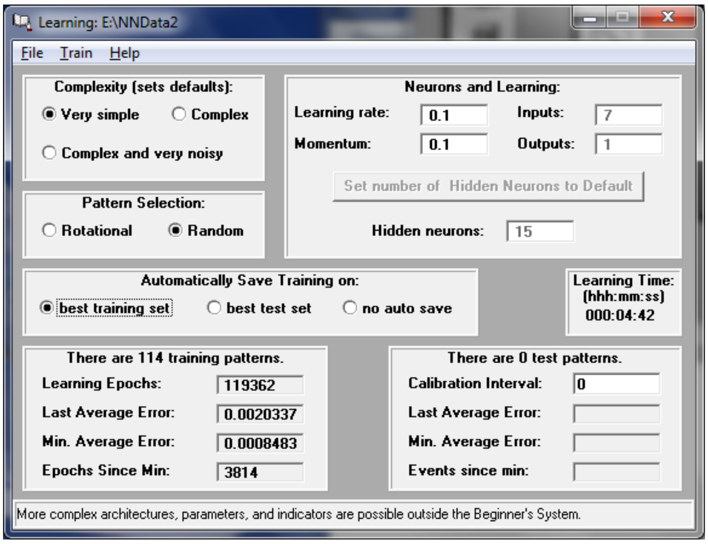


Figure 2: *Training Parameters*

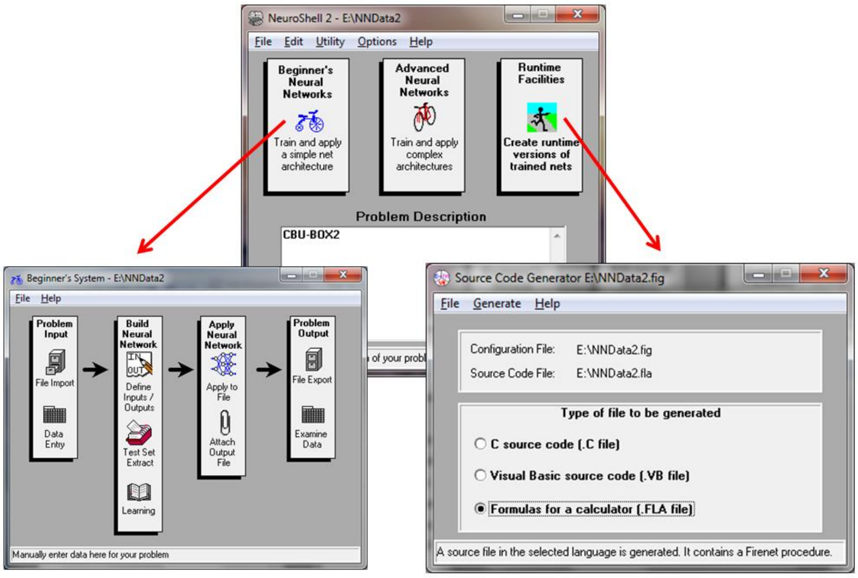


Figure 3: *NeuroShell2 Neural Network Development Software*

Table 1: *Training Data Samples*

TH	WD	DP	HT	EC	TM	RH	P	Mark
0.16	9	9	9	17	83.1	58	341	V
0.145	9	9	9	17	78.4	57	344	T
0.151	12	12	12	14	79.2	58	411	T
0.148	12	12	12	14	88.3	57	439	T
0.151	12	12	12	14	81.1	57	462	T
0.156	16	16	16	17	89.8	56	589	V
0.156	16	16	16	17	88.2	57	534	T
0.159	16	16	16	17	87.9	57	592	T
0.141	4	4	12	15	72.0	53	319	T
0.141	4	4	12	17	72.5	53	275	T
0.082	4	4	4	16	71.4	53	232	V
0.082	4	4	4	14	71.8	53	215	T
0.058	4	4	6	24	72.0	53	355	T
0.098	4	4	6	17	72.3	53	334	T

3. Results and Discussion

Figure 4 shows a partial output generated by CBU-BOX2 neural network. For each of the 141 cases, NeuroShell2 compared the predicted strength, i.e., Network(1), and the actual strength, i.e., Actual(1). It also outputted the difference of the two figures, i.e., Act-Net(1).

Datagrid: E:\NNData2.out

File Edit Format Help

Number of row with variable names (blank if none): 3 ☒ left/right arrow keys end edit

First row containing actual training data: 4 Size: 144 row 20 columns

Note: This is not a commercial spreadsheet and may not load fast enough for large files. The NeuroShell 2 Options menu allows you to change the datagrid call to your own spreadsheet. Search help file for "datagrid" for details.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Thickness	Width	Depth	Height	ECT	Temp	Humidity	Max Load				
2	(In)	(in)	(in)	(in)	(lb/in)	(F)	(%)	(lb)				
3	TH	WD	DP	HT	EC	TM	RH	P	Mark	Actual(1)	Network(1)	Act-Net(1)
4	0.117	5	5	5	31	67.6	48	303	T	303	315.62	-12.62
5	0.118	3	3	3	36	67.6	48	194	T	194	211.68	-17.68
6	0.173	9	9	9	35	73.4	49	694	T	694	684.73	9.27
7	0.160	9	9	9	36	73.9	49	709	T	709	704.04	4.96
8	0.158	9	9	9	36	74.5	49	645	T	645	695.15	-50.15
9	0.152	9	9	9	36	74.3	49	665	T	665	692.59	-27.59
10	0.158	9	9	9	36	74.5	49	668	V	668	695.15	-27.15
11	0.118	5	5	5	31	75.0	49	364	T	364	336.37	27.63
12	0.115	5	5	5	31	74.5	49	354	T	354	322.68	31.32
13	0.120	5	5	5	31	75.0	49	325	T	325	346.02	-21.02
14	0.118	5	5	5	31	74.8	49	327	T	327	335.50	-8.50
15	0.546	3	3	3	36	75.2	49	217	V	217	197.43	19.57
16	0.525	3	3	3	36	75.4	49	214	T	214	215.66	-1.66
17	0.105	3	3	3	36	74.8	49	200	T	200	223.88	-23.88
18	0.104	3	3	3	36	75.2	49	216	T	216	223.56	-7.56
19	0.154	12	12	12	37	70.3	61	581	T	581	661.81	-80.81

Figure 4: *A Partial Output Generated by NeuroShell2*

A generic source code was generated by NeuroShell2 (Appendix A). An Excel spreadsheet developed based on the source code is shown in Figure 5.

	A	B	C	D	E
2	CBU-BOX2				
3	Version 12.24.2015				
4					
5	netsum				
6	feature2(15)				
7					
8	Note - the following are names of inputs and outputs:				
9	Note - inp(1) is TH	inp(1)	0.155		
10	Note - inp(2) is WD	inp(2)	6		
11	Note - inp(3) is DP	inp(3)	6		
12	Note - inp(4) is HT	inp(4)	12		
13	Note - inp(5) is EC	inp(5)	35		
14	Note - inp(6) is TM	inp(6)	66.6		
15	Note - inp(7) is RH	inp(7)	50		
16	Note - outp(1) is P	outp(1)	431		
17					
18	if (inp(1)<0.058) then inp(1) = 0.058				
19	if (inp(1)>0.546) then inp(1) = 0.546				
20	inp(1) = (inp(1) - 0.058) /0.488	INPUT(1)	0.198770492		
21					
22	if (inp(2)<3) then inp(2) = 3				

Sheet1 Sheet2 Sheet3

Figure 5: *CBU-BOX2 Excel Application*

The CBU-BOX2 performance was evaluated and compared with McKee formula performance in Table 3, Figure 6, and Appendix B.

***Table 3:** CBU-BOX2 & McKee Formula Performance Comparison*

Category	Number Of Cases	<=5% Error	>5% to 10% Error	>10% to 20% Error	>20% Error	*Error Range (Average)*
CBU-BOX2 (All Cases)	141	60 or 42.55%	30 or 21.28%	35 or 24.82%	16 or 11.35%	*0% – 56.98% (Avg = 9.21%)*
McKee (All Cases)	141	13 or 9.22%	16 or 11.35%	24 or 17.02%	88 or 62.41%	*0.33% – 149.27% (Avg =30.79%)*
CBU-BOX2 (Cases with V Mark)	27	11 or 40.74%	4 or 14.81%	6 or 22.22%	6 or 22.22%	*1.26% - 40.28% (Avg = 11.30%)*
McKee (Cases with V Mark)	27	1 or 3.70%	2 or 7.41%	7 or 25.93%	17 or 62.96%	*2.08% - 149.27% (Avg = 37.46%)*
CBU-BOX2 (Rectangular)	43	20 (46.51%)	8 (18.60%)	11 (25.58%)	4 (9.30%)	*0.06% - 36.49% (Avg = 8.27%)*
McKee (Rectangular)	43	2 (4.65%)	2 (4.65%)	5 (11.63%)	34 (79.07%)	*3.14% - 62.59% (Avg = 37.05%)*
CBU-BOX2 (Cubical)	98	40 (40.82%)	22 (22.45%)	24 (24.49%)	12 (12.24%)	*0% - 56.98% (Avg = 9.47%)*
McKee (Cubical)	98	11 (11.22%)	14 (14.29%)	19 (19.39%)	54 (55.10%)	*0.33% - 149.27% (Avg = 28.04%)*

***Figure 6:** CBU-BOX2 & McKee Formula Performance Comparison*

4. Conclusion

As seen from Table 3, Figure 6, and Appendix B, CBU-BOX2 significantly outperforms McKee formula, including the unseen cases, i.e., those cases with a "V" mark. Table 3 also shows that CBU-BOX2 performs well for both rectangular and cubical boxes. The 141 cases used to develop CBU-BOX2 cover wide ranges of box sizes and conditions, i.e., width/depth/height ranges from 3" to 36", temperature range from 66°F to 104°F, and humidity range from 48% to 80%.

In order to make the neural network more comprehensive, material (virgin versus recycled) should be added as an input parameter. This can be accomplished by testing recycled corrugated boxes of different sizes and environmental conditions. With additional data, a new version of neural network can be trained and developed.

References

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[3] Malasri, S., Baroth, S., Cherukuri, S., Gurram, S., Vadlapatla, H. and Moats, R. *Estimating Corrugated Box Strength.* Proceedings of the PACKCON 2015 Conference. 2015. 11-14.

[4] Wadlington, C., Nguyen, N., Zheng, Zhihong, Loving, B. and Malasri, S. *Validation of CBU-BOX1 Neural Network.* Proceedings of the PACKCON 2015 Conference. 2015. 21-24.

[5] Ward Systems Group, Inc. NeuroShell2, http:www.wardsystems.com/neuroshell2.asp (As of December 25, 2015)

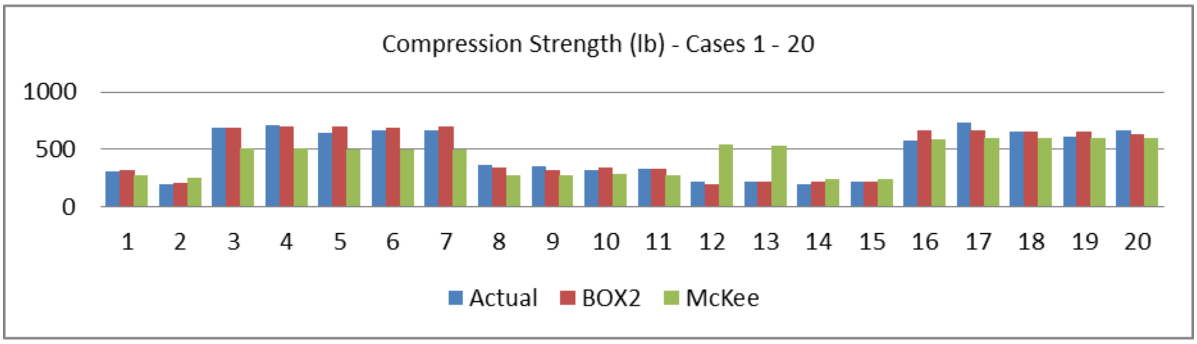
Appendix A Generic Source Code Generated by NeuroShell2

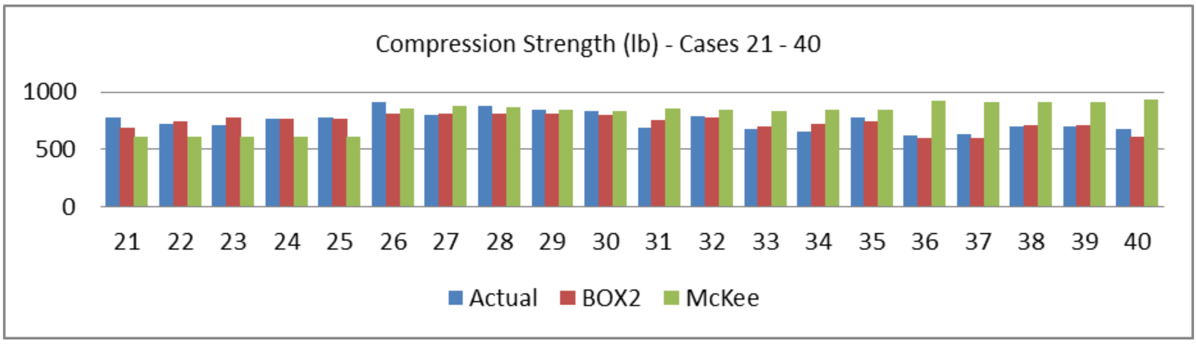
```
netsum
feature2(15)
Note - inp(1) is TH
Note - inp(2) is WD
Note - inp(3) is DP
Note - inp(4) is HT
Note - inp(5) is EC
Note - inp(6) is TM
Note - inp(7) is RH
Note - outp(1) is P
if (inp(1)<0.058) then inp(1) = 0.058
if (inp(1)>0.546) then inp(1) = 0.546
inp(1) = (inp(1) - 0.058) /0.488
if (inp(2)<3) then inp(2) = 3
if (inp(2)>36) then inp(2) = 36
inp(2) = (inp(2) - 3) /33
if (inp(3)<3) then inp(3) = 3
if (inp(3)>36) then inp(3) = 36
inp(3) = (inp(3) - 3) /33
if (inp(4)<3) then inp(4) = 3
if (inp(4)>36) then inp(4) = 36
inp(4) = (inp(4) - 3) /33
if (inp(5)<12) then inp(5) = 12
if (inp(5)>40) then inp(5) = 40
inp(5) = (inp(5) - 12) /28
if (inp(6)<66) then inp(6) = 66
if (inp(6)>104) then inp(6) = 104
inp(6) = (inp(6) - 66) /38
if (inp(7)<48) then inp(7) = 48
if (inp(7)>80) then inp(7) = 80
inp(7) = (inp(7) - 48) /32
netsum = netsum + inp(4) * -0.6943372
netsum = netsum + inp(5) * -0.8443508
netsum = netsum + inp(6) * 1.534944
netsum = netsum + inp(7) * -7.410185
feature2(4) = 1 / (1 + exp(-netsum))
netsum = -0.6371768
netsum = netsum + inp(1) * -63.56625
netsum = netsum + inp(2) * -10.43079
netsum = netsum + inp(3) * -9.066187
netsum = netsum + inp(4) * -3.963259
netsum = netsum + inp(5) * -20.94891
netsum = netsum + inp(6) * 11.87389
netsum = netsum + inp(7) * 31.26726
feature2(5) = 1 / (1 + exp(-netsum))
netsum = -7.49949
netsum = netsum + inp(1) * 0.6761363
netsum = netsum + inp(2) * -7.165943
netsum = netsum + inp(3) * -5.918962
netsum = netsum + inp(4) * 2.023466
netsum = netsum + inp(5) * -0.4293676
netsum = netsum + inp(6) * 8.238652E-03
netsum = netsum + inp(7) * -5.399711
feature2(6) = 1 / (1 + exp(-netsum))
netsum = -9.673411
netsum = netsum + inp(1) * 57.20142
netsum = netsum + inp(2) * 52.36789
netsum = netsum + inp(3) * 38.6922
netsum = netsum + inp(4) * -86.51951
netsum = netsum + inp(5) * 0.2131806
netsum = netsum + inp(6) * 7.545617
netsum = netsum + inp(7) * -31.17518
netsum = netsum + inp(3) * -4.812082
netsum = netsum + inp(4) * 0.6202544
netsum = netsum + inp(5) * -0.610349
netsum = netsum + inp(6) * 0.9391114
netsum = netsum + inp(7) * -5.874597
feature2(11) = 1 / (1 + exp(-netsum))
netsum = -2.139933
netsum = netsum + inp(1) * -14.47617
netsum = netsum + inp(2) * -4.172575
netsum = netsum + inp(3) * 14.07384
netsum = netsum + inp(4) * -26.67177
netsum = netsum + inp(5) * 9.429369
netsum = netsum + inp(6) * 11.32987
netsum = netsum + inp(7) * -4.766322
feature2(12) = 1 / (1 + exp(-netsum))
netsum = -0.2524938
netsum = netsum + inp(1) * -1.072484
netsum = netsum + inp(2) * 8.087201E-02
netsum = netsum + inp(3) * 20.43565
netsum = netsum + inp(4) * -11.70324
netsum = netsum + inp(5) * 0.3484668
netsum = netsum + inp(6) * -56.12461
netsum = netsum + inp(7) * -2.363098
feature2(13) = 1 / (1 + exp(-netsum))
netsum = -3.89846
netsum = netsum + inp(1) * -1.38506
netsum = netsum + inp(2) * -5.276136
netsum = netsum + inp(3) * -3.536175
netsum = netsum + inp(4) * 0.1051574
netsum = netsum + inp(5) * 1.241501
netsum = netsum + inp(6) * 3.577389
```

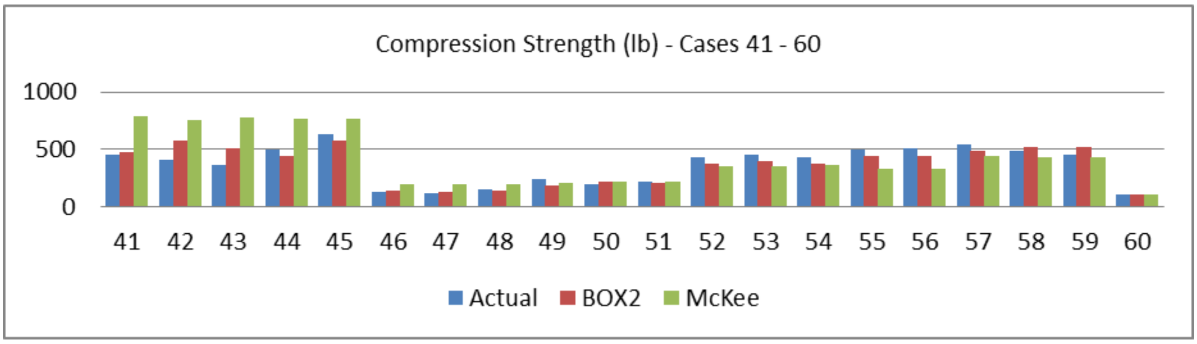
```
netsum = -7.247163
netsum = netsum + inp(1) * -7.162368E-02
netsum = netsum + inp(2) * -6.672145
netsum = netsum + inp(3) * -5.509887
netsum = netsum + inp(4) * 1.965163
netsum = netsum + inp(5) * -0.1127764
netsum = netsum + inp(6) * -0.3749207
netsum = netsum + inp(7) * -6.057019
feature2(1) = 1 / (1 + exp(-netsum))
netsum = -6.879015
netsum = netsum + inp(1) * -3.016899
netsum = netsum + inp(2) * -5.380744
netsum = netsum + inp(3) * -3.580803
netsum = netsum + inp(4) * -0.4355183
netsum = netsum + inp(5) * -0.9137687
netsum = netsum + inp(6) * 1.621481
netsum = netsum + inp(7) * -7.314968
feature2(2) = 1 / (1 + exp(-netsum))
netsum = 2.58671
netsum = netsum + inp(1) * -56.1168
netsum = netsum + inp(2) * 19.70152
netsum = netsum + inp(3) * 18.78237
netsum = netsum + inp(4) * -23.49325
netsum = netsum + inp(5) * 13.29584
netsum = netsum + inp(6) * -8.186071
netsum = netsum + inp(7) * -13.79474
feature2(3) = 1 / (1 + exp(-netsum))
netsum = -6.930517
netsum = netsum + inp(1) * -3.43881
netsum = netsum + inp(2) * -5.543357
netsum = netsum + inp(3) * -3.266341
feature2(7) = 1 / (1 + exp(-netsum))
netsum = -6.69485
netsum = netsum + inp(1) * -2.424634
netsum = netsum + inp(2) * -5.845432
netsum = netsum + inp(3) * -3.707195
netsum = netsum + inp(4) * -0.2126636
netsum = netsum + inp(5) * -0.6274015
netsum = netsum + inp(6) * 1.344668
netsum = netsum + inp(7) * -6.710152
feature2(8) = 1 / (1 + exp(-netsum))
netsum = -7.186853
netsum = netsum + inp(1) * -1.09149
netsum = netsum + inp(2) * -6.539968
netsum = netsum + inp(3) * -4.775326
netsum = netsum + inp(4) * 0.8580441
netsum = netsum + inp(5) * -0.1386947
netsum = netsum + inp(6) * 0.6256868
netsum = netsum + inp(7) * -6.080272
feature2(9) = 1 / (1 + exp(-netsum))
netsum = -1.865983
netsum = netsum + inp(1) * 1.98675
netsum = netsum + inp(2) * -11.25155
netsum = netsum + inp(3) * -10.4184
netsum = netsum + inp(4) * 1.585183
netsum = netsum + inp(5) * -0.5645384
netsum = netsum + inp(6) * 1.33543
netsum = netsum + inp(7) * -3.745443
feature2(10) = 1 / (1 + exp(-netsum))
netsum = -6.47867
netsum = netsum + inp(1) * -0.8656681
netsum = netsum + inp(2) * -5.996781
netsum = netsum + inp(7) * -6.608476
feature2(14) = 1 / (1 + exp(-netsum))
netsum = -7.510636
netsum = netsum + inp(1) * 2.029926
netsum = netsum + inp(2) * -7.943251
netsum = netsum + inp(3) * -7.275569
netsum = netsum + inp(4) * 2.87489
netsum = netsum + inp(5) * -1.476773
netsum = netsum + inp(6) * 0.559886
netsum = netsum + inp(7) * -3.235952
feature2(15) = 1 / (1 + exp(-netsum))
netsum = -0.2801921
netsum = netsum + feature2(1) * -0.4374026
netsum = netsum + feature2(2) * 3.453336E-02
netsum = netsum + feature2(3) * 1.700875
netsum = netsum + feature2(4) * -0.1481685
netsum = netsum + feature2(5) * -0.9338183
netsum = netsum + feature2(6) * -0.5930923
netsum = netsum + feature2(7) * 1.477526
netsum = netsum + feature2(8) * 0.1232549
netsum = netsum + feature2(9) * -0.5360605
netsum = netsum + feature2(10) * -5.806566
netsum = netsum + feature2(11) * 0.4093191
netsum = netsum + feature2(12) * -2.210154
netsum = netsum + feature2(13) * -2.185017
netsum = netsum + feature2(14) * 2.029893
netsum = netsum + feature2(15) * -6.077104E-03
outp(1) = 1 / (1 + exp(-netsum))

outp(1) = 810 *  (outp(1) - .1) / .8  + 103
```

Appendix B Graphical Comparison of Actual, CBU-BOX2, and McKee Formula for 141 Cases



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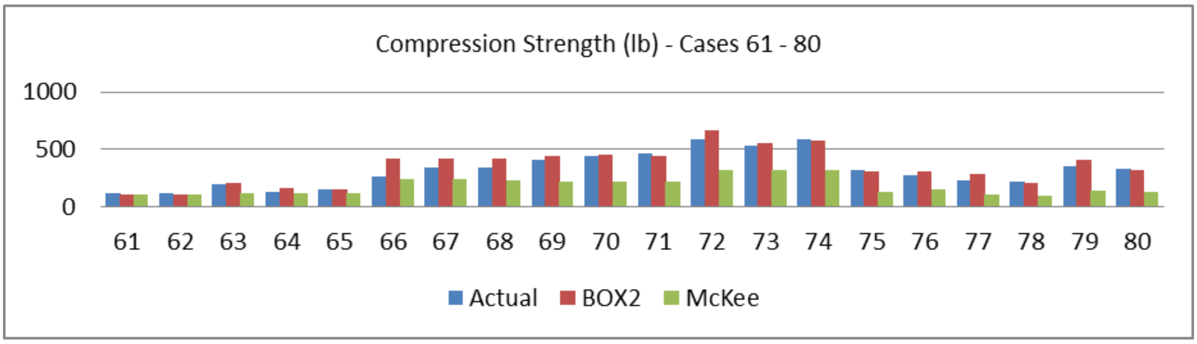
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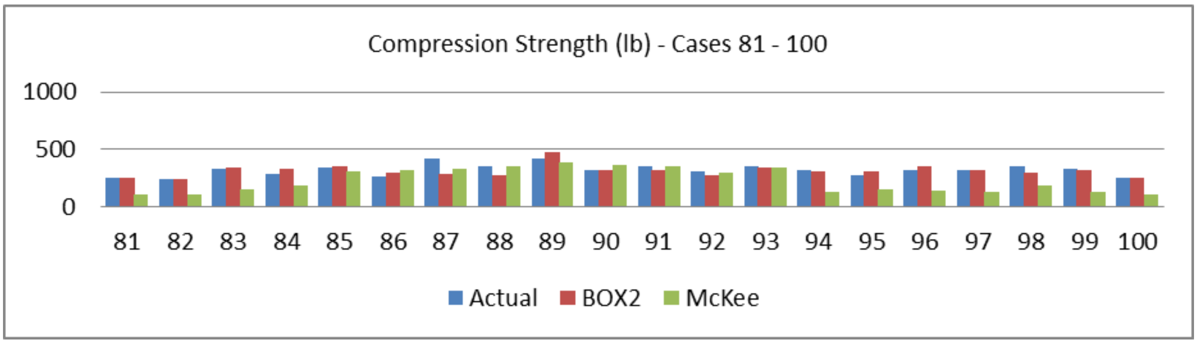
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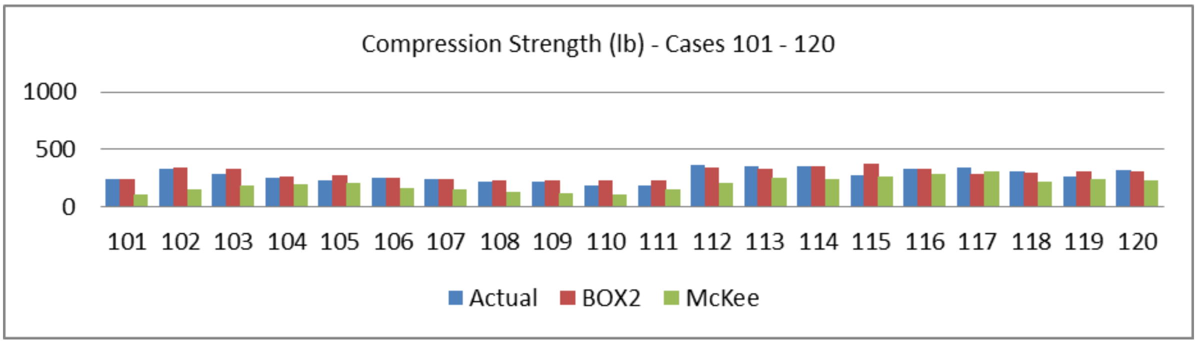
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Actual
BOX2
McKee

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Research Article

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Design Process and Its Application on the Improvement (Re-Design) of the Coke Bottle

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Abstract Profitability of a product depends upon the supply chain as well as its acceptability to the end user in a good condition i.e. unspoiled and undamaged. The primary function of packaging of a product is to ensure the product for safe transit. The secondary function of packaging is to make it attractive to the customer and act as 'silent sales person'. Here in this research work a hypothetical design project was undertaken upon 2ltr package of Coca Cola party/family bottles. Accordingly, a market research was carried out on the design of the bottle. Based on the market research a design possibility is planned and proposed for doing some modification on the Coca Cola family bottle. Finally the prototype of the bottle is developed in institute studio.
Keywords *Consumer; Design Methods; Ergonomics; Form; Graphics; Packaging; User Interface*

1. Introduction

Design as described by John Chris Jones in his book- Design Methods [2] (Second edition 1992), may be described as follows:

- A goal directed problem solving activity [15] (Archer, 1965)
- Decision making in the face of uncertainty with high penalties for error [16] (Asimow, 1962)
- Optimum solution to the sum of true needs of a particular set of problems [17] (Matchett, 1968)
- Relating product with situation to give satisfaction [18] (Gregory, 1966)

Let [19] us assume that a group of tribal people are staying together without many tools and resources. They are on a move and they are hungry (Ref Figure 1). They come across a tall mango tree. They crave to have mangoes (That is Desire). But the question is how to achieve the mangoes

(That is the Problem)? They look at the mangoes (That is the Goal) and start thinking of possibilities of achieving the goal utilizing the existing resources (that's the basic Brainstorming Process). The basic brainstorming process initiates a number of activities within the group to achieve the goal like throwing stones, using long branches, using climbers to climb the tree (that is Problem Solving Activity). All these decisions taken to achieve the goal are not certain and may bear consequences for error e.g. during the stone throwing process someone may get wounded.

The overall process led to a jump from present facts and resources to future possibilities and opportunities.

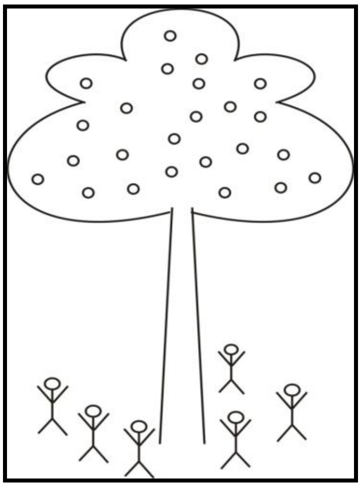


Figure 1: *Mango Tree with Primitive Men* [8]

Lateral thinking [3] as described by Edward De Bono is a unconventional way of addressing problems. Edward De Bono defines Lateral Thinking as a technique of addressing problems by lateral thinking instead of vertical thinking. Idea is to consider [4] alternatives. It is extremely important to 'break out of the box'.

A simple interaction design model [12] in Figure 2.

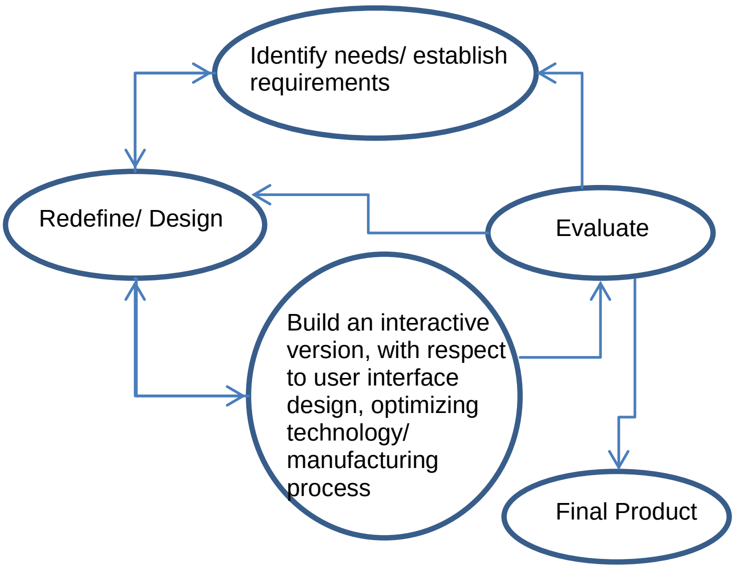


Figure 2: *Design Model* [1]

Figure 3: *Traditional Crate*

Figure 4: *Redefined Packaging* [3]

Exemplifies a user centred design approach. This is also followed in a big way while addressing product packaging. For example recent packaging of eggs found in hypermarkets (Figure 3 and 4).

The thermoformed PVC packaging is a complete break out of the box concept if compared with the traditional and generic practices of egg packaging (Figure 3). This packaging concept's role has extended in response to consumer's changing lifestyles. Generally eggs are transported in papier mache or plastic (HDPE) crates stacked together. Consumers usually carry eggs in poly bags/ paper envelopes. The redefined packaging (Figure 4) provides better controllability to the person carrying it/ user, resulting in better user experience brand manifestation. Thus it can be seen that there is a lot of scope in packaging design in design context.

In early days, packaging's [1] role was principally utilitarian. It facilitated the effective distribution/ delivery of merchandise. To this day, these basic purposes play an important role in the form and function of packaging. Products may have become more sophisticated but still there is a basic prerequisite to protect them. Distribution may have become a complex process, but products still need to survive the transportation so that they not only arrive unspoiled on shelf but also look appealing to the consumers.

2. Progress and Change in Packaging

2.1. History

The earliest forms of packaging [5], for edible items were made from bi-products of animals and plants e.g. animal skins, large leaves etc. Water was kept in containers made from coconut shells, animal skins or the hollowed-out dried skins of fruit and vegetables.

By Egyptian and Roman times, containers were being made of clay and other materials. Later, glass, metal and paper were introduced. It evolve through the passage of time, e.g. in Victorian times, butter and cheese were kept in baskets and vinegar in barrels.

Nowadays, packaging may be very different, but its main functions are still to make food and other products easy to transport, and to protect it until it is consumed or used reduces the amount we waste.

2.2. Invention of Can

It was during Napoleonic Wars [5] can was developed and initiated to retain food fresh for the troops. In 1795, circumstantial need pushed Napoleon to offer a prize to any one for an idea which would keep food safe for the troops. Nicolas Appert, a chef from Paris, took up the challenge and invented a method of preserving food by heating it in a sealed container. Meanwhile, in England scientists discovered that steel with a very fine layer of tin coat, can be used as packaging material for food items. It can retain the freshness of food for substantial longer duration.

By the Second World War, the steel cans evolved a lot. It was lighter than the original version, opened at the end of a can opener, and contained a wide variety of foods – from spaghetti, mushy peas and pilchards, to sardines, evaporated milk and soft drinks.

In 1897 Shiseido [1] introduced its first cosmetic product, Eudermine (Figure 5). Taking its name from the Greek “for good skin”, Eudermine skin lotion embodied the latest pharmaceutical technology and the company’s desire to create “cosmetics that nurture, beautiful healthy skin”. The product’s packaging always reflected the taste and design influences of the period, each time it is redefined. By 1997 Eudermine’s packaging had evolved radically (Figure 6). Good designers know how to adapt and manipulate the influences to exceed mere cult or fad, to develop designs that reflect the spirit of the time and are relevant and meaningful to consumers.


Figure 5: *Packaging in 1897* [4]*;* ***Figure 6:*** *Packaging in 1997* [5]

It is now established [1] that packaging is no longer a docile functional device, but a lively and vigorous sales tool that can make its presence felt in crowd, and sells a product at the point of purchase. Moreover, with the protuberance of branding, packaging is often the living quintessence of a brand’s, face, value and personality.

Effort is made to delineate these attributes and traits, understanding the consumer’s perception of them and then manipulating packaging design to communicate them. Packaging design plays a critical role in ensuring the consumer’s perception of the brand is mirrored on the pack. Consumers make a brand purchase just as much as they make a product purchase. They may in reality be buying a body lotion but their choice is affected by their perception of the brand and its inherent promise.

2.3. Consumer Lifestyle and Behavioural Patterns

Consumer’s changing lifestyles also affected packaging. For example people now live more mobile lives. In simplistic terms, this has led to travel size variants of products leading to packaging, designed specifically to fit in hand bags and luggages e.g. retractable razor [6].

It is advantageous [6] to add one or more features of the product on its packaging in addition to visual attractiveness. It provides consumers with a greater opportunity to appreciate. For Example, packaging that allows consumers to interact with a product, e.g. activate or manipulate the product, while the product is displayed within the packaging provides consumers with an opportunity to appreciate the features and functions of the product.

One of the most renowned shapes in the world is the iconic contour fluted lines of the Coca-Cola [7] bottle. Recognized as a design classic and described by noted industrial designer, Raymond Loewy as the "perfect liquid wrapper," the bottle has been celebrated in art, music and advertising. When Andy Warhol wanted a shape to represent mass culture, he drew the bottle and when Volkswagen wanted to celebrate the shape of the Beatle, they compared the car to the bottle.

The Root Glass Company [7] put forth a patent registration under Samuelsson's name which was granted on November, 16th, 1915. In 1923, the patent for the bottle was renewed. Patents expire in 14 years so the bottle patent was renewed again in 1937. On April 12th, 1961, the Coca-Cola bottle was recognized as a trademark.

1899 - 1902 1900 - 1916 1915 . 1957 1961 1991 1994

Figure 7: *The Coca-Cola Bottle Evolution with Years* [6]

The form has evolved [7] [11] over the years with universal recognition. Just that the original patent from 1915 was a slightly fatter shape than the bottle that went into production. When King and Family sized packaging were introduced in 1955, Raymond Loewy was part of the team that worked to recast the bottle but retained the e proportions. The Company took advantage of this classic shape.

The Coke bottle has many nick names [7] [11] over the years. The most famous of them is the "hobble skirt" bottle. The hobble skirt was a fashion trend during the 1910s where the skirt had a very tapered look. The bottle was also called the "Mae West" bottle after the actress's famous curvaceous figure. The first reference to the bottle as a "contour" occurred in a 1925 French Magazine, La Monde, which described the Coca-Cola bottle with a distinctive contour shape. To the general public, the shape is just "the Coke bottle."

The Coca Cola company launched the first PET plastic bottle in 1978. Packaging [13] pushes the boundaries on sustainable innovation. This has led the Coca Cola company to innovate world's first PET plastic bottle made entirely from plant materials. Coca Cola is presently into Plant Bottle packaging [14] using materials that are up to 30% plants-based instead of using petroleum and other fossil fuels to produce a key ingredient in the plastic (PET). It uses patented technology that converts natural sugars found in plants (sugarcane ethanol), into the ingredients for making PET plastic bottles.

Nowadays beverage products [8] come in a variety of packaging styles. For example, carbonated beverages are supplied in traditional glass bottles, in plastic bottles and in aluminium cans. Wine, by contrast has been traditionally sold in glass bottles, although the use of a cardboard cask container enclosing a bladder is also known and there have been more recent attempts, as yet not commercially widespread, to promote wine in alternative packages such as aluminium cans or even cartons typically used for milk and fruit juice products. A further driver for the development of alternative packaging methods is the demand for packaging method/s that will allow the user to consume only a portion of the contents of the package without compromising the quality, or reducing the longevity of the remaining package contents and at great ease. Going by the principles of user interface design by Lary Constantine and Lucy Lockwood [9], i.e.

Tolerance: The design should be able to withstand varied usages by the user.

Simplicity: The design should make simple, common tasks easy and communicate clearly its affordance.

Visibility: The design should make all needed options and materials for a given task visible without distracting the user and should stimulate through one or more senses.

Affordance: Communicating to the user through form and design regarding its usage e.g. water taps and door handles.

Consistency: Uniformity pertaining to the performance in context to time and varied environments.

Structure: Most often the form along with the material.

Feedback: The design should communicate the users regarding actions or interpretations, changes of state or condition.

These seven principles may be considered at any time during the design of a user interface in any order. It engulfs the pedagogy of human factors and ergonomics within.

2.4. Silent Sales-Person

Good packaging [1] designers use their understanding of the marketing mix while devising their packaging solutions. It is a challenging task and sometimes it results in a design solution that gives a brand owner a device which can work across different media, in a holistic way. Packaging designer should understand the different magnitude “shout” that needs to be executed in packaging design in an attempt to create awareness about a product.

These days the Coca-Cola company practices [10] the 4Ps of marketing mix i.e. price, product, place and promotion. The company is aware of the potential of the Indian soft drink industry. The mission of the company is as follows:

- To refresh the world
- To inspire moments of optimism and happiness
- To create value and make difference

It silently says a lot about the heritage of the company and the packaging is very much integral part of it. The brand inspires creativity, passion, optimism and fun. The packaging so far has been instrumental in helping to achieve the same.

Figure 8: *Party/Family Packs* [7]

3. Methodology

A hypothetical packaging design project was undertaken upon the Coca Cola party/family (net quantity 2.25L) pack. The process began with role play and interviewing (with a questionnaire) a sample of approx 150 people in Bhopal, Delhi and Kolkata (who are frequent or regular consumers of party packs of beverages) of various age and different gender. SWOT analysis (refer to pg.no-9) was done on the packaging of Coca Cola party/family (net quantity 2.25L) pack based on the **primary data** collected, as depicted in Figure 10-12.

3.1. Primary Data Collection

Primary data was collected from consumers belonging to varied socio-economic background, varying between age group of 15-55 and both males and females.

Many consumers were keenly observed while using the bottle. The design process followed is depicted in the flowchart in Figure 9.

3.2. Analysis and Interpretation of Data

The sample segment was asked a few questions which are interpreted in the charts in Figure 10, Figure 11, and Figure 12 below.

Question-"What is the best thing about the (2.25L) party pack bottle?"
The interpretation is as follows in Figure 10.

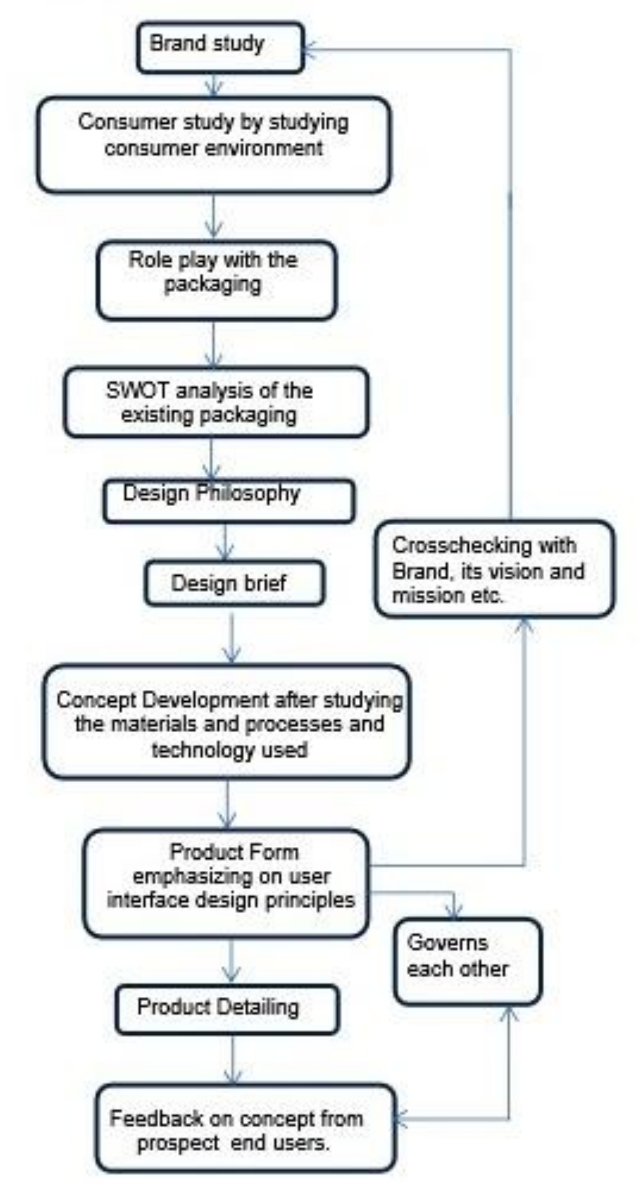


Figure 9: *Design Process Flow-Chart*

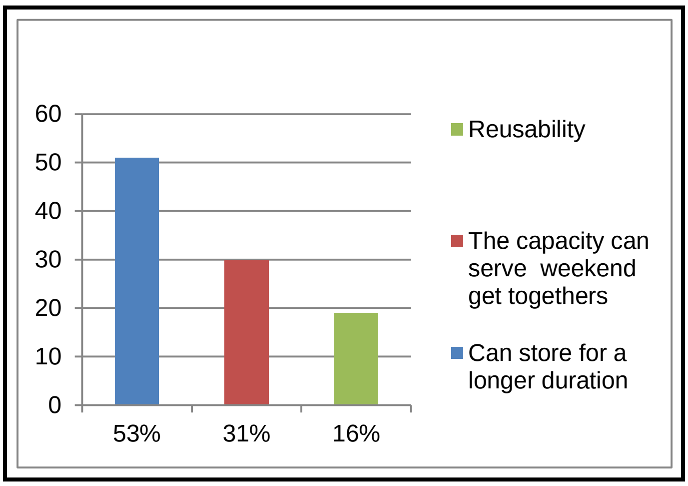


Figure 10: *The Best Thing about the 2.25L Party Pack Bottle*

From Figure 10 it is observed that as per the comments received from the market research maximum persons selects 2.25L bottle for keeping the cold drinks in longer duration (53%). 31 % of the sample choose the bottle for week end get together and 19% choose the bottle for its reusability as packaging in future.

Question-“What is/ are the thing/s or features about the (2.25L) party pack bottle that is disliked?” The interpretation is as follows in Figure 11.

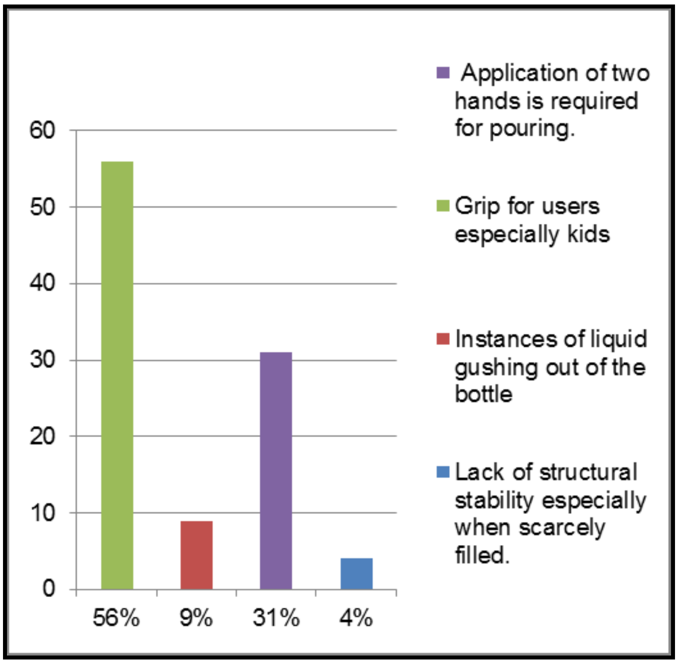


Figure 11: *Things that are disliked in the Bottle*

From Figure 11 it is observed that 56% of the respondent agrees that the due to formation of moisture over the bottle surface as well as the girth, it is a challenge to grip the bottle with one hand while pouring. So better gripping of the bottle, especially for the kids, are required. 31% of respondent agree that two hands are required to safely grip the bottle when pouring. 9% of respondents agree that at the time of pouring coke in the glasses the beverage tends to gush out from the bottle.

Question-“What is/ are the thing/s or features about the (2.25L) party pack bottle that is aspired?” The interpretation is as follows in Figure 12.

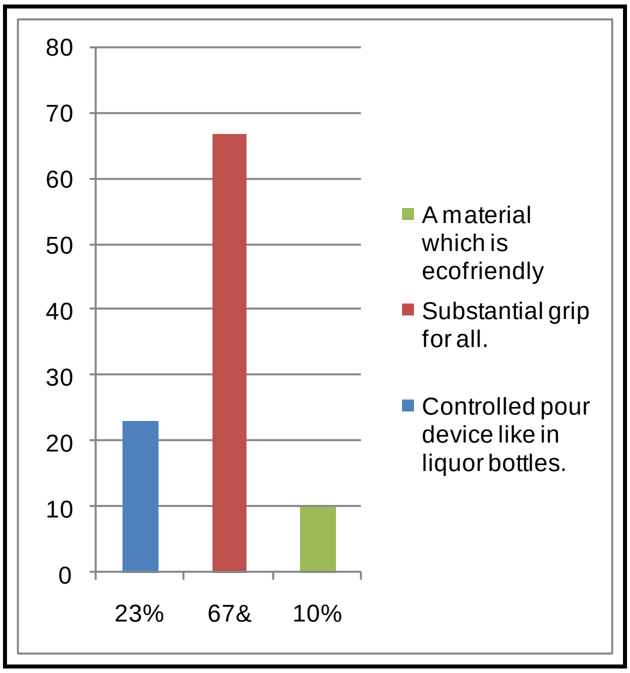


Figure 12: *Things that are aspired in the Bottle*

From Figure 12 it is observed that 67% of the respondents aspire better gripping arrangements for family pack to avoid unwanted slippage when pouring and 23% aspired to have a controlled pour device like in liquor bottles.

3.3. SWOT Analysis

Strengths

- Iconic form / silhouette of the PET Bottle.
- Reusability
- Same size cap for every bottle. It comes as an advantage.
- Low production costs.

Weaknesses

- Ergonomically difficult to grip/pour especially when full.
- Lack of control while pouring the beverage, especially when the bottle is half filled because of gradual weight transfer from bottom to top of the bottle.
- As per present affordance the grip of the bottle lies somewhere on the label of the brand. Going by anthropometry the curvature of the bottle there doesn't suit the palm size of teens and females mostly. Thereby making them conscious while pouring.
- Lack in stability.

Opportunities

- Stand out of the crowd by giving the form a new dimension retaining the iconic dignity.
- To provide a better experience with packaging thereby creating a larger impact of the brand.
- Enduring reusability thereby reducing garbage brooding.

Threats

- Competition in market. Almost every cold drink (party/family pack) packaging is similar. The packaging other than the graphics doesn't stand out.

4. Results and Discussion

4.1. Design Philosophy

To empower the users with an utmost confidence while using the product.

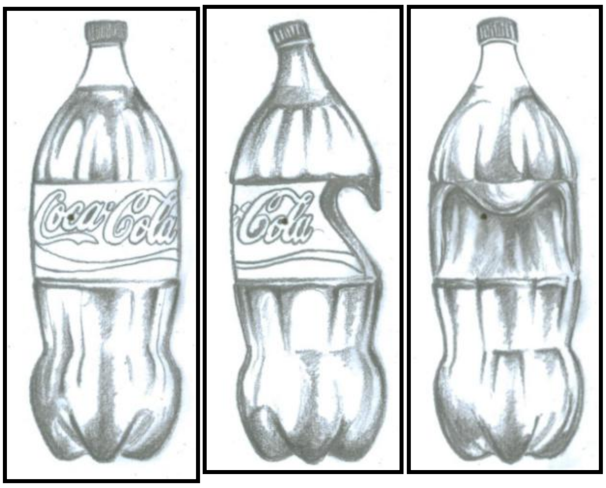
4.2. Design Brief Statement

Redefining the packaging of Coca Cola (2.25 L) party/family pack bottles without disturbing much the iconic contour while incorporating a better grip and beverage flow would thereby enhance the controllability and affordance.

It should be within the existing cost of mass manufacturing which is done by Injection blow moulding process (excluding the die cost) i.e. Rs 2.00 to Rs 3.50.

4.3. Design Strategy

Refreshing optimisim and happiness in style. A positive change would enhance brand value. A concept is recommended below in Figure 13 with the same material as existing i.e. Polyethylene Terephthalate and same manufacturing process as existing i.e. Injection blow moulding process.



Front View *Side View* *Back View*

***Figure 13**: Redefined Coke Party Pack bottle 2.25 L*

It may be perceived as sculpting out cosmetic changes in the existing packaging without disturbing the iconic contour and proportion much. May be the size (existing size is 13.75" x 4" tentatively) will increase marginally because of the negative space created.

The negative space creates a distinct affordance towards the grip providing remarkable control to users of all age groups especially while pouring.

In the concept the neck is slightly moved forward by around 10^{o}. It shall help in pouring the liquid with comparative ease. It is depicted in the 3D Studio Max screen shot in Figure 14.

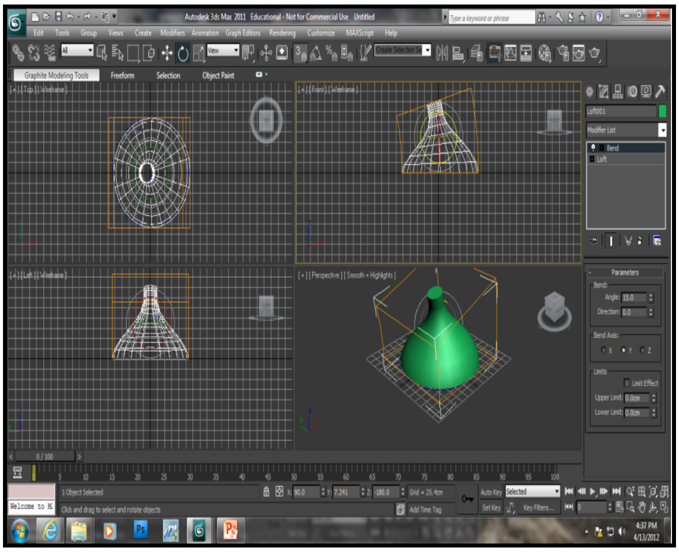


Figure 14: *The Slight Bend at the Neck*

A tentative prototype is developed with plaster of Paris. As depicted in Figure 15.

Figure 15: *Plaster of Paris Model*

Below mentioned in Figure 16 is the existing contour, the transformed contour of the bottle.

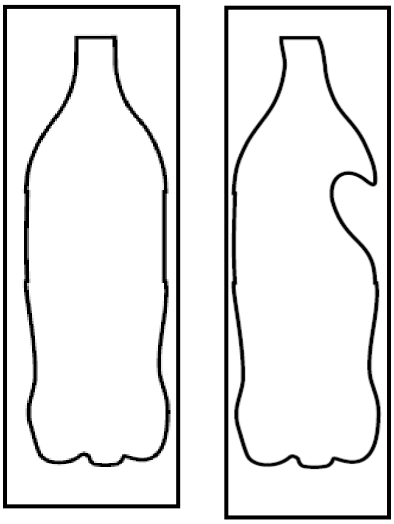


Figure 16: *Silhouette*

Below mentioned in Figure 17 the Figure depicts how the bottle works.

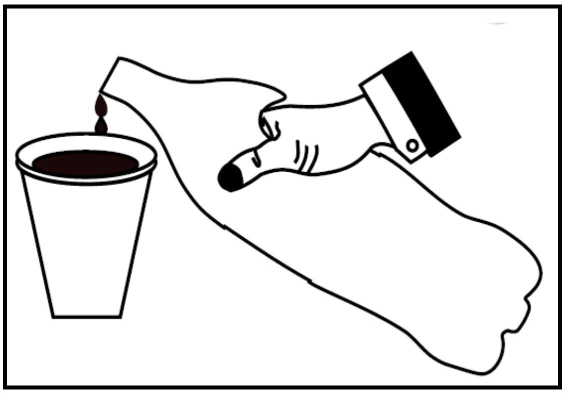


Figure 17: *How the Bottle Works*

5. Conclusion

Controlled pour devise, as in liquor bottles, has not been used as hardware for reasons as mentioned below:

- There is already substantial transition in the packaging. Adding the hardware would be too much for the consumers to feel nostalgic with the form and brand.
- Cost implications.

The Coca Cola company has evolved from packaging [13; 14] in traditional PET bottles to Plant Bottles. 30% of material in Plant Bottles is sugars found in plants which are absolutely renewable. The Plant Bottle has a lighter footprint on the planet and its scarce resources. Due to its manufacturing ingredients it reduces potential carbon dioxide emissions and dependence on fossil fuels, like petroleum, when compared to traditional PET plastic. It is presently available in over nine countries including Sweden, Denmark, Mexico, Brasil, Japan, Chile, The USA, Canada etc. It is fully recycleable and thus may be proposed to be the ideal material to develop the concept.

The feedback from the respondents is as follows:

- The iconic dignity of the pack is not getting disturbed with the cosmetic changes in the form and unchanged graphics
- Ergonomically it reduces two hand handling to one hand
- It would have a endured and preferred reusability
- It will surely stand out of the crowd
- It will inevitably go with the brand mission (ref page 6) i.e. To create value and make difference.

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Research Article | Open Access

Synchrosqueezing Transform for High Resolution Time-Frequency Analysis of Shock and Vibration Measurements

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Abstract This article presents the use of the synchrosqueezing transform (SST) for the time-frequency analysis of shock and vibration measurements. The time-frequency resolution properties of SST is demonstrated by analyzing acceleration measurements from pallets dropped from heights and vibration of pallets acquired in controlled laboratory settings. The article presents results that indicate that SST, in conjunction with continuous wavelet transform (CWT) based preprocessing for noise reduction, can be used as an effective spectral analysis tool for shock and vibration measurements.

Keywords *Synchrosqueezing Transform; Continuous Wavelet Transform; Shock; Vibration*

1. Introduction

Shock is a transient event defined as a mechanical disturbance characterized by a rise and decay of acceleration in a short period of time, while vibrations are random oscillations about a reference point, usually for a longer period of time [1]. Packaged products often undergo shock and vibration during distribution. An accurate simulation of the shock and vibration phenomenon enables effective testing of packaging components and provides direction for further improvement of packaging and transportation design. Hence, the understanding of spectral (frequency) components and time periods when the spectral components occur as a result of stimulus caused by shock and vibration is important. Given the definitions and observations made through measurements, shock and vibration are considered non-stationary processes. Non-stationary signals contain different frequency components at different periods of time. Wavelet Transform maps a temporal signal on to a 3-D time-frequency space and is used extensively to analyze non stationary signals [2, 3]. The time-frequency localization properties of wavelet basis functions and the mechanism of the transform process makes continuous wavelet transform (CWT) provide better interpretation of Shock and Vibration signals than techniques based on Fourier Transform, Short Time Fourier Transform and Shock Response Spectrum (SRS) [4]. Fourier Transform based spectral analysis only provides information about the frequency content of the signal but not the time periods when those frequencies are present. It is a 2-D representation of the signal, with power spectral density of the y axis and frequency on the x axis. The Shock Response Spectrum (SRS) is another approach to analyze shock data that assumes a model containing a set of single degree-of-freedom, mass-damper-spring oscillator subsystems that are excited by base motion [5]. Although STFT provides information in the time-frequency domain in a 3D format with coefficients/Power on the z-axis, time on the x-axis and frequency on the y-axis, the trade-off between time resolution and frequency resolution is non-optimum.

Synchrosqueezing transform (SST) is a method to further sharpen the time-frequency representation of the continuous wavelet transform (CWT). SST process starts with the implementation of the wavelet transform, followed by reallocation of the wavelet coefficients to improve the time-frequency representation [6]. Since wavelet transform is the first step to the computation of SST, as an intermediate step, between computation of wavelet coefficients and coefficient reallocation, wavelet based noise suppression techniques can be introduced to increase accuracy of the analysis. In this article, the use of SST with wavelet based noise suppression technique for time-frequency analysis of shock and vibration of pallets is demonstrated.

The subsequent sections in this article are as follows: In section 2, data collection methods and signal processing algorithms are described. Section 3 discusses the results of the analysis of the data and section 4 presents the conclusions drawn from this research.

2. Materials and Methods

In this section, first, a description of the shock and vibration experiment is provided. Next, the CWT and SST based signal processing for analyzing the data are presented. Finally, the software tools to implement the analysis are discussed.

2.1. Data Collection Procedure

The shock and vibration data collection was done in a controlled laboratory environment [4]. For recording shock data, a Lansmont Saver 3M30 recorder was used to measure acceleration versus time at 1000 samples/sec along three directions. It was attached to a pallet, which was raised and dropped from a certain height. In this experiment, a wooden pallet was dropped from 2 inches, 4 inches, 6 inches, 8 inches and 10 inches. Figure 1 shows the setup of the shock experiment. For each height, acceleration versus time was measured through the three channels of the shock recorder. Channel 3 measured the acceleration along the direction of the drop, while the other two channels measuring acceleration along the other two orthogonal directions. For measuring vibrational data, a wooden pallet was mounted on a vibration platform as shown in Figure 2. The Lansmont recorder was used to measure the vibrational acceleration versus time signal sampled at 1000 samples/sec along three orthogonal directions (x, y and z axis). A truck vibration simulation in accordance with ASTM D 4169 Truck Level I was utilized.

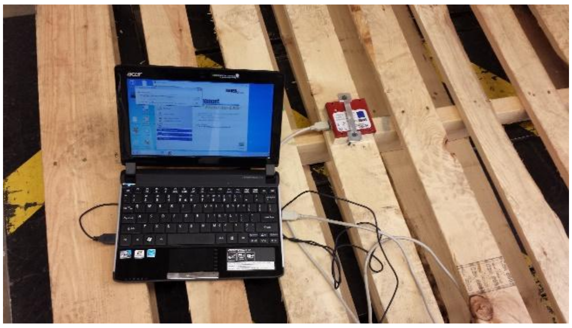



Figure 1: *Experimental Setup for Collection of Shock Data*

Figure 2: *Experimental Setup for Collection of Vibration data*

2.2. Signal Processing/Modeling Techniques

In this sub-section, the theoretical background and software tools CWT, SST in combination with noise suppression using CWT. In the context of this article, the time varying, zero-mean function $x(t)$ represents the acceleration versus time signal associated with the shock or vibration data. Further, the signal $x(t)$ is normalized by subtracting its mean value from the signal.

2.2.1. Continuous Wavelet Transform

Wavelet Transform represents a signal $x(t)$ as a weighted sum of basis functions referred to as wavelets. The weights correspond to the wavelet coefficients. The Continuous Wavelet Transform (CWT) of a signal $x(t)$ is given by [7]: $W(a,b) = \int x(t)\frac{1}{\sqrt{a}}\phi^*\left(\frac{t-b}{a}\right)$, where b is the translation parameter and a is the scale parameter. The basis function $\phi(t)$ is referred to as a mother wavelet. $\phi^*(t)$ is the complex conjugate of $\phi(t)$. The translation parameter, b, shifts $\phi(t)$ in time and the scale parameter, *s,* controls the temporal width of $\phi(t)$. The scale parameter is inversely related to frequency. An example of a mother wavelet function is a Morlet function. The Morlet wavelet is a complex valued function given by: $\phi(t) = e^{-2\pi^2 \frac{t^2}{z_0^2}}\left(e^{j2\pi t} - e^{2\pi^2 t^2}\right)$. The envelope factor z_o controls the number of oscillations in the wavelet with a typical value of z_o = 5 [8]. The Morlet basis function is used in this article for the computation of CWT.

The CWT is the correlation or the inner product of the signal $x(t)$ with various shifted and stretched/shrunken versions of the mother wavelet $\phi(t)$. It is this ability to manipulate the width (stretching or shrinking) of the mother wavelet and shift it along the time axis that makes the CWT time-frequency analysis effective. The plot of CWT coefficients for the signal $x(t)$ is a 3D plot. The x-axis corresponds to the time shift, b. The y-axis represents frequency *f* or scale *a*. The amplitude of the CWT coefficients is represented by the z-axis.

2.2.2. Synchrosqueezing Transform

SST further sharpens the time-frequency representation of wavelet transform by constructing a more concentrated representation. This is done by combining all wavelet coefficients corresponding to same instantaneous frequencies into one SST coefficient [9]. This process is referred to as frequency reallocation.

The steps involved in computing the SST coefficients is as follows [6][10]:

1) SST starts with the decomposition of the signal x(t) to determine the wavelet coefficients $W(a,b)$ as described in the section 2.2.1. The wavelet coefficients are however computed for discrete values, a_k and $a_k - a_{k-1} = (\Delta a)_k$ The instantaneous frequencies is computed, $\omega(a,b) = -i(W(a,b)^{-1}\frac{\partial}{\partial b}W(a,b)$. Note that $\omega = 2\pi f$ is the frequency expressed in radians/second.

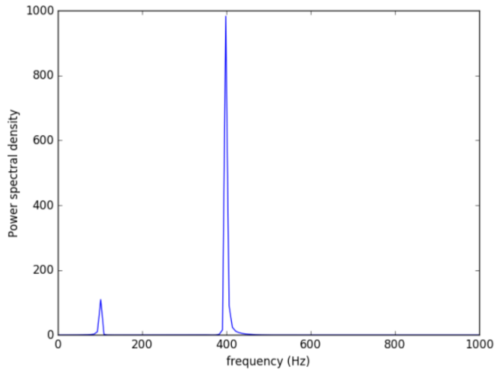
2) Each point in the wavelet time-scale domain, located at co-ordinates (b,a), is mapped in to a corresponding point (b,ω) using the synchrosqueezing process. This process, synchrosqueezing transform $T_S(\omega,b)$, is computed at center ω_l of successive bins $[\omega_l -$ *12Δω, ωl+12Δω*, where *ωl−ωl−1=Δω*, by:

$$T_s(\omega_l,b) = (\Delta\omega)^{-1} \sum_{a_k:|\omega(a_k,b)-\omega_l|\le\Delta\omega/2} W_s(a_k,b)a_k^{-3/2}(\Delta a)_k$$

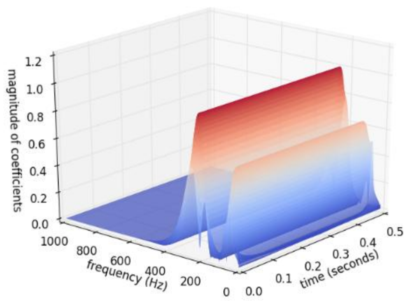
Measurement and environmental noise can be suppressed using wavelet transform based noise reduction techniques. Wavelets provide a sparse representation of the signal in that most of the energy in the signal is concentrated in small number of wavelet coefficients. Hence, noise can be reduced by setting to zero most of the small valued wavelet coefficients that fall below a certain hard threshold. In this research, the threshold is determined using the RiskShrink algorithm which mimics the performance of an oracle for selective wavelet reconstruction, minimizing the error between the estimated signal and the true signal [11]. This process of noise reduction is introduced as an intermediate step between step 1 and 2 in computation of SST described above.

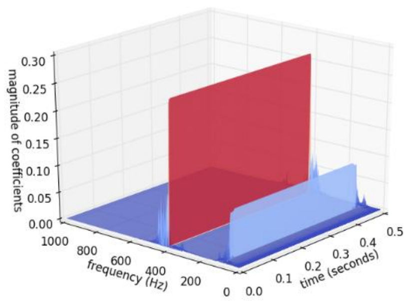
3. Results and Discussion

The shock and vibration data collected in the experiments are processed using SynchWave package implemented in R programming language CWT and SST with noise suppression [12]. Before the analysis of shock and vibration signal, to demonstrate the improvement in time-frequency resolution that SST provides over CWT, a well characterized signal $x(t) = sin(2\pi 100t) + 3\sin(2\pi 400t)$ sampled at 2000Hz is transformed by SST and CWT. Figure 3 shows the results of the transformations. The 3-D time-frequency representation is sharper with SST as indicated by the clearly resolved coefficients at focused at 100Hz and 400Hz. On the other hand, CWT spectrum is smeared over the region around 100Hz and 400Hz. The Fourier Transform based power spectral density (FT-PSD), Figure 3(a) based Power spectral density is shown to provide a clear picture of frequencies in the signal in a 2-D plot (PSD vs frequency).



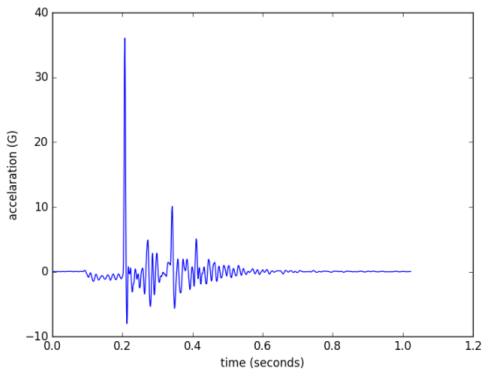
(a)

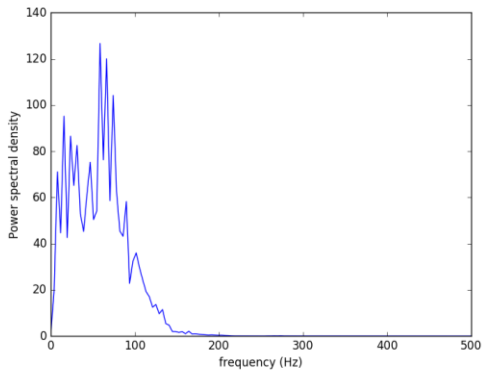




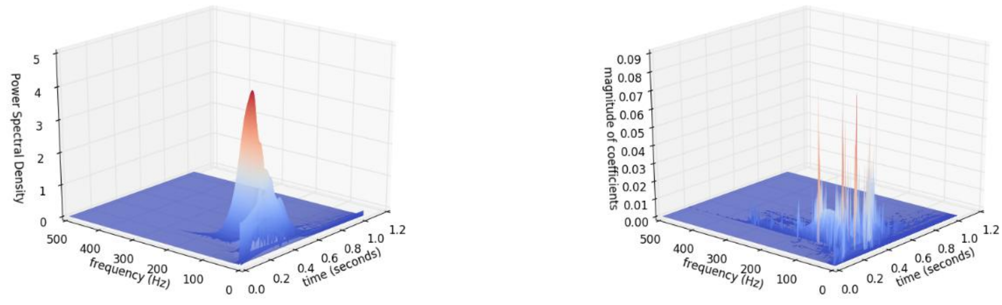
(b) (c)

Figure 3: *(a) Fourier Transform based PSD of sum of 100Hz and 400Hz sine wave (b (c) CWT*



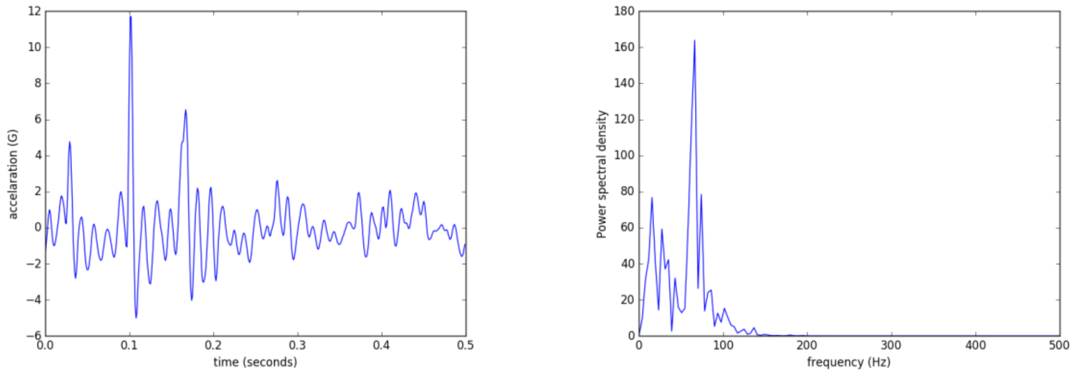


(a) (b)

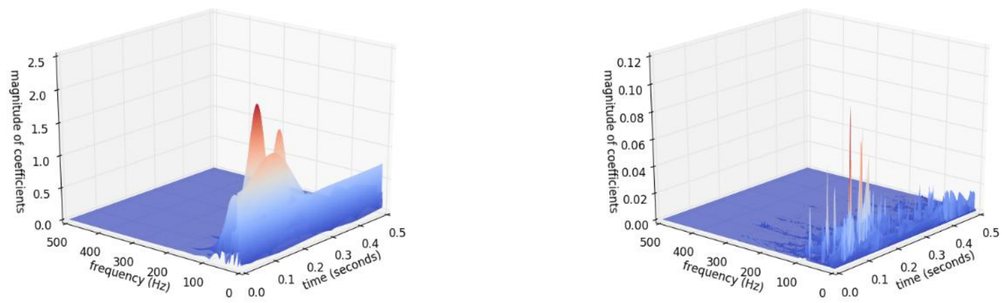


(c) (d)

Figure 4: *(a) Acceleration Measurement of Shock Produced by 2 inch drop (b) Fourier Transform based PSD (c) CWT (d) SST*



(a) (b)



(c) (d)

Figure 5: *(a) Acceleration Measurement of Shock Produced by 2 Inch Drop (b) Fourier Transform based PSD (c) CWT (d) SST*

Figure 4 shows the acceleration, FT-PSD, SST and CWT for the shock experiment for a 2 inch drop along the direction of the drop (z axis). Figure 5 shows the acceleration, FT-PSD, SST and CWT for the vibration measurement along the direction of the drop (z axis). Figures 4 and 5 are exemplar plots and the observations derived through these are consistent for other measurements from the experiment as well. For the shock signal, FT-PSD, CWT and SST shows peaks at 75 Hz. Several other frequency components are seen at between 10Hz and the peak at 75Hz. For FT-PSD, there is no information about the time periods when these frequencies are present. It is shown here to provide a clear view of the frequency components present in the signal. Both SST and CWT indicate that the dominant frequency component occurs approximately in a temporal region around 0.2 seconds. Uncertainty principles in time-frequency resolution dictates that the time instant when a specific frequency signal occurred can only be estimated up to certain accuracy. The CWT coefficients are smeared in over various frequency components, but the synchrosqueezing process described in section 2.2.2 allows SST to resolve those frequency components more clearly. Similarly, inferences can be made for vibrational data analysis as represented in Figure 5. The vibrational data analysis shows strong frequency components in the frequency band less than 100 Hz. CWT and SST show that these frequency components occur around 80Hz and other frequency components between 10 Hz and 50Hz. The resolution is once again better in the SST domain than the CWT with better resolved frequency components. The use of CWT noise suppression as an intermediate step in SST also reduces possible measurement or environmental noise in the time-frequency analysis.

4. Conclusion

This article introduces SST in conjunction with CWT based noise suppression as a tool to analyze the time-frequency characteristics of shock and vibration and compare its analytical effectiveness to conventional CWT based time-frequency analysis. In a controlled laboratory setting, acceleration of wooden pallets associated with shock and vibration was measured. Results of the analysis show that the process of frequency reallocation through synchrosqueezing employed by SST can better resolve joint frequency and time resolution at CWT. In conclusion, it can be stated that SST is an effective tool for modeling and simulation of non-stationary signals such as shock and vibration.

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Research Article

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Simultaneous Multi-Translational-Axis Motion used in the Evaluation of Product Component Frequency Response and Unit Load Stability

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Abstract The motion of packaged product transport vehicles can be described with six axes of motion: three translational (vertical, lateral, longitudinal) and three rotational (pitch, yaw, roll). Laboratory simulation of six axis motion is complex and typically requires expensive equipment with many moving parts. For these reasons, the packaging industry has focused laboratory simulation on the one axis that contains the most energy, the vertical translation axis. Analysis of three axes translational motion in truck, rail, and air transport reveals that although the vertical motion often contains more overall energy, the lateral and longitudinal motion is equal, or even higher, in intensity than that of the vertical motion within particular frequency ranges. In this study, a relatively cost effective way of reproducing simultaneous three-axis-translational motion is used to evaluate the vibration frequency response of a product's components. In addition, the stability effect of multi-translational-axis motion as compared to single-axis motion is evaluated on both a unit load and a single stack of packaged products. The value of simultaneous multi-translational-axis vibration testing is demonstrated through literature review and results from laboratory testing of unit loads, single stacks of packaged products, and the analysis of the frequency response of a product's components.
Keywords *Packaging Dynamics; Multi-Axis Vibration; Transport Vibration Testing; Frequency Response; Load Stability*

1. Introduction

The motion of packaged product transport vehicles occurs in multiple axes all at the same time; motion along the lateral, longitudinal, and vertical axis, and rotation about these axes: pitch, yaw, and roll, Figure 1. This fact makes laboratory simulation of this complex motion challenging and expensive. Based on the typical depiction of motion in a truck bed, it is often assumed that the most intense packaged product input exists in the vehicle in the vertical axis, thereby simplifying simulation in a laboratory to reproducing only the fully constrained single-axis vertical motion. This paper highlights a study that supports the assumption that vertical motion is always the most intense motion is incorrect. It is shown that at particular frequencies, the lateral and longitudinal motion of vehicles can exceed levels of the vertical motion.

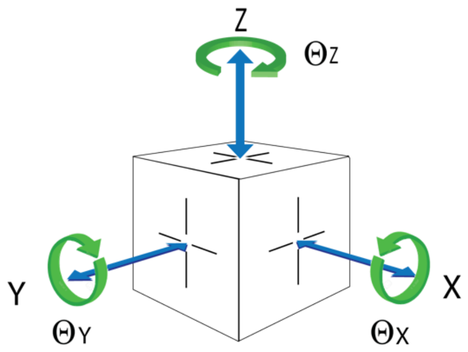


Figure 1: *Six axis motion*

Single axis vibration is the packaging industry standard for simulation of the distribution environment and the fragility evaluation of products. Different electrical/mechanical/fluid mechanisms are used to produce the motion of the platen each with their pros and cons. Due to its relative simplicity as compared to multi-axis motion systems, single-axis systems are less expensive and easier to maintain. However, development of the technology related to reproducing and controlling a vibration table's motion has made simultaneous multi-translational-axis vibration a more reasonable consideration. This study utilizes an electric servo-motor driven multi-axis shaker resulting from this development.

It is logical that the frequency response of a component inside a product and the stability of a unit load or stack of packages is dependent on the axis of motion. If single-axis motion is used to simulate a multi-axis environment, would the component and packaged product response differences be? This study answers this question by comparing the response of a product, a unit load, and a stack of packaged products when subjected to single-axis motion versus simultaneous multi-translational-axis motion.

Additionally, this paper addresses different industries employing the technology of multi-axis vibration. Several industries currently use simultaneous multi-axis vibration. Interest has grown since the mid 1980's [1] and facilities with this equipment are located around the world. This paper provides a brief overview of which industries are using multi-axis vibration in laboratory simulation and why they are doing so. Studies showing the inadequacies of single-axis vibration testing and the benefits of multi-axis vibration testing are highlighted.

1.1. Vehicle Motion

The motion of trucks, trains, and planes is stochastic or non-deterministic in nature, meaning that the output can vary for a given set of controlled inputs. This phenomenon is called random vibration. To graphically illustrate this complex motion, the average intensity of the vibration is plotted versus frequency in a power spectral density (PSD) plot. The power density, typically in units of G^2/Hz, represents the average intensity of the motion versus the frequency. This tool produces a "fingerprint" for a given vehicle enabling one to see at which frequencies a particular vehicle vibrates with a higher intensity than at others. The energy represented by the PSD plot can be calculated as the square root of the area under the curve called the overall grms value of the motion. The overall grms value for different PSD plots can be used to compare the overall intensities of the different motions represented. While the overall grms is valuable for comparing PSD plots, it can be misleading in that a peak intensity of the motion of a vehicle over a small frequency range will not have a significant effect on the overall grms. This “averaging out” of the peak can lead to a distorted frequency specific comparison between two PSD plots.

1.2. Multi-Axis Laboratory Testing

Several studies were conducted to examine the effect on results of using single-axis vibration testing to characterize the fragility of a product’s component. Two such studies used environmental stress screening (ESS) testing which involved subjecting a post-production product to “stresses which are more severe than anticipated in service. The object of this is to precipitate latent defects into recognizable failures, so that a particular unit does not proceed further in production…” [2]. The results from these studies supported the claim made by Harman and Pickel that “multi-axis testing excites all modes simultaneously with a more realistic stress loading (and) test objects may pass uniaxial testing but fail under actual operating conditions” [3]. Another study cited, “Although test engineers try to build in a safety margin by using high vibration levels, sequential tests still lack the interactive effects of vibration on multiple axes and may fail to excite certain critical modes” [4].

In a study by Whiteman and Berman, the researchers used notched aluminum round bar test specimens fixed on one end and free on the other. The specimens were subjected to random vibration in a horizontal and vertical orientation sequentially. Results were recorded as a number of cycles to failure defined by crack propagation in the region of the notch. Interestingly, by merely changing “the order in which the uniaxial excitation was applied during the test caused a variance in the results” [5].

A second similar study was conducted by French, Handy, and Cooper. In this study, specimens were made from square aluminum beams which were notched on two adjacent sides and tested in a fixed-free configuration. Samples were vibrated on a simultaneous two-axis (X,Y) shaker with a sinusoidal input at 4 g from 10 to 35 Hz. Specimens were tested by two methods: 1) Sequential single-axis testing and 2) Simultaneous two-axis testing. “The two methods produced different failure times, different failure distributions, and different failure modes” [6].

There are benefits to simultaneous multi-translational-axis testing as compared to sequential single-axis testing beyond the aforementioned component failure response differences. One such benefit is time savings. In applications where samples must be vibration tested in the lateral, longitudinal, and vertical orientations, using a single-axis shaker requires that the sample be rotated and retested for each of the three axes. If the goal is to simulate an automobile use cycle, vibration testing lengths can be anywhere from several hours to several hundred hours. Simultaneously testing all three axes can save hundreds of hours in test time over sequentially testing one axis at a time [3].

Several industries currently use simultaneous multi-axis vibration in the evaluation of their products and packaging structures. One of the first large scale multi-axis test facilities was in Julich, Germany in 1983 called SAMSON. This facility was developed primarily to improve experimental qualification of nuclear reactor components and their fitting against seismic events. It was recognized that because of its capacity to test items as large as 25 tons, SAMSON could be used to test building structures and spacecraft components [7].

In its most recent revision of MIL-STD-810G, the US Department of Defense recognized the value of simultaneous multi-axis testing by specifying Multi-Exciter Testing (MET) [8]. Prior to this change, MIL-STD-810F specified sequential Single-Exciter Testing (SET) [9]. The change in specification recognizes the previously mentioned benefits of laboratory simulation improvement and cost and time savings.

It is noteworthy to comment on the automotive industry's quest for the use of multi-axis vibration technologies. In the automotive industry, the lack of published standards has not prevented the use of multi-axis testing procedures. The continued search for improved product quality and reduced warranty has led to the development of a number of multi-exciter, multi-axis test systems [3].

No literature was found on the use of multi-axis vibration by the packaging industry even though packaged products undergo this complex motion in transport vehicles. ASTM D5112 specifies a horizontal product frequency response test and ASTM D3580 specifies a vertical product frequency response test [10, 11]. Both tests utilize either sinusoidal or random vibration input and both tests are performed in the single axis only. ASTM D999 and D4728 specify frequency response testing of packaged products in the vertical axis only [12, 13]. The only place vibration testing is specified for packaged products in more than one axis is the sequential three-axis testing of packaged products going into a less-than-truck load (LTL) or small parcel delivery system environment [14, 15]. In these distribution systems, packaged products could be oriented with any of the three product axes positioned vertically in the vehicle. In other words, this is still only a vertical vibration test for a packaged product that could be placed in a vehicle on any of its six faces.

Singh et al. conducted a multi-axis vibration study of the truck transportation environment to compare lateral, longitudinal, and vertical vibration generated by a commercial truck with heavy and light loads. The results showed that below 20 Hz, lateral and longitudinal vibration levels were generally much lower than vertical levels, but at frequencies above 20 Hz, all three were similar. The more heavily loaded trucks showed higher lateral and longitudinal levels of vibration than the lightly loaded ones [16]. These results indicate that if a product or packaged product system had critical modes above 20 Hz, vertical axis only vibration simulation would miss an important part of the vibration intensity input to the system. Such glaring omission in the full spectrum of vibration intensities is alleviated by using multi-axis vibration in testing.

2. Materials and Methods

2.1. Vehicle Motion Axis Comparison

Power spectrum density profiles from several vehicle types were compared. The average intensity of the vibration and power spectral energy from each of the axes (lateral, longitudinal, and vertical) were compared at different frequencies. The comparisons were used to show whether lateral and longitudinal vibration input was significant as compared to the assumed more intense vertical motion.

2.2. Single-Axis versus Multi-Translational-Axis Testing Comparison

A fully constrained simultaneous three-translational-axis vibration table from Kokusai, Inc. was used to perform this testing, Figure 2. This vibration table is powered by six servo motor driven screws (two in each axis) forcing motion of the platen along linear bearings in each of the three axes. The machine is capable of vibrating loads up to 200 kg in weight, has a frequency range of 1-300 Hz, and a peak-to-peak displacement of 51 mm. A Vibration Research VR9500 three-axis controller enabled the input of both sinusoidal and random vibration to all three axes simultaneously.

Figure 2: *Kokusai, Inc. three-axis electric servo motor vibration table*

2.3. Product Frequency Response

The frequency response of the compressor and condenser in an Electrolux upright refrigerator/freezer unit (Model: FRT18S6JW4) was recorded using a three-axis accelerometer attached to each component. The frequency response was obtained from a vertical input and compared to the frequency response from a sequential lateral and longitudinal input. The unit was strapped to the vibration table to isolate motion of the critical components inside, Figures 3 and 4. For each axis, a sinusoidal sweep was performed at 0.25g from 1 to 100 Hz at a sweep rate of 1 octave/min per ASTM D3580 [11]. A transmissibility versus frequency plot was generated for each axis of each component when excited with sequential vertical, lateral, and longitudinal input. The transmissibility plots were compared for analysis. An environmental stress screening test was performed on the unit using only vertical input at each component's fundamental natural frequency at an acceleration level of 0.25g. Then each component was subjected to simultaneous three-translational-axis input at the vertical, lateral, and longitudinal fundamental natural frequencies at an acceleration level of 0.25g. Component acceleration response was recorded for comparison.

Figure 3: *Frequency response of the refrigerator/freezer unit test setup*

Figure 4: *Refrigerator components tested*

2.4. Unit Load Stability

A unit load of 24 HP printers (Model: LaserJet 1200 Series, product weight: 8.0 kg) was banded and stretched wrapped for truck load shipment. The printers were packaged one per corrugated box, six boxes per layer, and four layers high. Using steel channel, the load was constrained to the vibration table which was allowed to move freely in all three-axes, Figure 5. The unit load was subjected to various vehicle random vibration inputs in the vertical axis only and then in the simultaneous lateral, longitudinal, and vertical axes. Motion of the load and perceived unit load stability was visually recorded for comparison between the two different inputs. The test sequence was then repeated for a single stack of packaged printer's four layers high, unstrapped and unwrapped.

Figure 5: *Unit load stability test setup*

3. Results

3.1. Vehicle Motion Axis Comparison

PSD plots of the motion generated in the vertical, lateral, and longitudinal axes from different vehicles and different vehicle types were evaluated. One typical example from each vehicle type is illustrated and analyzed below. While the PSD plots selected were typical of plots evaluated in this study, they may not be representative of all studies. The PSD plots were used for illustrative purposes.

3.1.1. *Railcar Vibration*

Railcar data revealed that the overall grms of the vertical motion is the highest, 0.20 grms versus 0.11 grms and 0.07 grms for the lateral and longitudinal axes, respectively, Figure 6 [17]. However, the average intensity of the lateral motion is clearly higher than that of the vertical motion between 4.5 – 7.5 Hz and 79 – 132 Hz. This indicates that although the vertical motion contained the highest overall input energy, omitting the lateral motion in simulation would miss simulation of the largest input within these frequency ranges.

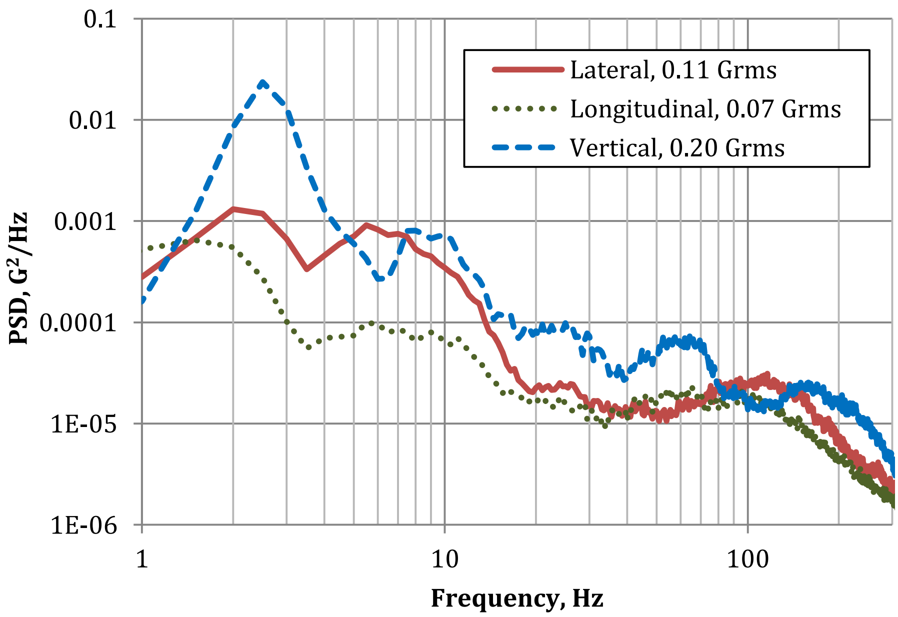


Figure 6: *PSD plot from a railcar, Melbourne to Perth, Australia*

3.1.2. *Truck Vibration*

Analysis of data from a truck revealed that the overall grms of the vertical motion is much higher at 0.14 grms versus the lateral at 0.04 grms and longitudinal at 0.05 grms, Figure 7 [18]. However, the average intensity of the lateral motion exceeds that of the vertical motion between 17 – 25 Hz and the longitudinal motion exceeds that of the vertical motion between 167 – 181 Hz. This analysis supports that found in the railcar analysis where omission of the lateral motion in simulation removes the highest input component in the range 4.5 – 7.5 Hz, and the omission of the longitudinal motion removes the highest input component the 79 – 132 Hz range.

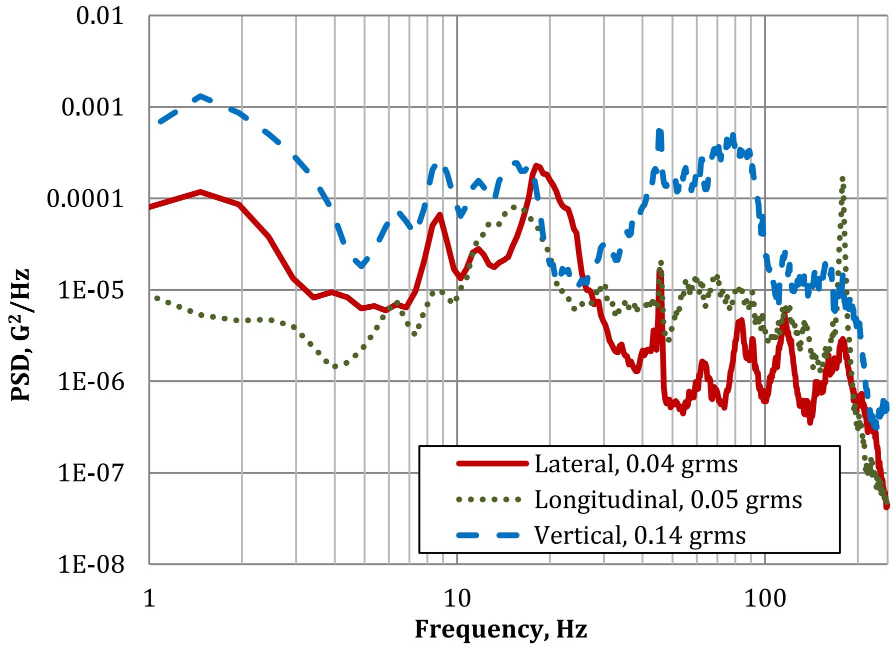


Figure 7: *PSD plot of a leaf spring truck*

3.1.3. *Airplane Vibration*

Analysis of the airplane vibration data revealed that the overall grms of the motion in all three axes was exactly the same, 0.10 grms, Figure 8 [19]. Even the average intensity of the motion contributed by each of the three axes was very similar over the entire frequency range. These results indicate that each of the three axes contribute nearly equally to the packaged product input and are all significant for consideration in laboratory simulation.

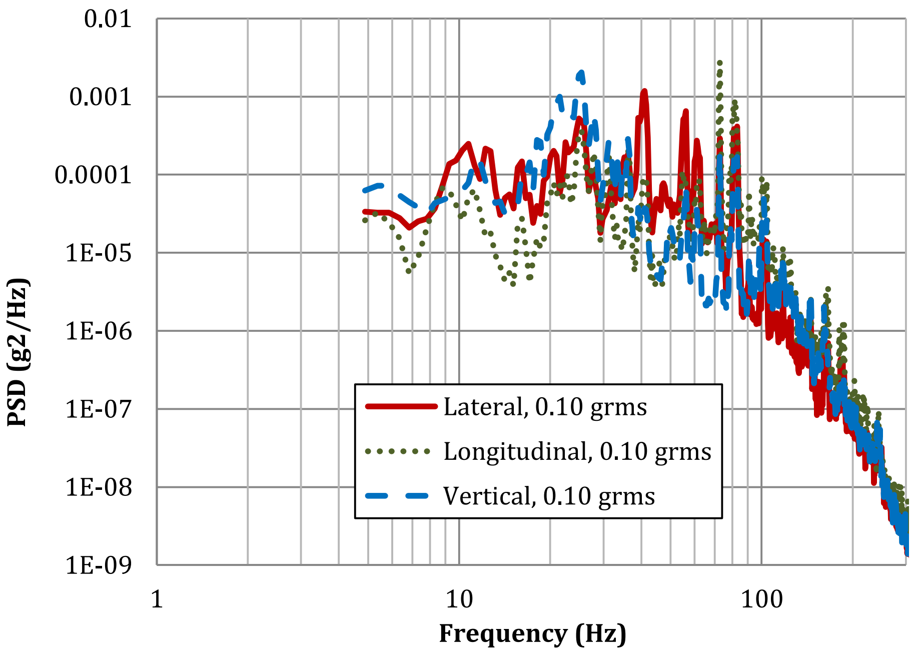


Figure 8: *PSD plot of a typical turbo-prop airplane*

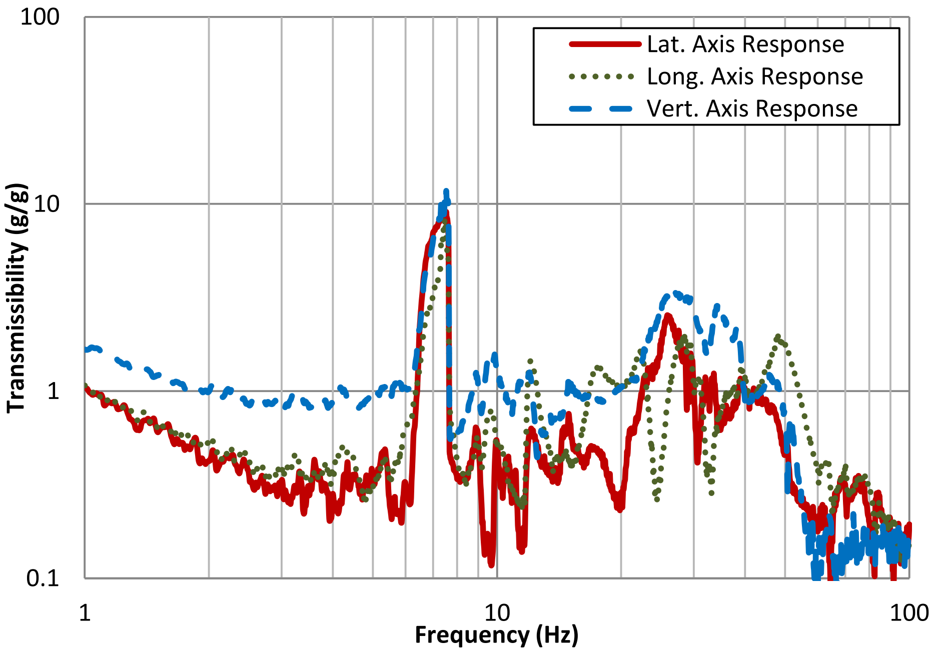
All three PSD plots analyzed in this paper show that the lateral and longitudinal motion exceeds the vertical motion at frequencies above 40 Hz. The data support the results observed by Singh et al., where results showed that above 20 Hz, lateral and longitudinal vibration levels were similar to the vertical motion [16]. Since protective package systems are typically soft in nature, the natural frequencies of these systems are typically less than 40 Hz. Therefore, the damage potential for packaged products and their components is greater at lower frequencies. The PSD plots analyzed in this study illustrate that the intensity of the lateral and longitudinal motion can equal or exceed the vertical in this particularly damaging frequency range of less than 40 Hz and even at frequencies less than 20 Hz.

3.2. Single-Axis versus Multi-Translational-Axis Testing Comparison

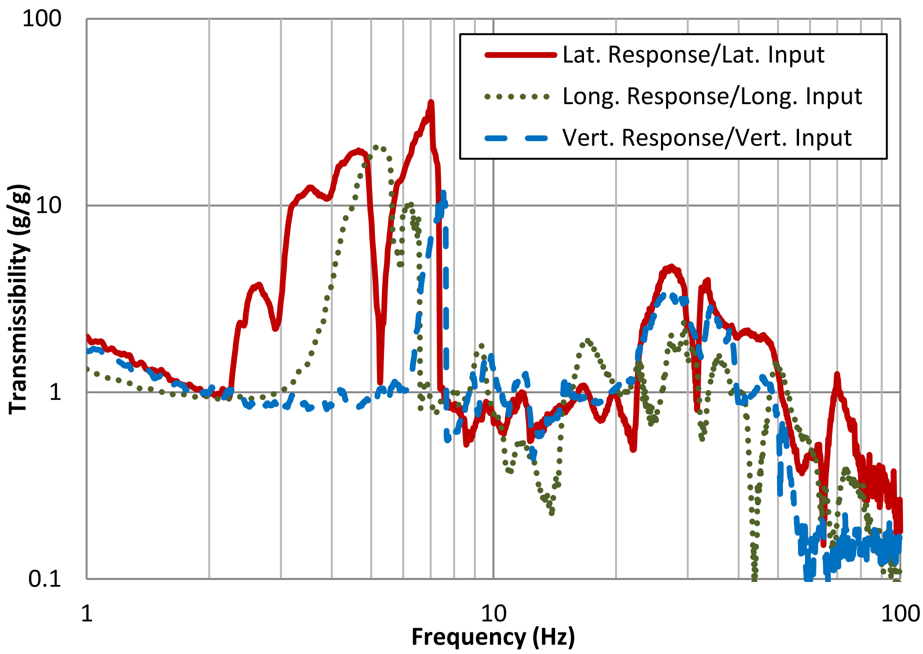
3.2.1. *Product Frequency Response*

Integrity of a refrigerator compressor is a concern during transportation due to its low natural frequency. A visual comparison of Figure 9 reveals the effect the input axis has on the frequency response of the compressor. When tested with vertical input only, as specified in ASTM D 3580 [11], the fundamental frequency is in a narrow band between 6.3 and 7.6 Hz, Figure 9a. However, when subjected to inputs in the vertical, lateral, and longitudinal axes, the fundamental frequency range extends to include a large range from 2.3 – 7.6 Hz, Figure 9b.

The condenser is another critical component during transport and exhibited a similar widening of the fundamental natural frequency range when subjected to multi-translational-axis input versus single axis vertical input. Although not as clear as in the case of the compressor, visual comparison of the vertical, lateral, and longitudinal responses, Figure 10, illustrates the effect. The fundamental frequency range was 6.3 – 14.0 Hz with vertical only input, Figure 10a, but widened to 3.0 – 17.5 Hz when the input was sequentially lateral, longitudinal, and vertical, Figure 10b.

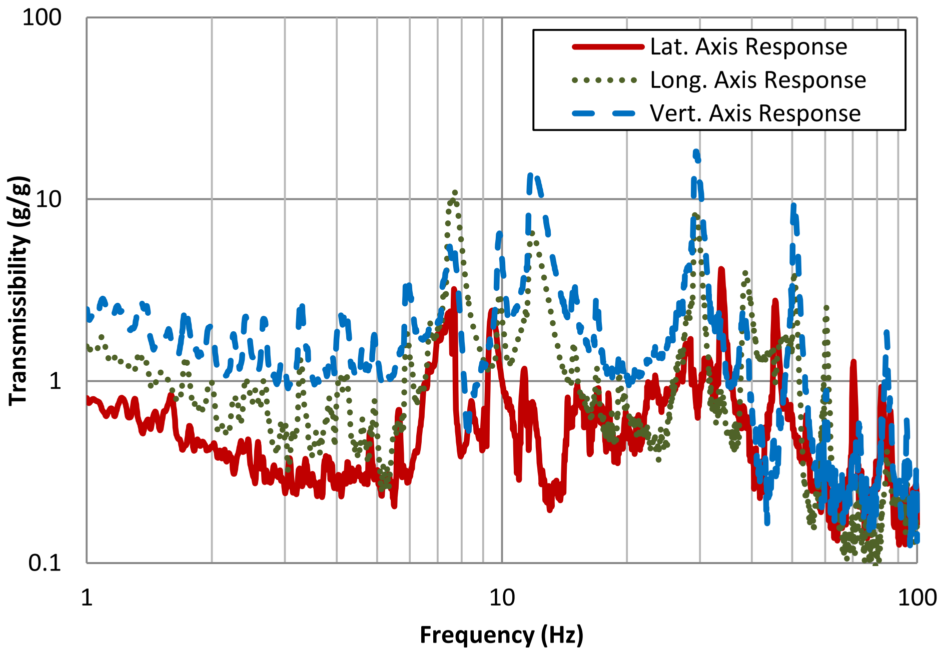


(9a)

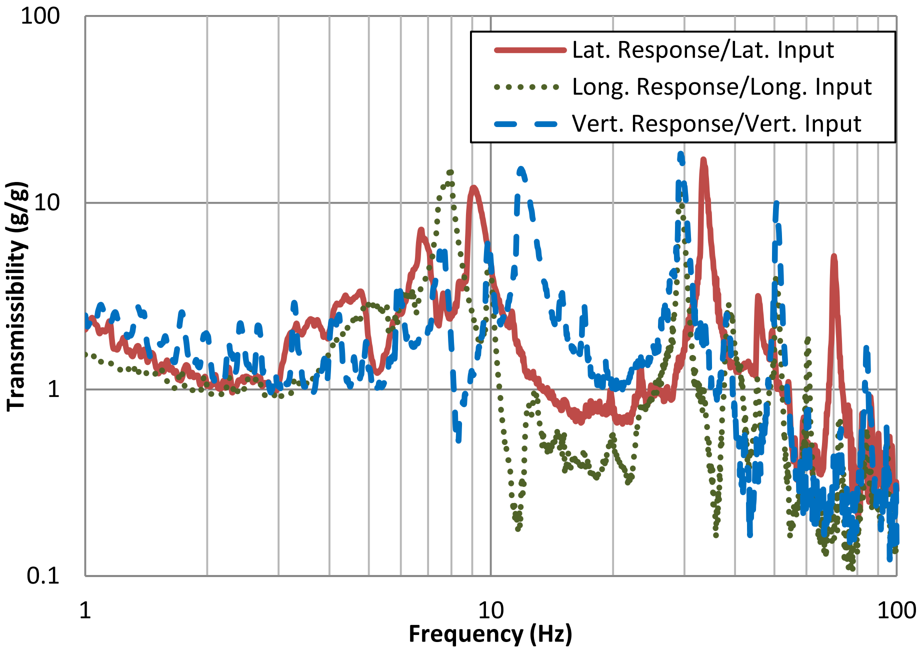


(9b)

Figure 9: a. *Compressor response to vertical motion only,* ***b.*** *Compressor response to sequential lateral, longitudinal, and vertical motion*



(10a)



(10b)

Figure 10: *a. Condenser response to vertical motion only, b. Condenser response to sequential lateral, longitudinal, and vertical motion*

An alternative way to compare the frequency response of a component when subjected to single versus multi-translational-axis motion is to look at the difference in shape of the frequency response plot in one axis when excited in different axes. Per ASTM D3580 [11], response of a component to motion in the vertical axis is recorded. However, by comparing the first response to that obtained by exciting the system in the two horizontal axes results in a different response, particularly at low frequency where frequency response is of greatest concern.

Figure 11 illustrates the difference in the longitudinal response of the condenser when excited in the lateral, longitudinal, and vertical axes sequentially. Similarly, Figure 12 illustrates the difference in the lateral response of the condenser when excited in the lateral, longitudinal, and vertical axes, and Figure 13 illustrates the difference in the vertical response of the condenser when excited in the lateral, longitudinal, and vertical axes. If the three curves in each of these figures had the same shape, then input axis would not affect the frequency response of a component. Clearly this is not the case at frequencies below 20 Hz, highlighting the importance of multi-translational-axis testing of critical components in determining response to vibration.

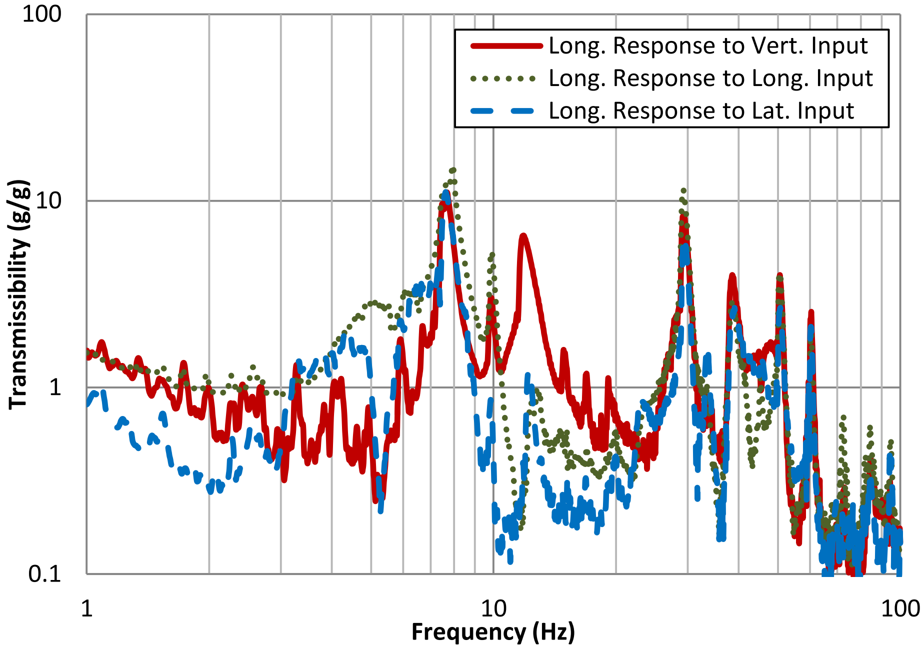


Figure 11: *Lateral response of the condenser with sequential lateral, longitudinal, and vertical input*

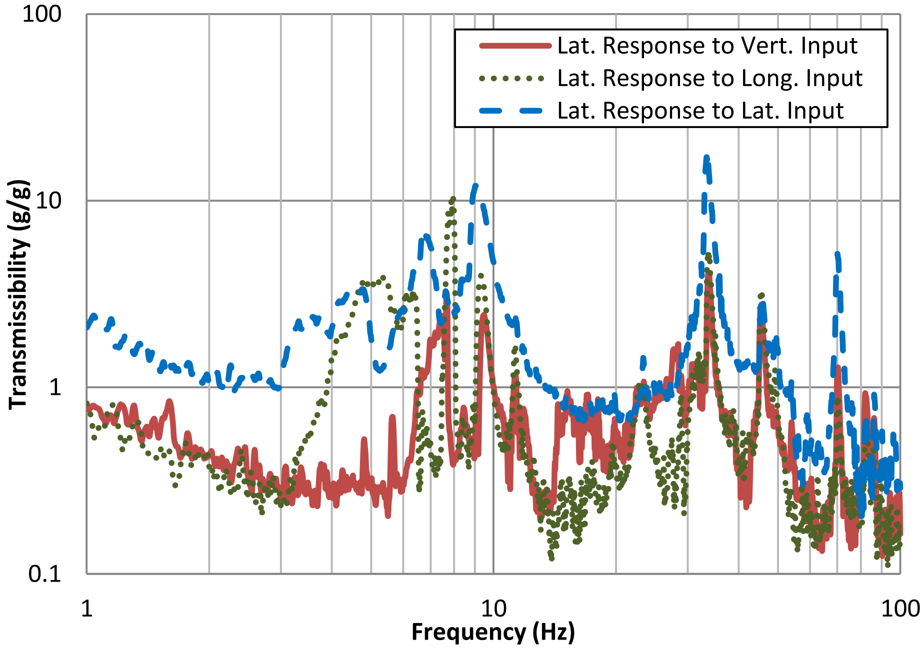


Figure 12: *Longitudinal response of the condenser with sequential lateral, longitudinal, and vertical input*

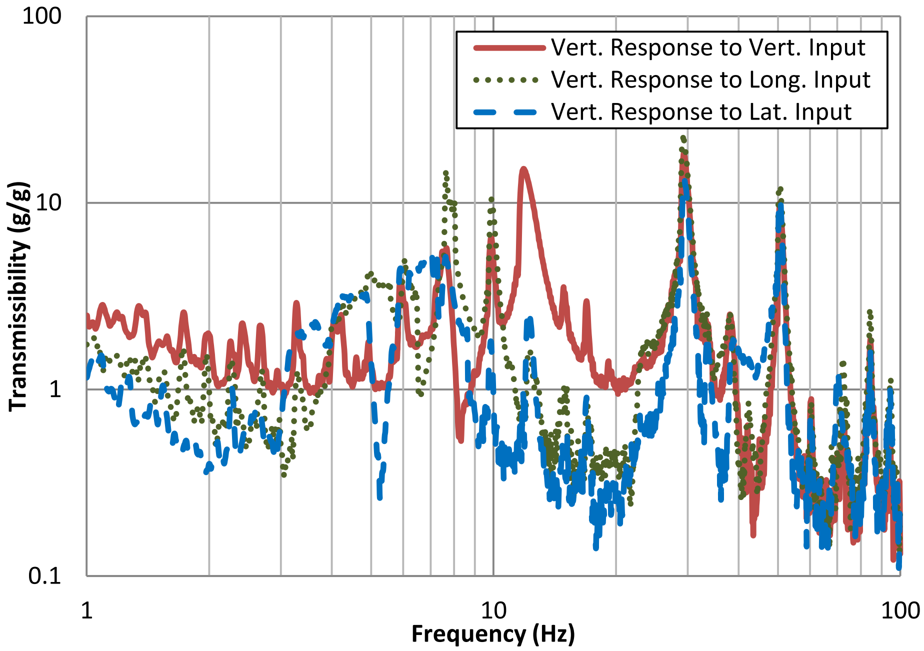


Figure 13: *Vertical response of the condenser with sequential lateral, longitudinal, and vertical input*

3.2.2. *Unit Load Stability*

The railcar vibration PSD from Melbourne to Perth [17], Figure 6, was used as the driving PSD for the unit load stability comparison. A clear visual difference in unit load stability was observed between the single-axis vertical input and the simultaneous multi-translational-axis input. When vibrated in the vertical axis only, no instability was observed. The strapping and machine stretch wrapped load had no observable box shifting or box-pallet misalignment. Contrastingly, within three minutes of simultaneous multi-translational-axis vibration, boxes in the same pallet load shifted as much as two inches, Figure 14. Similar results were found when testing the single stack of packaged printers.

The single stack of packaged printers included boxes that were not strapped or wrapped, and were subjected to only vertical and then multi-translational-axis simultaneous motion. There was no observed shifting of the load when vibrated vertically, however the simultaneous multi-translational-axis vibration caused immediate instability and eventual tip over, Figure 15. Although the overall grms of the lateral and longitudinal motion was less than that of the vertical motion (0.11 and 0.07 versus 0.20), their contribution to affecting the performance of the unit load and single stack packaged product systems was significant.

Figure 14: *Unit load instability as a result of three minutes of simultaneous multi-axis vibration*

Figure 15: *Single stack instability as a result of simultaneous multi-axis vibration*

4. Conclusions

The results from this study led to several conclusions:

- Previous work in the aerospace, nuclear power facilities, and automotive industries has demonstrated clear differences in the dynamic response of components and structures when exposed to multi-axis vibration as compared to single-axis vibration.
- Analysis of various three axis vibration power spectrum density profiles from rail, truck, and air transport indicate that within particular frequency ranges, lateral and longitudinal vibration levels can equal or exceed those in the vertical axis.
- Overall grms, while useful for comparing PSD profiles, can average out or hide large variations in the average intensity of vibration over narrow frequency ranges thereby making true frequency specific comparison inconclusive.

- The frequency responses of components in a refrigerator vary significantly at frequencies below 20 Hz when comparing vertical to lateral to longitudinal input. Similarly, the frequency responses in the vertical, lateral, and longitudinal axes of components in a refrigerator vary significantly depending on the axis of input vibration.
- The stability of a unit load and a single stack of printers when exposed to simultaneous three-translational-axis railcar vibration inputs was clearly less than when exposed to only the vertical axis motion. These results for multi-translational-axis vibration reinforce the value of using simultaneous three-translational-axis vibration in the laboratory simulation of the vehicle motion for the evaluation of packaged product systems.

Acknowledgements

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Research Article

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Effects of Packaging Geometry on Heat Penetration Time in Retortable Semi-Rigid Plastic Trays

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Abstract Semi-rigid, retortable trays were filled with a food simulate and thermally processed in a water immersion automated batch retort system at rotational speeds of 6 RPM and 11 RPM. Triangle, rectangle, oval, and round trays were evaluated, each having approximately the same overflow capacity. During processing, trays were fixed in place with racks containing one shape per rack. Various rack location combinations were tested to provide processing data for each shape in each rack location. Heat penetration data was gathered using thermocouples located in the geometric center of each tray shape and this data was modeled to determine the slowest heating container. No differences were observed in rack location among tray geometries at either RPM level ($P>0.05$). The data generated during heat penetration runs was also used to model different retort temperatures and lethality values. A retort temperature of 215°F and a lethality value of 10 showed the highest average sterilization time ($P<0.05$) and these conditions were subsequently used for evaluation of tray geometry during thermal processing. At a rotational speed of 6 RPM, the average time to lethally was higher ($P<0.05$) for the triangle shaped tray than the rectangle and round shaped trays while the average process time to lethality for the oval tray was not different ($P>0.05$) than any other shape tray. At a rotational speed of 11 RPM, differences in average process time to reach lethality between tray geometries were insignificant ($P>0.05$).
Keywords *Retort Trays; Heat Transfer; Thermal Processing; Packaging*

1. Introduction

Thermal processing of prepackaged foods is one of the most widely used forms of food preservation (Teixeira and Tucker, 1997). A visit to any U.S. grocery store will find many different packaged food formats that have had some form of thermal process applied. The most familiar version of a retorted package is the metal can. Even with newer, more innovative packaging options available the metal can continues to be used in large quantities due to universal acceptance, low cost, and existing industrial infrastructure. However, there are multiple options available for shelf stable retort packaging including retort-able cartons, pouches, and semi-rigid trays, all which continue to grow in market penetration. A recent example of alternate package growth in the shelf stable marketplace is a new microwavable semi-rigid tray for the SpagettiOs® brand by the Campbell Soup Company (Campbell Soup Company, Camden, NJ). This offering, targeted at younger users, offers benefits beyond the traditional metal can such as microwave-ability and safe edges once opened.

The process of retorting delivers a packaged product that is commercially sterile. Commercial sterility is defined in 21 CFR Part 113.3 as "the condition achieved either by the application of heat which renders the food free of microorganisms capable of reproducing in the food under normal non-refrigerated conditions of storage and distribution and free of viable microorganisms (including spores) of public health significance, or by the control of water activity and the application of heat which renders the food free of microorganisms capable of reproducing in the food under normal non-refrigerated conditions of storage and distribution" (21 CFR 113.3).

The basic principle that governs the retort process is the transfer of heat from a heating medium into the packaged product (Rattan and Ramaswamy, 2014). Two specific modes of heat transfer are convection and conduction. Convection heating is observed in liquid based foods, such as broths, while conduction heating is observed in solid containing foods such a beans. Foods that contain both liquid and solid parts, such as soups and some sauces heat via a combination of effects (Rattan and Ramaswamy, 2014).

Consumer expectations have grown over the years to the point where higher quality levels at reasonable prices are expected. As process engineers and food scientists work to provide these types of products, balancing thermal processing for the destruction of microorganisms and the loss of nutrients is a critical consideration. For example, vitamin degradation is a first order reaction similar to microorganism destruction, only with a higher decimal reduction time associated with vitamins (Al-Baali and Farid, 2006). If a product was processed in a traditional retort process, nutrients could be degraded as microorganisms were eliminated to render the food commercially sterile. In this example, one possible alternate to maintain preserve some nutrient integrity would be to use higher temperatures at shorter processing times (Ramaswamy and Dwivedi, 2011). In an effort to further minimize quality impact on retorted foods, the thermal processing industry has continued to develop retorts and thermal processes which optimize sterilization times and retain the maximum amount of food quality (Singh et al., 2014)

Another possible strategy for delivering optimized heating to a food product could be the use of packaging type and geometry. Heat transfer could be designed at an optimum rate, retaining nutritional and organoleptic attributes that consumer's desire. Ramaswamy and Grabowski (1998) showed a significant reduction in processing time for salmon packaged in semi-rigid plastic containers compared to product packaged in a metal can. Additionally, other research found shorter processing times which resulted in less browning of products such as pumpkin puree when processed in retort pouches versus cans (Snyder and Henderson, 1989).

By viewing packaging geometry as an impactful element in thermal processing, product developers would gain another tool to deliver consumer expectations of shelf stable food. This expanded approach to retort processing could give manufacturers an advantage in product cost, quality, and consistency.

Existing literature is unclear with regard to the effect of packaging geometry on overall processing time and heat penetration in packages of like construction and identical internal volumes. The goal of this study was to understand what impact geometry plays in overall processing by studying semi-rigid plastic trays of the same construction, same internal volume, but different geometries. Oval, triangle, rectangle, and round trays were produced via flatbed thermoforming and used for the evaluation. A water immersion rotary retort process was employed at two rotational speeds (6RPM and 11RPM) to study the influence of rotation on heating rates.

2. Materials and Methods

Trays used for this experiment were constructed of polypropylene (PP) / ethylene vinyl alcohol (EVOH) / polypropylene (PP) while the heat sealable lid-stock used to seal the tray consisted of cast polypropylene (CPP) / adhesive / Nylon / adhesive / EVOH / polyethylene terephthalate (PET). Four different shapes (Figure 1) were used in this experiment, including, rectangle, oval, round, and triangle (Sonoco Products Company, Hartsville, SC).

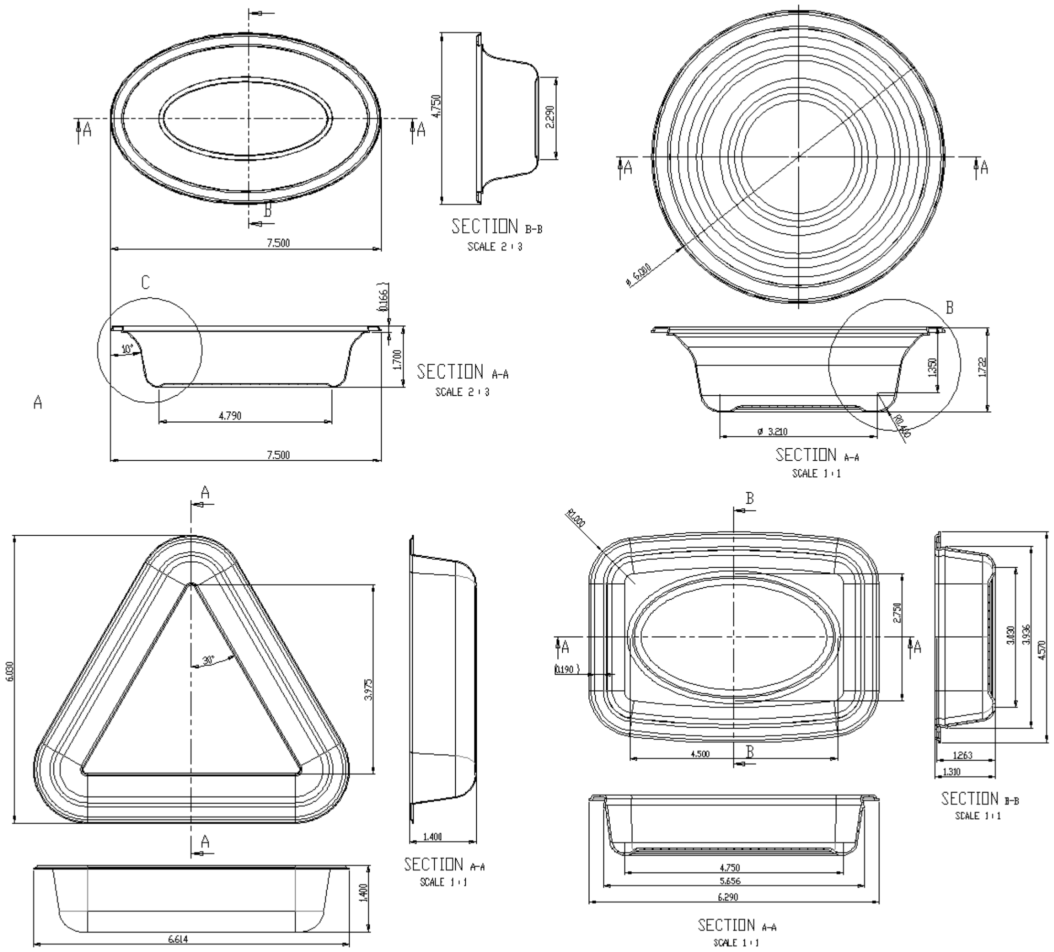

***Figure 1**: Retort tray shapes evaluated*

A model food system was designed to allow for easier quantification of the heat exposure impacts. This model system consisted of tomato paste (36 brix, ConAgra Foods, Omaha, NE), soybean oil (ConAgra Foods, Omaha, NE), water, ascorbic acid (Graham Chemical Corp., Barrington IL), and Panodan® 150 emulsifier (Danisco, Madison, WI) per Table 1. The model system was prepared in a steam-jacketed kettle with minimal heat applied during blending (not greater than 90°F). Manual mixing with a whisk and a direct drive pressure batch mixer (SPX, Rochester, New York) was used for thorough mixing of all components.

Table 1: *Food model system formula*

Ingredient	% of Total
Water	49.1%
Tomato Paste, 36 Brix	32.7%
Oil, Soybean	16.3%
Ascorbic Acid	1.0%
Emulsifier, Panodan 150	0.8%
Total	100.0%

Trays of each geometry were filled with approximately 12 net ounces of model system and sealed via a platen heat sealer (Pack Line PLB-15, New York, NY) with the appropriate seal platen and carrier system for each geometry. Once sealed, the lid-stock on each tray was manually trimmed and all units were stored at refrigerated temperatures for 12 hours prior to processing. Additionally, three (3) trays of each geometry were prepared with a needle style thermocouple (CNS, Ecklund Harrison, Fort Myers, FL) located through the sidewall of each tray with the end of the thermocouple located in the geometric center of the model food product. These trays were also filled with 12 ounces net weight of product prior to heat sealing and storage. After the rest period, trays were loaded into the appropriate retort racks based on the layout described in Figure 2. Thermocouples were then attached via 22-gauge type T copper-constantan wires (Ecklund Harrison, Fort Myers, FL) to a rotary CALplex™ data logger (TechniCAL, Metairie, LA). Two free leads were used, one placed next to the mercury in glass (MIG) temperature gauge probe and the other in the center of the process basket. Data was recorded from each thermocouple in 15-second intervals. Trays filled with water were used as ballast in each run to reduce the amount of food model system and trays needed for each run as indicated in Figure 2.

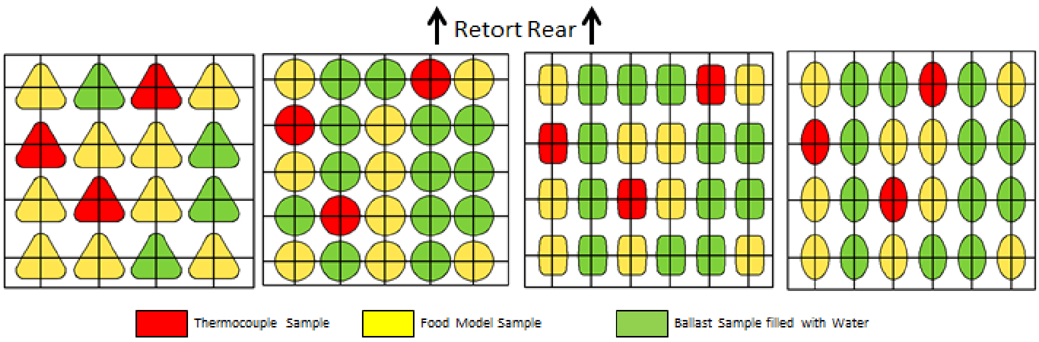

Figure 2: *Retort rack layout with sample type*

With four different tray geometries and corresponding racks, a total combination of six different rack to rack configurations were evaluated to determine if rack position inside the retort would have any effect on heating profiles. Figure 3 details the configurations used for each processing run.

		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Top	1	Rectangle	Round	Oval	Triangle	Rectangle	Oval
	2	Triangle	Rectangle	Round	Oval	Oval	Rectangle
	3	Oval	Triangle	Rectangle	Round	Triangle	Round
Bottom	4	Round	Oval	Triangle	Rectangle	Round	Triangle

Figure 3: *Rack location matrix for heat penetration runs*

An Allpax 5202 multimode pilot retort (Allpax, Covington, LA) was used in water immersion mode for each processing run with a maximum over pressure of 30 pounds per inch gauge (psig) used during processing to prevent tray deformation and protect seal integrity. Each rack position, as described in Figure 3, was processed at both 6 revolutions per minute (RPM) and 11 RPM. This retort vessel had come-up time (CUT) of 12 minutes and the slowest in-package heating zone was quantified with CALsoft™ modeling software (TechniCAL, Metairie, LA) at a processing temperature of 220°F. Once all runs were completed, CALsoft™ was used to establish average processing times given the slowest heating zones for each container.

Analysis of variance (ANOVA) was used to interpret the impact of rack position in the retort relative to racks containing other shapes for both 6 RPM and 11 RPM runs. All analyses were conducted with SAS® (SAS Institute, Cary, NC) software, using a significance level of 0.05 for hypothesis testing.

Additionally, the heat penetration data collected was used to model additional process conditions via CALsoft™, as described in Table 2. These model conditions used an initial temperature (IT) of 75°F and varied with different retort temperatures (RT) of 220°F and 215°F respectively as well as lethality (F value) values of one (1) and ten (10). Once average time to process temperature for each variable was determined via the process modeling functionality of CALsoft™, ANOVA was used to interpret the impact of changing lethality and RT. All analyses were conducted with SAS® (SAS Institute, Cary, NC) software, using a significance level of 0.05 for hypothesis testing.

Table 2: *CALsoft™ modeling inputs for average time to process temperature*

CALsoft Input Variables for Modeling		
Retort Temperature (RT)	Lethality (F value)	Initial Temperature (IT)
220°F	1	75° F
220°F	10	75° F
215°F	1	75° F
215°F	10	75° F

3. Results and Discussion

3.1. Retort Rack Location

The analysis showed there was no significant difference (P>0.05) among rack locations for any of the tray shapes (round, oval, triangle, rectangle) with regards to time to maximum temperature (Table 3 and Figure 4).

Table 3: *Average time to maximum temperature by retort rack location for each tray shape*

Shape	Rack Positon	Average time to maximum temperature (seconds)	Standard Deviation
Oval	Rack 1	1856.25	405.33
Oval	Rack 2	1464.55	228.30
Oval	Rack 3	1494.00	73.94
Oval	Rack 4	1590.00	317.49
Rectangle	Rack 1	1278.75	286.98
Rectangle	Rack 2	1425.00	604.34
Rectangle	Rack 3	1735.00	415.11
Rectangle	Rack 4	1440.00	161.55
Round	Rack 1	1685.00	601.77
Round	Rack 2	1787.50	200.22
Round	Rack 3	1482.00	168.20
Round	Rack 4	1376.25	180.81
Triangle	Rack 1	1592.50	193.36
Triangle	Rack 2	1530.00	156.17
Triangle	Rack 3	1523.18	332.94
Triangle	Rack 4	1746.25	295.08

	F Value	P>F
Rack Location	0.31	0.8209

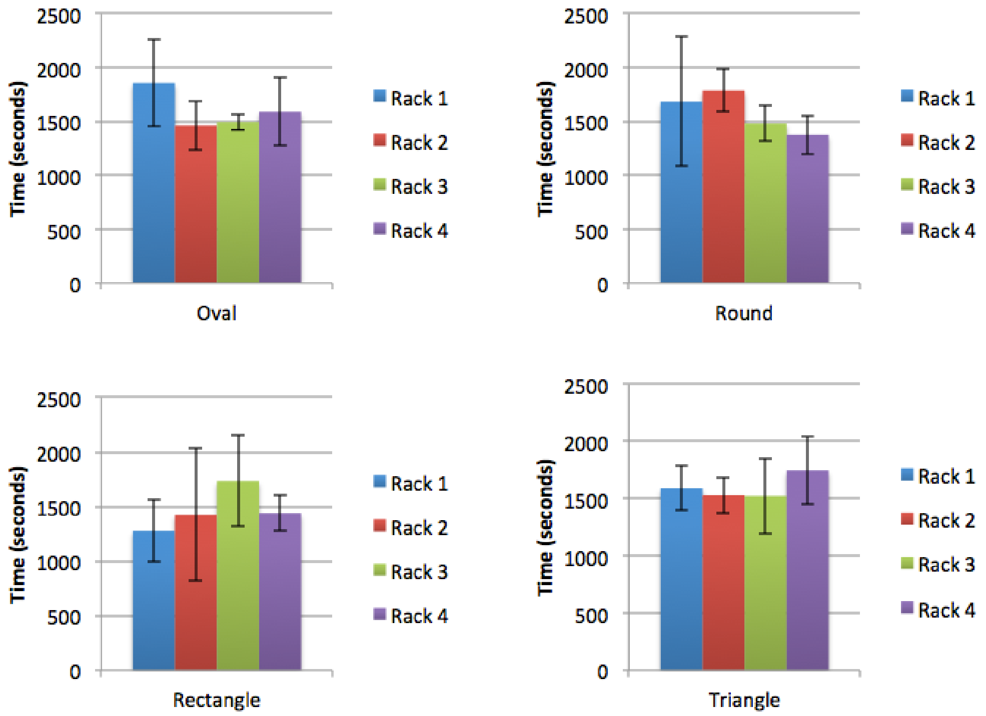

Figure 4: *Retort Rack Location – Average time to maximum temperature*

However, the analysis did show a difference (P<0.05) in average time to maximum temperature regarding the rotation speed of the retort basket used. There was longer time to maximum temperature (P<0.05) at 6 RPM versus 11 RPM across all tray geometries as seen in Figure 5.

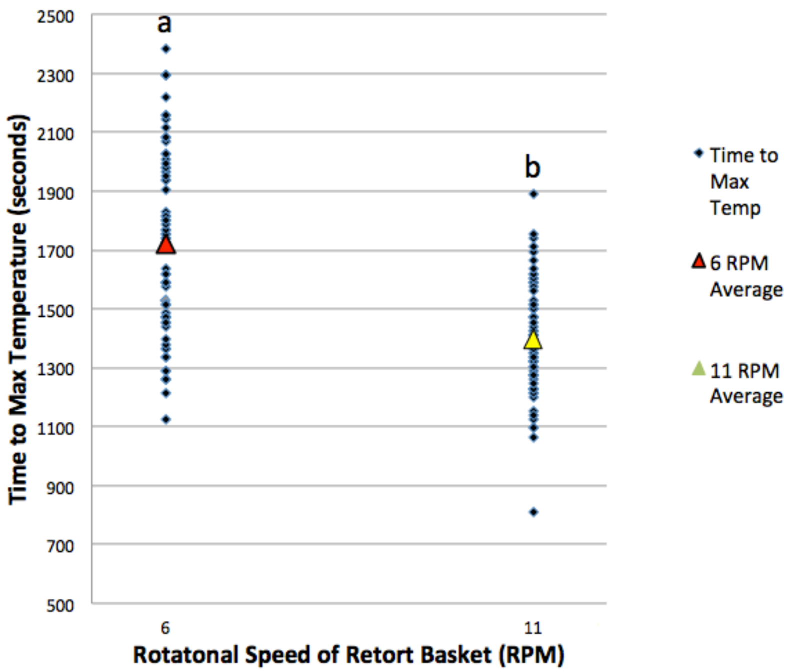

Figure 5: *Average time to maximum temperature versus rotational speed; letters denote statistical difference*

The impact of container position in the processing vessel on heat penetration was a foundational goal of this study. The use of rotation in a water immersion process intuitively leads to a conclusion of minimal localized heating due to the constant container movement within the vessel and maximum contact with the heating medium. Anecdotal information regarding temperature distribution tests using this process vessel supported this direction; however, basic data regarding this racking system did not exist. Without knowledge that location in this particular processing unit was not significant, subsequent data could be correlated by location. Since the data collected indicated there was no significance ($P>0.05$) in retort rack or thereby semi-rigid tray location inside the processing vessel (see Figure 2 & 3), further experimentation became possible using this loading methodology. Previous research around rotational effects on the slowest heating zone of a retort vessel supports these findings. Smout et al. (1998) studied effects of rotation on the slowest heating zone of retort in water cascading mode, finding that rotation caused the slowest heating zone to occur in the center of the retort basket, where as in static mode the slowest heating zone was located near the base of the basket. The authors concluded this was likely caused by the location of heating medium introduction from the top of the process vessel down, which is inherent to the water cascade design (Williams, 2012).

Furthermore, data collected showed there was no significance in rack position at either rotational speed. There was, however, a difference ($P<0.05$) for average time to maximum temperature for 6 RPM versus 11 RPM, with the higher rotational speed resulting in a shorter average time (Figure 5). This effect was observed in other published research where an increase in speed of rotation led to an overall reduction in total process time for a product that had broken heating characteristics (Bindu and Srinivasa Gopal, 2008; Ansar Ali et al., 2008). Additionally, Rattan and Ramaswamy (2014) also found a significant relationship between lethality level, rotational speed, color, and texture differences.

3.2. Average Time to Lethality by Process at 6 RPM

The average time to lethality at 6 RPM was found to be higher ($P<0.05$) for the process using a RT of 215°F and a lethality value (F) of 10 versus any of the other processes tested (Figure 6). For the process with a RT of 220°F, F=10, the average time to lethality was higher ($P<0.05$) than the RT of 215°F, F=1 process or the RT of 220°F, F=1 process. The average time to lethality for RT of 215°F, F=1 process and RT of 220°F, F=1 process were not different ($P>0.05$).

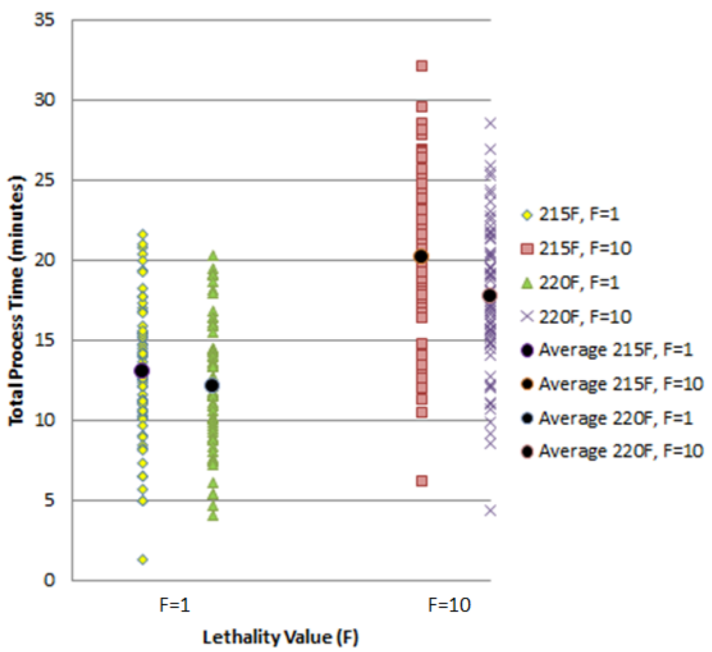

Figure 6: *Average time to lethality by process condition at 6 RPM with standard deviation*

3.3. Average Time to Lethality by Process at 11 RPM

The average time to lethality at 11 RPM was found to be higher ($P<0.05$) for the process using a RT of 215°F and a lethality value (F) of 10 versus any of the other processes tested (Figure 7). For the RT of 220°F, F=10 process, the average time to lethality was higher ($P<0.05$) than the RT of 215°F, F=1 process or the RT of 220°F, F=1 process. The average time to lethality for the RT of 215°F, F=1 process and the RT of 220°F, F=1 process was not different ($P>0.05$).

The average process time to lethality was found to be dependent on both retort temperature and the lethality value desired at both rotational speeds tested. A retort temperature (RT) of 215°F at a lethality value (F) of 10 was shown to have a longer ($P<0.05$) average time to lethality than any of the other processes analyzed (see Table 2). Since the average of the Ball process time was used, an understanding of how the Ball process time is calculated in CALsoft™ is needed to fully understand the logical effects of RT and lethality needs on the total process time.

$$B_b = f_h[\log(j_{ch}(T_{RT} - T_{IT})) - \log g] \quad (1)$$

The Ball formula method, as defined in Equation 1, determines the total process time (B_b) by using factors such as the heating lag factor (j_{ch}) and the heating rate index (f_h), as well as the retort temperature (T_{RT}), the initial product temperature (T_{IT}) and the number of degrees the slowest heating point in the container is below the retort temperature at the end of the heating process (Awuah et al., 2006; Awuah et al., 2007). As Equation 1 shows, a change in retort temperature has a direct impact on processing time. Heating factors also play a critical role in determining the Ball process time, however, each rotational speed was compared independently. This analysis showed the longest average processing time was achieved by the same process conditions (RT215°F, F=10) at both rotational speeds.

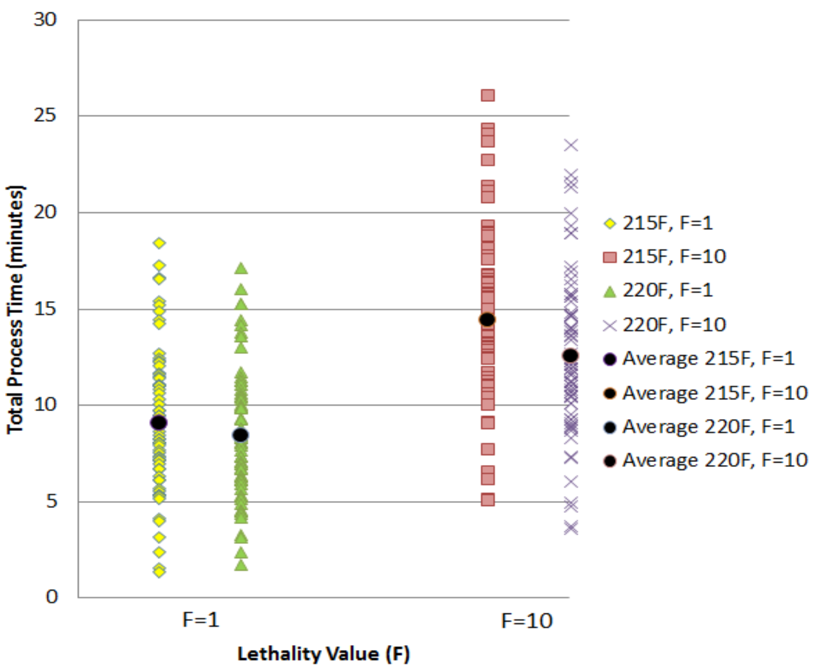

Figure 7: *Average time to lethality by process condition at 11 RPM with standard deviation*

3.4. Heat Penetration by Shape at 6 RPM

Since the RT of 215°F, F=10 process was shown to be significantly longer than the other processes evaluated, the heat penetration data was further evaluated by shape at these process conditions (heating factors for this process are shown in Table 4). At 6 RPM, the average time to lethality was higher ($P<0.05$) for the triangle shaped tray than for the rectangle and round shaped tray (Figure 8). The average time to lethality for the oval tray was not different ($P>0.05$) than any other shape tray.

Table 4: *Heating factors for trays at 6 RPM, for RT215°F, F=10 process*

Shape	Average heating rate index (f_h)	Average Lag Factor (J_{hc})
Triangle	23.81	0.94
Oval	22.48	0.79
Rectangle	20.69	0.66
Round	18.38	0.99

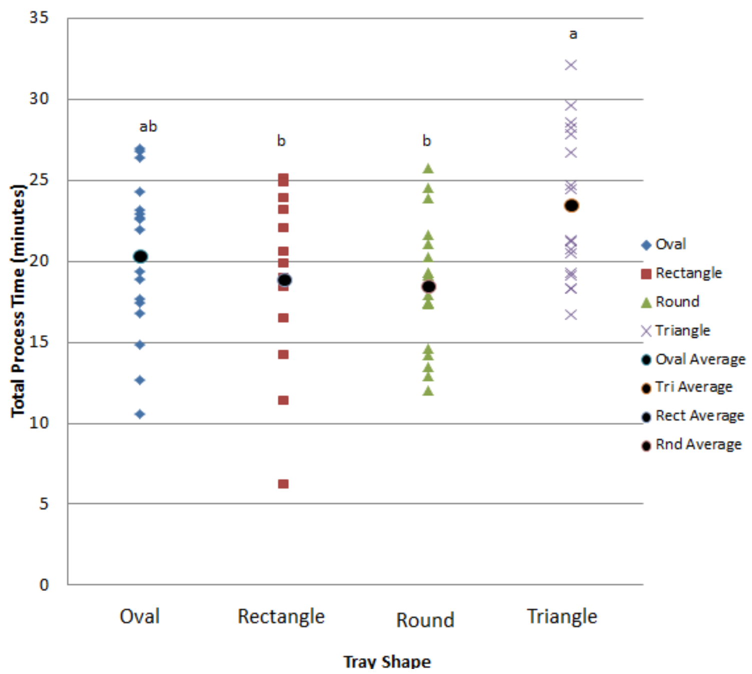

Figure 8: *Average time to lethality by tray shape at 6 RPM for RT215°F, F=10 process. Letters denote statistical difference*

3.5. Heat Penetration by Shape at 11 RPM

Using the process with a RT of 215°F and F value of 10, heat penetration data was evaluated by shape for 11 RPM runs (heating factors for this process are shown in Table 5). There was not a difference (P>0.05) in the average time to lethality among tray shapes for this process at 11RPM (Figure 9).

Table 5*: Heating factors for trays at 11 RPM, for RT215°F, F=10 process*

Shape	Average heating rate index (f_h)	Average Lag Factor (J_{hc})
Oval	15.92	0.79
Triangle	13.53	0.95
Round	14.38	0.76
Rectangle	13.64	0.60

At the 6 RPM rotational speed, the triangular shaped trays were found to heat more slowly than either the rectangular or round shaped trays. Initially, it was thought that a correlation between total surface area differences of each shape could explain the difference in heating rates. However, when the surface areas were calculated there was no dramatic difference between shapes (triangle = 90.25in^2, round = 91.66in^2, rectangle = 92.93in^2, & oval = 94.85in^2; includes surface area of lidstock). The data generated at 11 RPM provides further insight into the heat penetration mechanism. At 11 RPM, there was no difference (P>0.05) in the average time to lethality for each tray shape, indicating the increase in rotational speed nullified any heating impact of geometry. This data suggests that geometry does play a part in heating, to a critical level of movement (rotation). More aggressive agitation provided at a higher rotational speed could reduce temperature gradients faster. Therefore, at a lower rotation speed the geometry effect becomes more of a factor impacting heating than at higher rotational / agitation levels. Table 4 and Table 5 show the heating lag factors for each tray at both rotational speeds.

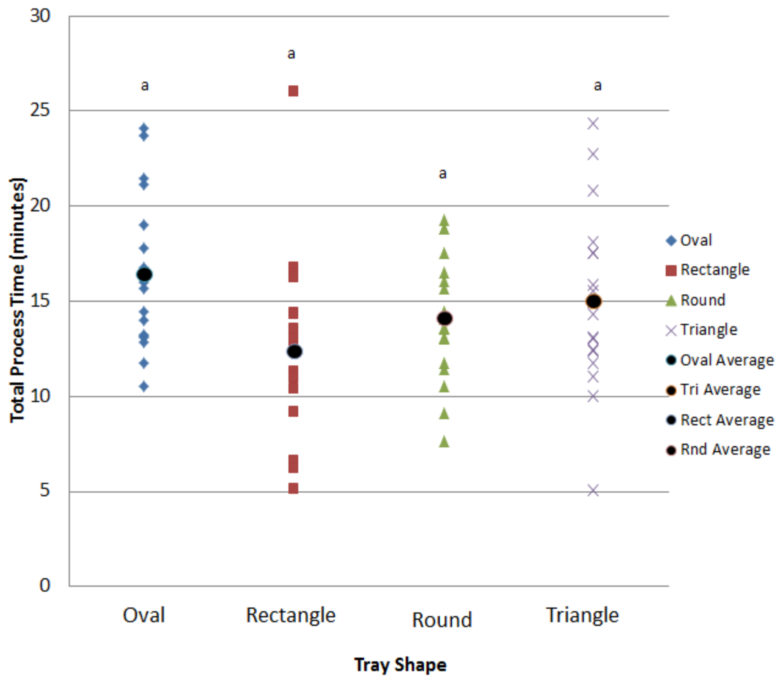

Figure 9: *Average time to lethality by tray shape at 11 RPM for RT215°F, F=10 process. Letters denote a statistical difference*

The impact of geometry change is demonstrated in the case of 6 RPM and the effect of increased agitation seen from rotational speed increases as 6 RPM values are compared to 11 RPM values for the same food system and same tray geometries. The geometry benefit seen at 6 RPM is negatively impacted as rotational speed is increased with a tip over point somewhere between 6 and 11 RPM. Ramaswamy and Dwivedi (2011) showed that rotation speed has a significant impact on the overall heat transfer coefficient in a retort environment, further confirming these results.

4. Conclusions

The impact of geometry on heat penetration was studied with the use of differently shaped semi-rigid trays of PP/EVOH/PP construction and similar internal volumes. A model food system or simulant, consisting of water, tomato paste, oil, ascorbic acid, and an emulsifier was used to fill the packages, which were subsequently sealed with a heat sealable lid stock. A thermal process was applied using a water immersion heating mode at two rotational speeds (6 and 11 RPM) in a pilot sized retort vessel. Trays were held in place during retorting with the use of racks which fit inside the retort basket of the processing unit and were designed specifically for each shape.

Previous research had indicated differences in product processed in different packages, such as metal cans versus flexible retort pouches or semi-rigid trays, but there was a lack of information available regarding the effects of geometry change as an independent variable only, excluding packaging construction and internal volumetrics as variables of possible influence to the study.

Results from this study showed there was no significant difference in average time to maximum temperature related to shape or rack location in the retort basket during processing ($P>0.05$) (Table 4). There was a significant difference in the average process time at 6 and 11 RPM, with 11 RPM resulting in significantly faster heating times ($P<0.05$). A retort temperature of 215°F and a lethality value of 10 showed the highest average sterilization time (P<0.05). At a rotational speed of 6 RPM, the average time to lethally was higher (P<0.05) for the triangle tray than the rectangle and round tray, which was likely due to uneven heating gradients within the triangle shape. The average time to lethality for the oval tray was not different (P>0.05) than any other tray shape. At 11 RPM differences it average time to lethality between tray shapes was insignificant (P>0.05).

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Case Study **Open Access**

Modeling of Changes: A Case Study on Corrugated Packaging Firm

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Abstract In this rapidly changing competitive industrial landscape, organizational survival is possible only after accepting changes. It simply means that organization is capitalising on its growth prospect for global developments and absorbing capabilities. The focus of organizations should not restrict to survival in competition and sustainability in market share but it should go beyond it. This is possible by applying an appropriate change management scheme. This study is based on a case study carried out in an Indian corrugated box manufacturing firm. A flexible strategic change management technique named 'SAP-LAP hills' has been used which depicts all situation, actor, process, learning, action and performance elements involved with the concerned organization. An actor-process matrix has been presented with both normal and prioritized scores. SAP-LAP index of change has helped in identifying the intensity of change forces. By locating the key result areas, it becomes possible to identify prime considerations relative to situation, actor and process.
Keywords *Change Management; Actor–Process Matrix; SAP-LAP Framework; Quantification*

1. Introduction

Information and technology travels with the pace of thought (Gates, 1999) which generates the necessity to cope with emerging trends and change. Technology, information and change are three dynamic factors which every time revolve around organizations and affect their workings. Successful organizations do not develop randomly but they need to have a strong change process to support the management's vision. Change and change management are most often discussed area around organizations (Bringezu and Bleischwitz, 2009). Change is an ambiguous term and it acts uniquely in accordance of different organizational situations. The business environment is changing and organizations are facing continuous challenges as variations are pervasive. The rate of change is accelerating; therefore, it becomes necessary to identify indicators of change impacting an organization.

It becomes essential for all organizations to adopt appropriate change management scheme for their long-term survival and sustainability. Change management involves implementation of new procedures with the changing demands of business environment, or to capitalize on business opportunities. In current industrial scenario, manufacturing sector is getting more popularity as it creates productive employment and business opportunities. Change management will help all manufacturing companies to boost their performance, improve quality and cut costs. The corrugated box industry is an inevitable part of Indian manufacturing sector. It is composed **of many small and medium independent players** to meet the increasing demand of high quality boxes. The study is an attempt to know about the strategies required for the adoption of an appropriate change management scheme. Situation, Actor, Process (SAP) & Learning, Action, Performance (LAP); (SAP–LAP) framework is one such model that provides opportunity to come out with different realistic strategies to manage change and to locate the seeds of change (Sushil, 2000; Hussain, Sushil, & Pathak, 2002) in the similiar direction of performance improvement. In current business scenario innumerable changes are witnessed. Situations are not stable for any industry; therefore, flexibility of every actor contributing to vision of business through different process is fundamental. This will result in effective outputs which will ultimately satisfy all consumer needs and remain ahead of the change.

A case study of corrugated manufacturing firm (a sub segment of paper packaging industry) is considered here. OSR Packaging Co. is situated in Gurugram district which provides complete printing and packaging solutions catering to diverse needs of different e-commerce companies in NCR region. Due to frequent changes in requirement of customers many unexpected situations and changes occurred to OSR which are considered for the study. This background about the identification of potential for change is the basis of the study. The study covers herein aims to:

- Understand the present status of OSR Packaging Co.
- Develop a SAP-LAP framework by identifying different SAP-LAP elements for further study.
- Make analysis related to interaction among elements for improvement of current situation.

Further in the study, operating environment of organization and learning issues have been described, feasible actions have been suggested and expected performance has been drawn.

1.2. SAP–LAP Framework

SAP-LAP means Situation-Actor-Process-Learning-Action-Performance analysis. This framework is used for developing models of inquiry in management (Sushil, 1997). It is a verified framework in the school of thought of change management (Sushil, 2000a, 2000b 2001a). The framework has been applied by several researchers (Kak, 2004) (Hussain, Sushil, & Pathak, 2002) (Sushil, 2001b) in diverse situations, industries and sectors through case studies. The applications of SAP-LAP framework by various researchers have been presented in Table 1.

Table 1: *Applications of SAP-LAP Framework by Various Researchers*

S. No.	Authors	Remarks
1	Sushil (2001)	Presented Mode of Inquiry using SAP-LAP Models.
2	Husain, Sushil and Pathak (2002)	Analyze Technological Management Practices of Firm in the Automobile Industry in India.
3	Kak (2004)	Learning Issues About Strategic Management, Core Competence, and Flexibility used in Pharmaceutical Organization.
4	Agarwal (2005)	Issues Regarding Cultural and Environmental Factor.

5	Arshinder and Deshmukh (2007)	Analyze a Case Study of XYZ, a Leading Automotive Parts Manufacturer in India, to Throw Light on the Status of Coordination.
6	Thakkar (2008)	Information Technology Adoption and Implementation in Supply Chain.
7	Garg (2009)	Engineering Support Issues in Maintenance
8	V.R. Pramod and D.K. Banwet (2010)	System Modeling of Telecom Service Sector Supply Chain: A SAP - LAP Analysis.
9	Palanisamy (2012)	Building Information Systems Flexibility in SAP- LAP Framework: A Case Study Evidence from SME Sector.
10	Plaiwal & Kumar (2014)	System Modeling of Service Supply Chain in Manufacturing Industry: Using SAP-LAP Hills Framework.
11	Venkatesh, Dubey, & Aital (2014)	Analysis of Sourcing Process through SAP-LAP Framework – A Case Study on Apparel Manufacturing Company.
12	Kabra & Ramesh (2015)	Analyzing ICT Issues in Humanitarian Supply Chain Management: A SAP-LAP Linkages Framework.
13	Ghosh (2016)	Creative leadership for Workplace Innovation: An Applied SAP-LAP Framework.

The SAP-LAP framework is a two-step model. Primarily, SAP analysis is done where 'S' means Situations, 'A' means Actors and 'P' means Process which are described in Table 2. The second phase considers Learning 'L' and experiencing the organizational environment, taking corrective Actions "A" and then observing or analysing improvement in Performance "P".

1.3. About the Company

OSR Packaging Co. was established in the year 2013 and since then it has been at the forefront for delivering exclusive printed corrugated boxes, corrugated storage boxes. It is located at Gurugram (District) Haryana, with huge and robust infrastructural unit. Their quality assurance is guaranteed by the constant monitoring and review of stern practices, policies, and procedures. Their printed corrugated boxes are really true epitome of extensive knowledge and experience to specific demands and objectives.

The main attributes are:

- Ethical business policies
- Stringent quality control
- State-of-the-art infrastructural base
- Wide range of products
- Trustworthy vendors
- Prompt delivery
- Dexterous team of professionals
- Spacious warehouse

All the packaging products are designed and crafted using quality corrugated sheets and other papers with the help of latest machines. As per the variegated needs of the customers, they make all paper packaging products in numerous sizes, colours and designs. OSR is currently having a turnover of Rs. 5 crores and the approximate number of employees working is 30.

Table 2: *SAP Framework*

Situation	They examine internal, external, past, present and future trends. They keep on changing in totally unexpected directions (Sushil, 1997). They represent status in which managerial system operates driving forces for good performance.
Actor	This means existence of external feasibility which varies from organisation to organisation (Sushil, 2000). They refer to influencing factors for all participants for improving organisational performance. It refers to transformation of input in to output for improving situations (Sushil, 2000a).
Process	They work as transforming inputs into improved or better outputs for recreating situations.

The fusion of SAP and LAP is pictorially shown in Figure 1.

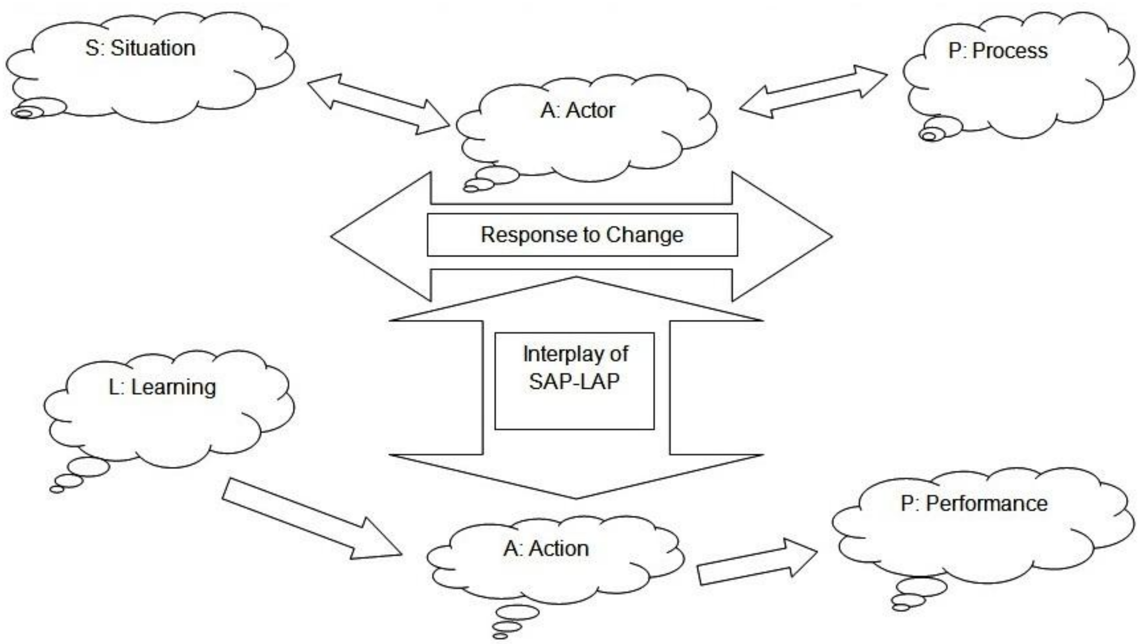

Figure 1: *SAP-LAP Framework*

2. Research Methodology

SAP-LAP framework has been extensively used in different sectors and industries through case study analysis. Here, a case study analysis of a leading packaging firm OSR is carried out to cope up with the fast changing business world; as only survival can't lead to retention of organization. Constant improvements with the growing industry are required; which can only be achieved through two attributes of success "flexibility" or "freedom of choice" (Sushil, 2001c). This will help in identifying the prospective areas for change and taking actions to setbacks faced in the change management process. The purpose of the study is to suggest actions for improvement in the performance of concerned firm.

The basic details of OSR Packaging Co. were gathered by referring to the website. The depth work for the research was carried out by frequently visiting the firm from September 2015 to May 2016. During this time period, different situations which were confronted by OSR were observed and analysed from different aspects. It has been realised that this organization requires application of change management scheme. After the careful study of organizational environment, eleven important situations were identified for analyses which were severely affecting firm's growth and performance. With the cooperation of employees, the actors responsible for identified situations and process involved in those situations were recognized. Further discussions with Managing Director, Technical Manager and employees helped to gather insights of the company.

The former part of case study represents SAP and the further processing will involves LAP. After analysing each situation, the learning issues were identified to take unbalanced situations on right path and the relevant actions were decided to formulate expected performance outcomes. A quantified actor-process matrix has been made.

The quantification has been done in two categories:

- Without considering their priorities and
- Considering their priorities.

In the first case all the situations, learning, actions and performances have been assigned unit values and their sum is considered as the score.

In the second case, the inputs of ten respondents almost from all level of the organization have been collected with the help of questionnaire. They have been asked to mark their priorities on Likert scale of range 1-10. The average was considered as the score. Figure 2 outlines flow of SAP-LAP framework of the current study.

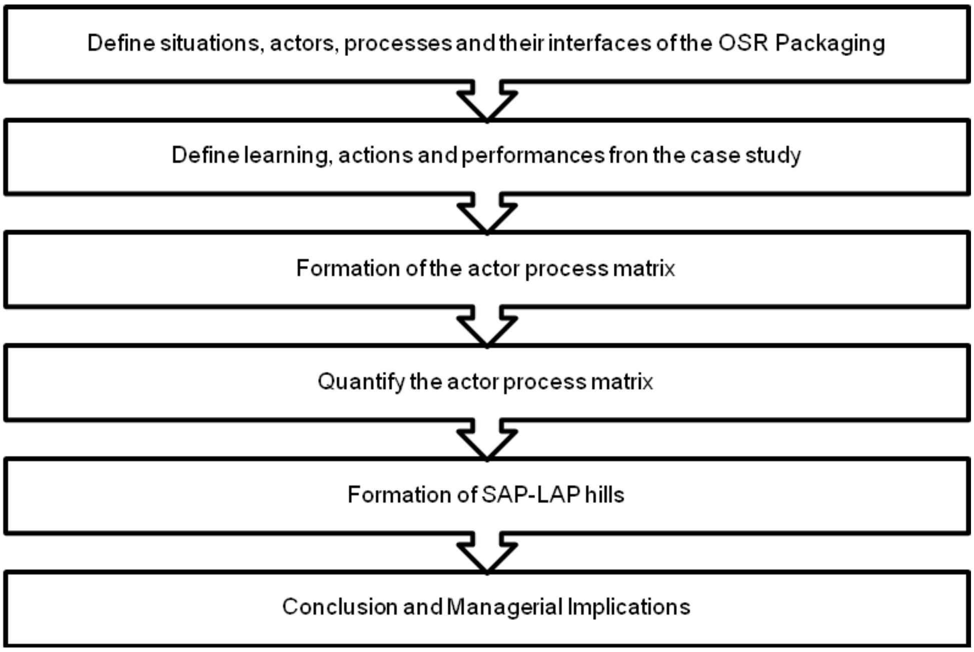

Figure 2: *Flow of the Study*

2.1. SAP–LAP Framework Formation

Actors should always be proficient enough to deal with diverse and unpredictable nature of situations. The situation for different actors can be different and the actors have to adapt as per the situations. The sudden and unexpected situation leads to an interplay of SAP (situation, actor, and process) and to handle it in an efficient manner ends with LAP (learning, action, and performance).

The interplay of SAP LAP helps in developing framework for organization to have in depth understanding about the problem and the best possible solutions. In the study, eleven major situations faced by the organization from September 2015 to May 2016 were analyzed to construct framework. A situation is dependent of internal and external factors which are described in Table 3.

2.2. Situations Considered for Study

The following situations are considered for the study:

1st Situation (S_1) - (September 2015)
Requirement of improved machines for large scale production

OSR had some big potential orders but because of absence of first hand die cutting technology, they were not in state to pitch those orders. It is utmost requirement to get fulfilled for their growth and stability.

Table 3: *Factors Responsible for Managerial Change*

External Factors	Internal Factors
Changes in customers' requirements and tastes;	New product and service design innovations;
Activities and innovations of competitors;	Low performance and morale, triggering job redesign;
New legislation and government policies;	Appointment of a new senior man top management team;
Shifts in local, national and international politics;	Inadequate skills and knowledge base, triggering training programmes;
Changes in social and cultural values;	Office and factory relocation,
Changing domestic and global economic and trading conditions;	Innovations in the manufacturing process;
Developments in technology and new materials.	New ideas about how to deliver services to customers.

2nd Situation (S_2) - (October 2015)
Increasing localized competition

Local competition is increasing because of presence of so many favourable circumstances:

- No experience is required in this corrugated field
- Huge customer base is present in this belt
- Easy availability of raw material and labour
- Government financial benefits are available
- Supportive government promotional schemes
- No requirement of managerial staff except one manager and proprietor

3rd Situation (S_3) – (October 2015)
Employee's attrition rate

As SMEs are regarded as largest source of employment generation, it has also been observed that they also have high attrition rate. During festive month of October and November, the demand of corrugated boxes was on its peak level because of association with maximum e-commerce customers. The employee's attitude towards their job has created big hurdle to fulfill the demand or respective orders.

4th Situation (S_4) – (November 2015)
Unfavourable weather conditions

No-one can control the climate. Excess winters and rain have huge impact on corrugated boxes. Their dimensions get changed, lose their strength and do not get dry to go for printing. These boxes while under manufacturing process are very temperature sensitive.

5th Situation (S_5) – (December 2015)
Future plan to set up one more plant

The vibrant opportunities and the internal strength in terms of finance and expertise provide OSR a scope to set up one additional plant in the near future. Currently, they are utilising 90% capacity of plant and existing customers want to increase their business to almost double with OSR.

Therefore, it can be a strategic decision to work for growth in all aspects.

6th Situation (S_6) – (January 2016)
Lack of skilled localized labour

Labour with better understanding of the technology to run machines like corrugation and slotting are very rare. Employees' attrition and no ease availability have setback many orders under process. This directly attacks to reliability of organisation. It does not provide chance to complete urgent orders.

7th Situation (S_7) – (February 2016)
Consumers belong to same domain

OSR has customer base of e-commerce companies as plenty of warehouses are present in their sales belt. They are operating limited in their domain. It is required for them to play strategically in market and pitch other sectors for more growth with lesser resources.

8th Situation (S_8) – (March 2016)
Excessive night shift production

To complete orders or urgent requirements, workers also need to work at night shifts. It was affecting their production rate and interest for work. Machines also need rest as in such cases it was not only increasing absenteeism but also frequent machine failures.

9th Situation (S_9) – (April 2016)
Unpunctuality of transportation agency

Transportation agency was very irregular and unpunctual in terms of time and providing right mode of conveyance. They never state their exact situation and give wrong information about their arrival time. There were late and improper deliveries. It was happening frequently and affecting goodwill of company.

10th Situation (S_{10}) – (May 2016)
Order fluctuations

Packaging is a matter of concern for online merchants, as consumers frequently object to receive their product in a corrugated container because of lacking permanence after the sale. Therefore, it is necessary for corrugated manufacturing firms to provide more and more facilities to their ultimate consumers. It is very difficult to survive among competitors or at least to retain their present orders. The other main reason of getting fewer orders was IPL (Indian Premier League) cricket matches as customers have minimized their frequency of placing online orders because of getting busy mostly in watching matches.

11^{th} Situation (S_{11}) – (May 2016)
Unmanaged execution of plans for production

Organisations with sound management system allow handling different operations simultaneously in an effective manner. But, in the organization of the study, there was no close supervision and no instruction schedule for workers. Orders were present but converting them into final products was getting complicated. Everything was present on papers and mails but end result was not coming out as desired.

2.3. Actors Considered for the Study

The following actors were considered for above situations:

Ar_1: Proprietor

Ar_2: Manager

Ar_3: Supervisor

Ar_4: Foremen

Ar_5: Skilled and Unskilled Labour

Ar_6: Suppliers

Ar_7: Customers

2.4. Process Considered for the Study

The following processes were considered for above situations:

Pr_1: Gain information about available, better and affordable machines.

Pr_2: Review the improved machines taken by other companies.

Pr_3: Conduct strength and weakness analysis of competitors.

Pr_4: Identify the reasons of competitor’s effectiveness.

Pr_5: Contact hiring/ consultancy agencies.

Pr_6: Fix terms or withhold remuneration while recruiting.

Pr_7: Analyze the effect of weather on product while manufacturing.

Pr_8: Find out prospective opportunities and orders for new plant.

Pr_9: Search for new ideal location

Pr_{10}: Outsource Labour.

Pr_{11}: Need to visit other industries and companies for order.

Pr_{12}: Teams can be made to work in different shifts

Pr_{13}: Search for other transportation agencies.

Pr_{14}: Reference to be taken from other manufacturers for selecting best transportation agencies.

Pr_{15}: Increase zone to supply final product.

Pr_{16}: Conduct supervision and instruction schedules may be prepared.

After identifying situations, actors and process in the study, learning is gained about SAP; which directs possible actions for impending situations that result into the performance. The learning, action and performances are enumerated in Table 4 and 5.

2.5. Actor Process Matrix

The Actor Process Matrix of SAP-LAP analysis clarifies and summarises all parameters involved in the concerned framework. All identified Processes are represented horizontally and Actors are shown vertically. Those cells which contain no situations, learnings, actions and performances were assigned value zero. The 'Actor-Process matrix' of OSR Packaging is shown in Table 5.

2.6. Quantified Actor Process Matrix

The matrix formed by using score 1 for each situation, learning, action and performance. The values represent the number of elements in each cell. In the study, maximum score is 6, where leading actors are Ar_1 (Proprietor), Ar_2 (Manager), and Ar_7 (Customers) and process are Pr_7 (Analyze the effect of weather on product while manufacturing), Pr_8 (Find out prospective opportunities and orders for new plant), Pr_9 (Search for new ideal location) and Pr_{11} (Need to visit other industries and companies for order). This whole scenario is represented through Table 6 and Figure 3.

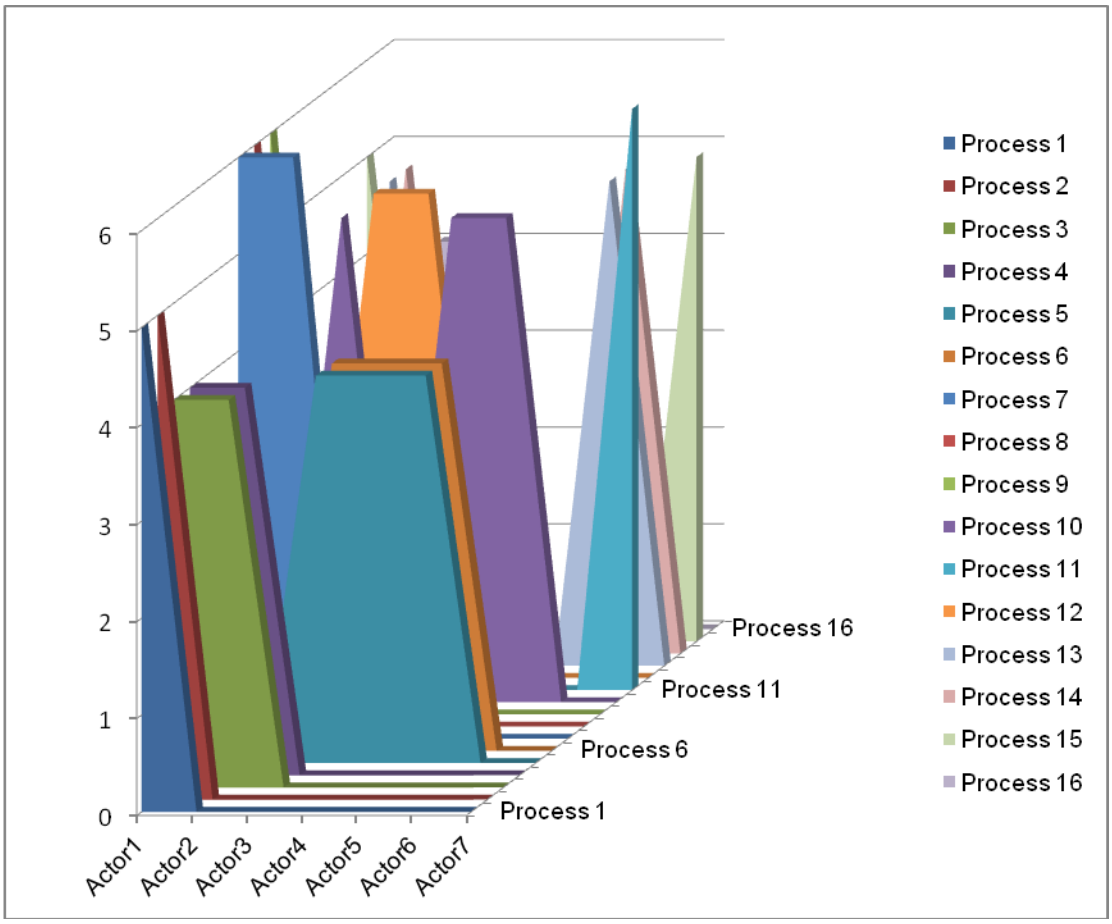

Figure 3: *SAP–LAP Hills Framework without Considering Weightages*

Table 4*: SAP–LAP Table for Company OSR Packaging Company*

S. NO.	Situation (Demographics)	Actor (Participants')	Process (considered by actors)	Learning (knowledge gain from SAP part)	Action (activities to be carried out after learning)	Performance (expected outcome of the analysis)
1	Requirement of improved machines for large scale production (S_1=7)	Proprietor (Ar_1)	Gain information about available better and affordable machines (Pr_1), Review the improved machines taken by other companies (Pr_2)	Analysis of upgraded and upcoming technology has to be taken in to account (L_1=7)	Purchase of new die cutting and stitching machine (a_1=8)	Increase in Production (P_1=9) Conversion time of raw material turnover in to final product decreases ($P_{1.1}$=8)

2	Increasing localized competitors (S_2=6)	Proprietor (Ar_1), Manager (Ar_2)	Conduct strength and weakness analysis of competitors (Pr_3), Identify the reasons of competitor's effectiveness (Pr_4)	Provide best and exact quality to customer at specified time (L_2=6)	Taking customer feedback about quality cost and compare with competitor (a_2=7)	Increase the strength of the company (P_2=6)
3	Employee's attrition rate (S_3= 9)	Supervisor (Ar_3), Foremen (Ar_4), Skilled and Unskilled Labour (Ar_5)	Contact hiring/ consultancy agencies (Pr_5), Fix terms or withhold remuneration while recruiting (Pr_6)	Employees motivation accompanied with benefits can be made (L_3=9)	Benefits are provided in view on individual output generation (a_3=8)	Employee retention (P_3=9)
4	Unfavourable weather conditions (S_4=9)	Proprietor (Ar_1), Manager (Ar_2)	Analyze the effect of weather on product while manufacturing (Pr_7)	Time gap between pasting and slotting arises because of non dryness of gum (L_4=9)	Gum imported having quality of instant dryness (a_4=9) Purchase of automatic plant sheets ($a_{4.1}$=7)	Regular Production (P_4=8) Timely Despatch of orders ($P_{4.1}$=8)
5	Future plan to set one more plant (S_5=7)	Proprietor (Ar_1)	Find out prospective opportunities and orders for new plant (Pr_8) Search for new ideal location (Pr_9)	Proper knowledge and information about the industry and region (L_5=6)	A new appointment is made to search for prospective potential of growth in same line (a_5=5)	Long term and continuous business (P_5=6) Purchase of latest automatic machinery which single will work equivalent of two to three machines ($P_{5.1}$=7) Less Dependency on Labour ($P_{5.2}$=8)
6	Lack of skilled localized labour (S_6=8)	Manager (Ar_2) Foremen (Ar_4), Skilled and Unskilled Labour (Ar_5),	Outsource Labour (Pr_{10})	Hire labour on referrals (L_6=6), Maintain records of labour which have left factory earlier ($L_{6.1}$=6)	Provide necessary training to available workforce (a_6=7)	Delays in order processing will be removed (P_6=7)

7	Consumers belong to same domain (S_7=8)	Proprietor (Ar_1), Customers (Ar_7)	Need to visit other industries and companies for order (Pr_{11})	Identify other industries except related to e-commerce (L_7=7)	Approach other sectors which use corrugated boxes for export (a_7=7)	Increased orders (P_7=7) Increased Profits ($P_{7.1}$=6) Supplying materials globally ($P_{7.2}$=8)
8	Excessive night shift production (S_8=7)	Manager (Ar_2), Supervisor (Ar_3)	Teams can be made to work in different shifts (Pr_{12})	Proper leadership and management skills will be required (L_8=7)	Advance production can be done. (a_8=8)	Goodwill on customers behalf will improve (P_8=6) Among competitors' distinguish identity will establish ($P_{8.1}$=6)
9	Unpunctuality of transportation agency (S_9=8)	Manager (Ar_2), Suppliers (Ar_6)	Search for other transportation agencies (Pr_{13}), Reference to be taken from other manufacturers for selecting best transportation agencies (Pr_{14})	Irresponsible and ignorant behaviour in any zone of manufacturing line can affect performance badly (L_9=7)	Purchase own tempo. (a_9=8)	Less Freight (P_9=8) Night despatch of orders will be possible ($P_{9.1}$=8)
10	Order fluctuations (S_{10}=7)	Proprietor (Ar_1), Customers (Ar_7)	Increase zone to supply final product (Pr_{15})	Will become hard to recover factory expenses (L_{10}=6)	Rush for new orders (a_{10}=6) Try to complete existing orders in l2 hrs in spite of 15 hrs ($a_{10.1}$=6)	Fixation of monthly orders with firms will help in recovering cost involved (P_{10}=7)
11	Unmanaged execution of plans for production (S_{11}=8)	Manager (Ar_2), Supervisor (Ar_3)	Conduct supervision and instruction schedules may be prepared (Pr_{16})	Responsibility sustains on part of proprietor himself. (L_{11}=6)	Authority should be centralised for execution (a_{11}=7)	Effective execution will lead to proper management of orders and employees. (P_{11}=6)

Table 5: *Actor-Process Matrix with Estimated Weightages*

Actors	*Process*															
	Pr_1	Pr_2	Pr_3	Pr_4	Pr_5	Pr_6	Pr_7	Pr_8	Pr_9	Pr_{10}	Pr_{11}	Pr_{12}	Pr_{13}	Pr_{14}	Pr_{15}	Pr_{16}
Ar_1	$(S_1=7)$ $(L_1=7)$ $(A_1=8)$ $(P_1+P_{1.1}=9+8)$	$(S_1=7)$ $(L_1=7)$ $(A_1=8)$ $(P_1+P_{1.1}=9+8)$	$(S_2=6)$ $(L_2=6)$ $(A_2=6)$ $(P_2=6)$	$(S_2=6)$ $(L_2=6)$ $(A_2=6)$ $(P_2=6)$			$(S_4=9)$ $(L_4=9)$ $(A_4+A_{4.1}=9+7)$ $(P_4+P_{4.1}=8+8)$	$(S_5=7)$ $(L_5=6)$ $(A_5=5)$ $(P_5+P_{5.1}+P_{5.2}=6+7+8)$	$(S_5=7)$ $(L_5=6)$ $(A_5=5)$ $(P_5+P_{5.1}+P_{5.2}=6+7+8)$						$(S_{10}=7)$ $(L_{10}=6)$ $(A_{10}+A_{10.1}=6+6)$ $(P_{10}=7)$	
Ar_2			$(S_2=6)$ $(L_2=6)$ $(A_2=6)$ $(P_2=6)$	$(S_2=6)$ $(L_2=6)$ $(A_2=6)$ $(P_2=6)$			$(S_4=9)$ $(L_4=9)$ $(A_4+A_{4.1}=9+7)$ $(P_4+P_{4.1}=8+8)$			$(S_6=8)$ $(L_6+L_{6.1}=6+6)$ $(A_6=7)$ $(P_6=7)$		$(S_8=7)$ $(L_8=7)$ $(A_8=8)$ $(P_8+P_{8.1}=6+6)$	$(S_9=8)$ $(L_9=7)$ $(A_9=8)$ $(P_9+P_{9.1}=8+8)$	$(S_9=8)$ $(L_9=7)$ $(A_9=8)$ $(P_9+P_{9.1}=8+8)$		$(S_{11}=8)$ $(L_{11}=6)$ $(A_{11}=7)$ $(P_{11}=6)$
Ar_3					$(S_3=9)$ $(L_3=9)$ $(A_3=8)$ $(P_3=8)$	$(S_3=9)$ $(L_3=9)$ $(A_3=8)$ $(P_3=8)$						$(S_8=7)$ $(L_8=7)$ $(A_8=8)$ $(P_8+P_{8.1}=6+6)$				$(S_{11}=8)$ $(L_{11}=6)$ $(A_{11}=7)$ $(P_{11}=6)$

Ar_4					$(S_3=9)$ $(L_3=9)$ $(A_3=8)$ $(P_3=8)$	$(S_3=9)$ $(L_3=9)$ $(A_3=8)$ $(P_3=8)$				$(S_6=8)$ $(L_6+L_{6.1}=6+6)$ $(A_6=7)$ $(P_6=7)$						
Ar_5					$(S_3=9)$ $(L_3=9)$ $(A_3=8)$ $(P_3=8)$	$(S_3=9)$ $(L_3=9)$ $(A_3=8)$ $(P_3=8)$										
Ar_6													$(S_9=8)$ $(L_9=7)$ $(A_9=8)$ $(P_9+P_{9.1}=8+8)$	$(S_9=8)$ $(L_9=7)$ $(A_9=8)$ $(P_9+P_{9.1}=8+8)$		
Ar_7											$(S_7=8)$ $(L_7=7)$ $(A_7=7)$ $(P_7+P_{7.1}+P_{7.2}=7+6+8)$				$(S_{10}=7)$ $(L_{10}=6)$ $(A_{10}+A_{10.1}=6+6)$ $(P_{10}=7)$	

***Table 6:** Quantified Actor-Process Matrix without Considering Weightages*

Actors	Process															
	Pr_1	Pr_2	Pr_3	Pr_4	Pr_5	Pr_6	Pr_7	Pr_8	Pr_9	Pr_{10}	Pr_{11}	Pr_{12}	Pr_{13}	Pr_{14}	Pr_{15}	Pr_{16}
Ar_1	5**	5**	4*	4*			6***	6***	6***						5**	
Ar_2			4*	4*			6***			5*		5**	5**	5**		4*
Ar_3					4*	4*						5**				4*
Ar_4					4*	4*				5**						
Ar_5					4*	4*				5**						
Ar_6													5**	5**		
Ar_7											6***				5**	

2.7. Classification based on the Intensity of Change

The change forces on the basis of intensity of change can be classified into four regions:

- Still, where the change forces are minimum
- Breeze, where the change forces are moderate
- Wind, where the change forces are intense
- Storm, where the change forces are extremely high

In the study,

- No cell belongs to still region.
- The cells (Ar_1, Pr_3), (Ar_1, Pr_4), (Ar_2, Pr_3), (Ar_2, Pr_4), (Ar_2, Pr_{16}), (Ar_3, Pr_5), (Ar_3, Pr_6), (Ar_3, Pr_{16}), (Ar_4, Pr_5), (Ar_4, Pr_5), (Ar_5, Pr_5), (Ar_5, Pr_6) belong to moderate region.
- The cells (Ar_1, Pr_1), (Ar_1, Pr_2), (Ar_1, Pr_{15}), (Ar_2, Pr_{10}), (Ar_2, Pr_{12}), (Ar_2, Pr_{13}), (Ar_2, Pr_{14}), (Ar_3, Pr_{12}), (Ar_4, Pr_{10}), (Ar_5, Pr_{10}), (Ar_6, Pr_{13}), (Ar_6, Pr_{14}), (Ar_7, Pr_{15}) belong to wind region.
- The cells (Ar_1, Pr_7), (Ar_1, Pr_8), (Ar_1, Pr_9), (Ar_2, Pr_7), (Ar_7, Pr_{11}) belong to storm region.

2.8. Prioritized Actor Process Matrix

It is practically impossible that all situations, learning, actions and performances have equal values. Therefore, quantification was done to get more precise result. The prime actors involved in the study were requested to prioritize the situations, learning, actions and performances on the scale of 1-10. It was done through brainstorming sessions. The figures were added. The maximum score was 50. The values corresponding to each actor and process is shown in Figure 4 and Table 7.

2.9. Classification based on the Intensity of Change (with considering Weightages)

In the study,

- No cell belongs to still region.
- The cells (Ar_1, Pr_3), (Ar_1, Pr_4), (Ar_2, Pr_3), (Ar_2, Pr_4), (Ar_2, Pr_{16}), (Ar_3, Pr_{16}) belong to moderate region.

- The cells (Ar_1, Pr_1), (Ar_1, Pr_2), (Ar_1, Pr_8), (Ar1, Pr9), (Ar_1, Pr_{15}), (Ar_2, Pr_{10}), (Ar_2, Pr_{12}), (Ar_2, Pr_{13}), (Ar_2, Pr_{14}), (Ar_3, Pr_5), (Ar_3, Pr_6), (Ar_3, Pr_{12}), (Ar_4, Pr_5), (Ar_4, Pr_6), (Ar_4, Pr_{10}), (Ar_5, Pr_5), (Ar_5, Pr_6), (Ar_5, Pr_{10}), (Ar_6, Pr_{13}), (Ar_6, Pr_{14}), (Ar_7, Pr_{15}) belong to wind region.

- The cells (Ar_1, Pr_7), (Ar_2, Pr_7), (Ar_7, Pr_{11}) belong to storm region.

Table 7: *Quantified Actor-Process Matrix with Considering Weightages*

Actors	Process															
	Pr_1	Pr_2	Pr_3	Pr_4	Pr_5	Pr_6	Pr_7	Pr_8	Pr_9	Pr_{10}	Pr_{11}	Pr_{12}	Pr_{13}	Pr_{14}	Pr_{15}	Pr_{16}
Ar_1	39**	39**	25*	25*			50***	39**	39**						32**	
Ar_2			25*	25*			50***			34**		34**	39**	39**		27*
Ar_3					34**	34**						34**				27*
Ar_4					34**	34**				34**						
Ar_5					34**	34**				34**						
Ar_6													39**	39**		
Ar_7											43***				32**	

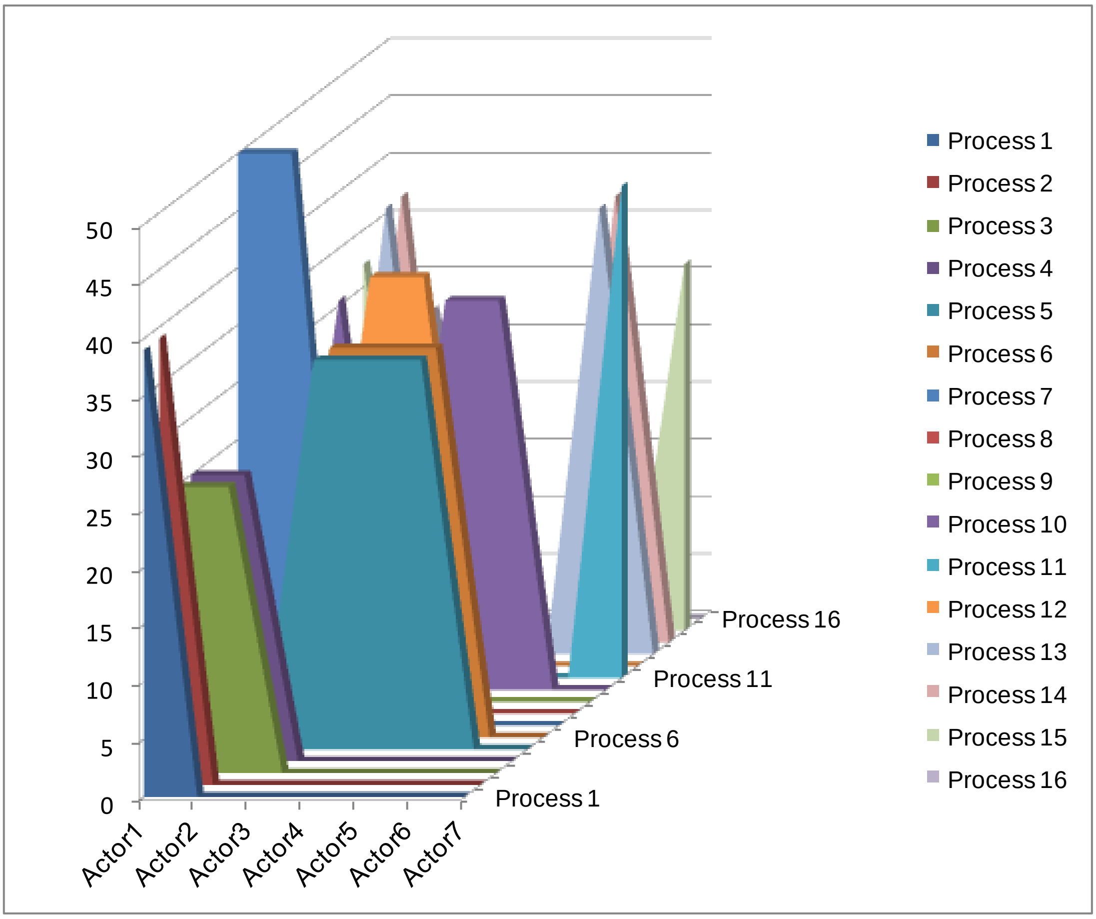

Figure 4: *SAP-LAP Hills Framework with Considering Weightages*

2.10. SAP-LAP Index of Change

SAP-LAP Index of change is a technique to benchmark the existing change force to the maximum possible. The strength of change forces in the organization calculated using this quantification approach. SAP-LAP Index of change is the ratio between the sum of the change indices to the sum of the change intensity at the extreme situation.

According to SAP-LAP Index of change, the change forces are divided into four regions as shown in Figure 5. They are explained as:

- In the first region, the change forces can be neglected as they are almost less than 10 percent of the benchmark.
- In the second region, the change forces are between 10 percent and 50 percent of the benchmark, where company needs to be little careful.
- In the third region, change forces vary from 50 percent to 75 percent of benchmark where company has to be cautious and require formulating emergency action.
- In the fourth region, the change forces vary from 75 percent to 100 percent of the benchmark which may lead to disastrous organizational failures.

SAP–LAP Index of change = Sum of change forces in cell * 100 / Maximum change * Number of cells

= 1047 * 100 / 50 * 112
= 18.696

In the study, SAP-LAP Index of change is 19 which lie in the second region, where care is required to be taken by organization. It acts as an instrument for condition monitoring. It makes possible to revise requirements and application of changes in the functioning of organization.

SAP-LAP INDEX OF CHANGE	10	20	30	40	50	60	70	75	80	90	100
ACTION RECOMMENDED	NEGLECT	CARE				CAUTIOUS			EXTREME		

Figure 5: *Regions Showing Impact of Change*

2.11. Managerial Implications

A detailed three dimensional figure of change i.e., "SAP-LAP Hills" is the major source of explanation to this study which is shown in Figure 3 and 4. A systematic procedure is illustrated by locating all the leading actors and processes in the SAP-LAP Hills Framework. To facilitate managers, to understand the necessity of change in this virtualization era, SAP-LAP index of change is an ideal parameter. It helps in identifying the vulnerability of organization.

3. Action Plan Based on the Research

An action plan was made for uplifting the most crucial aspects which were hindering the change management process. From the study it was observed that the leading actors and processes were concentrated in two clusters. In the first cluster, the leading actors were Ar_1 (Proprietor) and Ar_2 (Manager) and the process was Pr_7 (To find out effect of weather on product while manufacturing). In the second cluster, the leading actor was Ar_7 (Customers) and the process was Pr_{11} (Need to visit other industries and companies for order).

a. Proprietor

In this organization, the proprietor is an active member in almost all the situations. Maximum authority lies in his hands and very few have been delegated. All controls related to purchase, sale, process, dispatch lies in his hand. However, all these functions are performed by manger and foremen but after his approval. Daily schedules are sometimes also been drawn by proprietor. There is 80% of centralization.

b. Manager

In the hierarchy of the organization, there is very close involvement of proprietor and manager. Manager has the duty to maintain all the records related to stock and employees. All the finances are under his control. He is liable to maintain close supervision and all the work is performed under his guidance.

c. Customers

Customers are the prime stakeholders of an organization. In this regard, the organization requires making action plans for creating new customers as maximum of them belongs to only one sector (e-commerce). The needs and expectations of the existing customers should be maintained by providing and satisfying them appropriately in accordance of their requirement.

d. To find out effect of weather on product while manufacturing

A strong corrugated box is a result of healthy internal environment and appropriate external weather conditions. Suitable temperature is directly related to strength of box. If it is not properly manufactured, it will not serve the end result. Disturbance in the temperature directly affects quality of box which will become major obstacle on the growth of the organization.

e. Need to visit other industries and companies for order

OSR packaging is currently serving one industrial segment of the market and they are not identifying other opportunities in the market. Different segments have different requirements that will help the organization for creating innovations in the boxes. Therefore, it is essential and prime requirement for OSR to pitch other segments in the market for growth and performance improvement.

4. Conclusion

SAP-LAP is a framework used for analyzing and synthesizing any case context (Sushil, 1997, 2000, 2001). The interplay of situation, actor, and process helps to analyze the different perspectives related to business and better interplay leads to better results which can be calculated by performance measures or KRAs (key result areas) (Sushil and Stohr E., 2014). The structured flexibility analysis framework in the study; helped in bringing out all the learning issues and "suggested actions" for "improvement in the performance". The actors in the key result areas were "Proprietor", "Manager" and "Customers"; and the process were "To find out effect of weather on product while manufacturing" and "Need to visit other industries and companies for order".

Therefore, this framework helps in identifying all the key areas with concrete results and there was no scope for vague judgements. This will lead in directing all the essential efforts in the result oriented desired direction. Proper action plans for the organization were formulated but their implementation requires a lot of strategic involvement. The study reveals that in order to have a good change management scheme the organization needs to concentrate on all the identified parameters for their performance improvement.

5. Limitations and Future Scope

The study needs to be interpreted in light of the following limitations:

- The interdependencies among the elements in the Actor-Process matrix have not been taken into account.
- Strategic involvement was required to execute and implement action plan.

The limitations of study provides enough direction for the further research and future scope would be to consider interdependencies and in depth analysis.

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Research Article **Open Access**

Application of the Stress-Energy Method to Evaluate Enclosed Air Cushion Systems

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Abstract Cushion curves are used to ensure cushions used by packaging systems are adequately designed to protect products from shocks experienced during transport. However, no commercially available curves exist for enclosed air cushion systems despite its wide use as a cushioning material. In general, there are two types of enclosed air systems, individual bubble and continuous bubble. This paper summarizes the theory and recent work applying the stress-energy method and different curve fit models to these type systems to generate cushion curves. This paper also compares stress-energy predicted deceleration values to actual ASTM D4168 deceleration values as a method of determining whether the stress-energy method is a viable alternative for generating curves for these cushion systems. Results indicate the stress-energy method can be used to successfully generate cushions curves for enclosed air cushion systems. The following stress-energy equations were produced from this research. The stress-energy equation for the Individual Bubble cushion system was $y = 3.0611e^{0.435x}$. The stress-energy equation for the Continuous Bubble cushion system was $y = 1.9133e^{0.4782x}$. These equations are designed to predict cushion performance of these cushion systems. Predicted deceleration values were within ± 10% of the actual average deceleration indicating that the model is appropriate for applications where these cushion systems are employed.
Keywords *Stress-Energy; Cushion Curve; Enclosed Air Cushion; ASTM D4168*

1. Introduction

An important tool used when developing packaging systems is the cushion curve. Cushion curves can be used to select the proper thickness of material required to inhibit transmitted shock into the product when it is dropped during transit. Traditionally, cushion curves are generated from the test method outlined in ASTM D1596, “Standard Test Method for Dynamic Shock Cushioning Characteristics of Packaging Material” and are available for a wide variety of foam products and applications [1]. In recent years, numerous researchers have outlined the use of the stress-energy method to generate cushion curves for foam (polymer-based) and corrugated boards [2-9]. This research will explore whether the application of the stress-energy method can by employed for enclosed air cushion systems.

Cushion curves for enclosed air cushion systems are not commercially available for use by the packaging industry to identify the correct amount of cushioning needed for a given application. Air cushion systems are typically used for light-duty applications, but depending on material composition and inflated pattern, can be used for more strenuous applications as well. Like foam and corrugated cushioning solutions, air cushion systems should be evaluated to ensure the correct amount of cushion (protection) is identified to help save on freight costs while still providing adequate protection to the product.

In general, there are two types of enclosed air systems, individual bubble and continuous bubble. Individual bubble cushions are the traditional enclosed air cushion systems. These cushion systems come in different performance grades and provide protection for a wide range of applications. Continuous bubble cushions are laid out in columns of connected air pockets. These cushion systems can be inflated on-site offering on-demand and customized solutions without the need for curing time or cutting samples. This is critical for products passing through small parcel channels, such as e-commerce, which require high throughput. These on-demand solutions also provide a packaging solution for cases where traditional individual bubble cushions can tie up storage in a warehouse or may not be cost effective to ship long distances.

The purpose of this study was to apply the stress-energy method and develop cushion curves for enclosed air cushion products being designed and branded as protective packaging. In addition to developing curves, the stress-energy equations obtained from the research will be evaluated for fitness of use. Due to the wide variety and availability of these types of cushions, this paper limited the investigation to individual bubble and continuous bubble style air cushion systems (Figure 1).

Figure 1: *Individual Bubble (left) and Continuous Bubble (right)* [10]

2. Materials and Methods

Enclosed air cushion systems developed and marketed as cushioning materials were used for this evaluation. Table 1 outlines the typical properties for these materials.

Table 1: *Typical material characteristics*

Material ID	Trade Name	Avg. Bubble Height (in.)	Target Market
Individual Bubble	Bubble Wrap® Brand - DM	0.50	Light to Med. Duty
Continuous Bubble	Bubble Wrap® I.B. - Medium	0.50	Light to Med. Duty

2.1. Sample Preparation

Enclosed air cushion samples were cut down to include a fixed cushion area of 144 in^2 (this will be referred to as one sheet). After the samples were prepared, they were stored at standard conditions (23°C and 50% RH) for at least 24 h prior to testing. The samples were tested within 30 min of removal from the chamber.

In order to collect the data needed for the stress-energy plots, inflated cushion samples were placed inside corrugated containers with various static loads. Two sheets (layers) were placed inside the corrugated box. The corrugated box selected for this evaluation had a Mullen Test of 200 lbs/in^2. The weight of the wood static loading box could be changed to adjust the static stress occurring for a particular drop. The following formula is used to determine the static load:

$$Static\ Load = \frac{Force\ (lbs)}{Area\ (in^2)} \quad (1)$$

To determine the equivalent free fall drop height (EFFDH) the following formula was used:

$$EFFDH = \frac{\Delta V_c{}^2}{2g} \quad (2),$$

where ΔVc is the critical velocity change and *g* is the gravitational constant (386.1 in/s^2). A Lansmont Shock Tester M65/81 (Lansmont Corp., Monterey, CA) was used to execute all testing. The shock pulses were captured and analyzed using Test Partner 3 (TP3) software (Lansmont Corp., Monterey, CA). Figure 2 displays the testing setup used for this study.

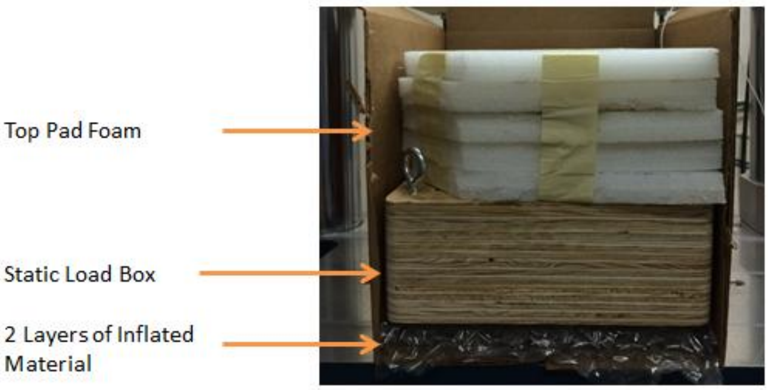

Figure 2: *Example test setup used for the cushion system*

Data were collected following the ASTM D4168, "Standard Test Methods for Transmitted Shock Characteristics of Foam-in-Place Cushioning Materials" procedure [11]. The ASTM D4168 method varies from the ASTM D1596 procedure, in that this method uses an in-package method for collecting transmitted shock data. Given the application and actual use of the inflatable cushion, the in-package method of ASTM D4168 was determined to be the most effective way to collect data. The stress-energy method utilizes the information collected from ASTM D4168, with the added benefit of generating an equation used to predict deceleration values of the cushion system at various static loads and thicknesses. This is done by calculating:

$$Dynamic\ Stress = G \times s \quad (3)$$

$$Dynamic\ Energy = \frac{s \times h}{t} \quad (4)$$

where *G* is the maximum deceleration, *s* is static load, *h* is equivalent to free fall drop height, and *t* is cushion thickness. Dynamic stress is plotted versus dynamic energy and curve fit analysis is completed on the data set to determine the highest correlation between the data set. This provides a goodness of fit (R^2) value, and based on the regression analysis generates the stress-energy equation. Curve fitting with an exponential model yields the general stress-energy equation in the form of:

$$y = Ae^{Bx} \quad (5)$$

where *y* is the dynamic stress and *x* is the dynamic energy. *A* and *B* are constants specific to the cushion system being explored.

Experimental preliminary testing dictated the dynamic energy levels chosen for this study. For this study twelve distinct energy levels were used for each type of enclosed cushion system. For each energy level, the testing was performed in triplicate and averages were used for analysis. Table 2 displays the testing specifications for each test material. Each in-package cushion was subjected to five drops, with the data collected and arranged as first drop and average two through five drops. Based on industry accepted standards, only the average two through five drops will be used for developing the stress energy model.

Table 2: *Test specifications for enclosed cushion systems*

			Individual Bubble				Continuous Bubble			
Energy Level No.	Area (sq.in.)	Cushion Thickness (in.)	Drop Height (in.)	Weight (lbs.)	Static Loading (psi)	Predicted Energy (in-lb/in^3)	Drop Height (in.)	Weight (lbs.)	Static Loading (psi)	Predicted Energy (in-lb/in^3)
1	144	1.00	18	9.0	0.06	1.1	18	9.0	0.06	1.1
2	144	1.00	24	9.0	0.06	1.5	24	9.0	0.06	1.4
3	144	1.00	18	14.4	0.10	1.8	30	9.0	0.06	1.8
4	144	1.00	30	9.0	0.06	1.9	18	14.4	0.10	1.8
5	144	1.00	24	14.4	0.10	2.4	24	14.4	0.10	2.4
6	144	1.00	18	21.6	0.15	2.7	18	21.6	0.15	2.7
7	144	1.00	18	28.5	0.20	3.6	30	14.4	0.10	3.0
8	144	1.00	18	36.0	0.25	4.5	24	21.6	0.15	3.6
9	144	1.00	30	21.6	0.15	4.5	18	28.8	0.20	3.6
10	144	1.00	24	28.5	0.20	4.8	24	36.0	0.25	6.0
11	144	1.00	30	28.5	0.20	5.9	30	28.8	0.20	6.0
12	144	1.00	30	36.0	0.25	7.5	30	36.0	0.25	7.5

3. Results and Discussion

Table 3 presents the averaged data collected as a result of the shock testing performed on the inflatable cushion systems.

Table 3: *Test results for Individual and Continuous Bubble Cushion Systems*

	Individual Bubble		**Continuous Bubble**	
Sample ID	Dynamic Energy (in-lb/in^3)	Dynamic Stress (lbs/in^2)	Dynamic Energy (in-lb/in^3)	Dynamic Stress (lbs/in^2)
1	1.1	4.48	1.1	2.94
2	1.5	5.29	1.4	3.75
3	1.8	7.65	1.8	4.41
4	1.9	6.77	1.8	4.91
5	2.4	9.03	2.4	6.46
6	2.7	10.33	2.7	7.62
7	3.6	15.76	3.0	8.60
8	4.5	22.27	3.6	8.88
9	4.5	21.51	3.6	10.46
10	4.7	23.91	6.0	31.71
11	5.9	38.46	6.0	37.20
12	7.5	78.15	7.5	68.42

Dynamic stress versus dynamic energy plots were constructed for the average two through five drops, using Equations 3 and 4. The plots for each material are displayed in Figures 3 and 4. The stress-energy plot was then analyzed using Microsoft Excel's regression analysis feature. An exponential curve fit was chosen to model this cushioning system. The calculated R^2 value showed good correlation and fit for each cushion system evaluated. In both cases, the correlation was greater than 95%, suggesting the stress-energy equation could be used to develop curves for a given material.

The developed stress-energy equations match previously published and available stress-energy equations for closed cell foams. Enclosed air cushions systems, like closed cell foams, rely on the displacement of air for cushioning properties. Closed cell foam cushions use an exponential curve fitting equation, expressed in the same form as the ideal gas model, suggesting the primary cushioning effect is related to the behavior of air [4]. Because of this relationship, the following equations can be used to describe the cushioning characteristics for these air cushion systems.

Individual Bubble: $y = 3.0611e^{0.435x}$ (6)

Continuous Bubble: $y = 1.9133e^{0.4782x}$ (7)

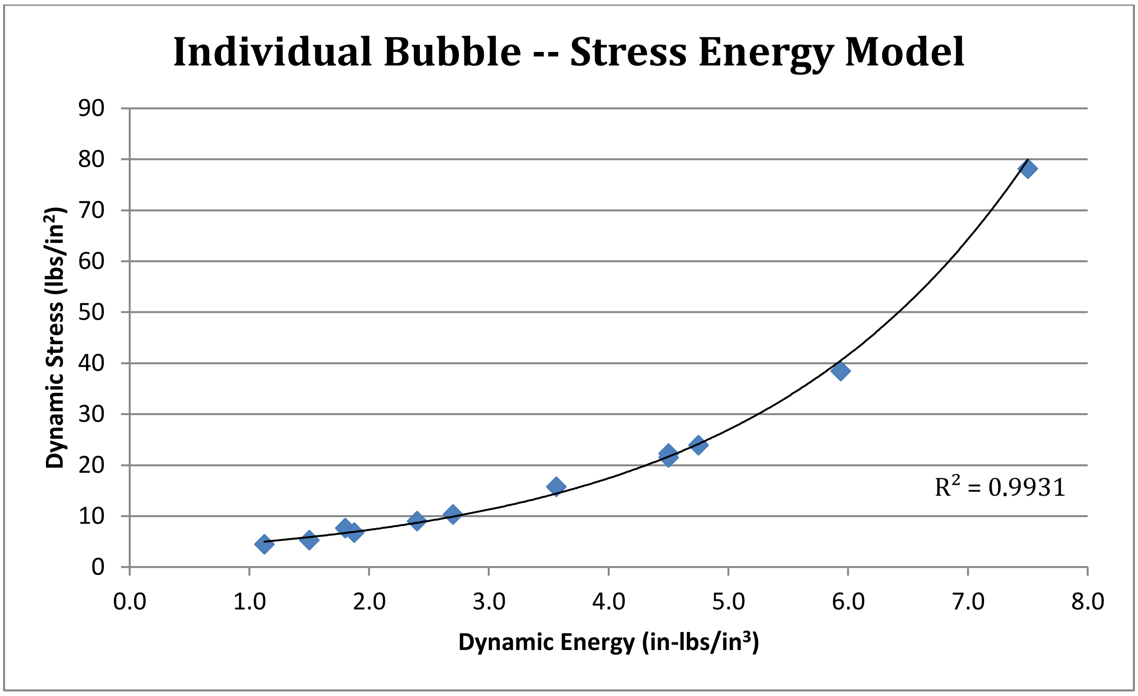

Figure 3: *Stress-energy plot for Individual Bubble*

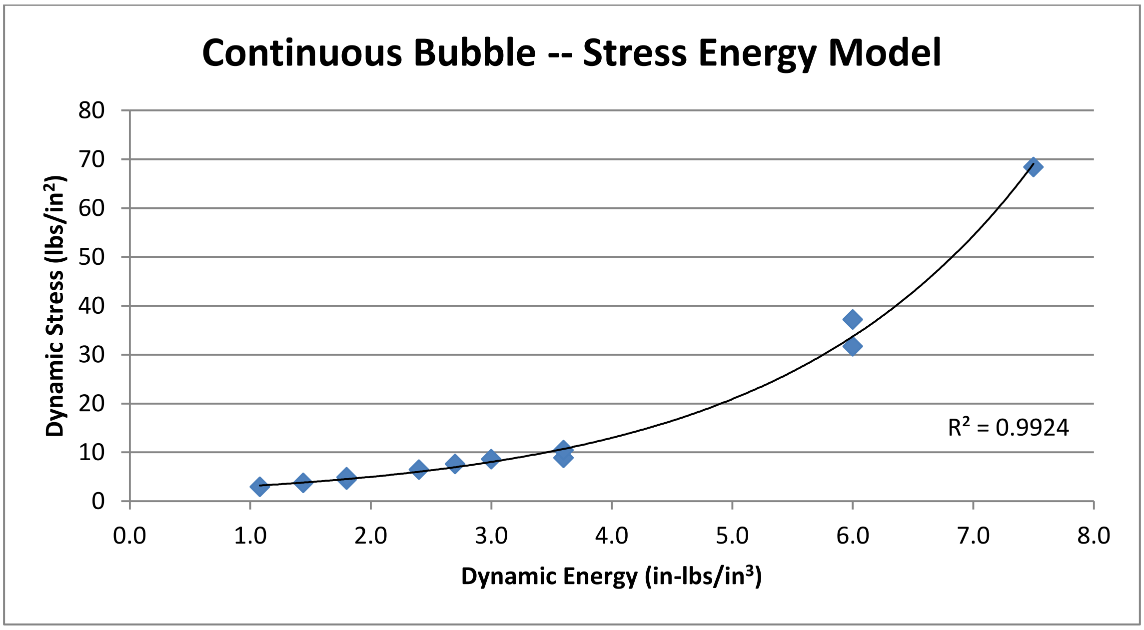

Figure 4: *Stress-energy plot for Continuous Bubble*

Additionally, the equations produced for the materials were further examined. The percent difference was calculated to compare actual and predicted values of deceleration. This was completed in order to determine the validity of the models and if the models could be used to predict cushion performance. Table 4 displays the recorded and predicted (from equations) percent differences for the material. The average percent difference for the Individual Bubble and Continuous Bubble were 5% and 6% respectively.

Table 4: *Percent difference for Individual and Continuous Bubble Cushion Systems*

	Individual Bubble			**Continuous Bubble**		
Sample ID	Recorded Deceleration (g)	Predicted Deceleration (g)	Percent Difference (%)	Recorded Deceleration (g)	Predicted Deceleration (g)	Percent Difference (%)
1	68.86	66.05	4%	49.02	53.75	9%
2	71.63	80.33	11%	62.47	63.67	2%
3	76.46	66.98	13%	73.56	75.85	3%
4	79.64	72.85	9%	49.06	44.82	9%
5	84.71	94.05	10%	64.56	59.71	8%
6	89.09	86.71	3%	50.79	46.72	8%
7	90.28	86.95	4%	85.99	79.56	8%
8	108.33	110.72	2%	79.22	72.37	9%
9	120.82	122.11	1%	52.28	53.51	2%
10	143.39	144.52	1%	126.83	134.87	6%
11	194.34	204.69	5%	185.99	167.79	10%
12	312.62	319.76	2%	273.69	279.66	2%

The stress-energy method uses known material properties of a cushion system and develops an equation to predict the performance of a cushion for a given drop height, cushion thickness and static load [4]. As noted earlier, Microsoft Excel can be used to simplify the presentation of stress-energy analysis. To do so, first substitute and rearrange Eq. 5 to calculate for peak deceleration (G):

$$G = \frac{A}{s} \times e^{B\frac{sh}{t}} \qquad (8)$$

In addition to creating cushion curves, exact deceleration and corresponding static loads can be computed from the equation for optimum designs. Figures 5 and 6 display an example of predicted cushion curves developed from the stress-energy equation and recorded cushion curves from additional laboratory testing. These recorded cushion curves were developed to visually show the correlation between the two separate collection methods for cushion curves.

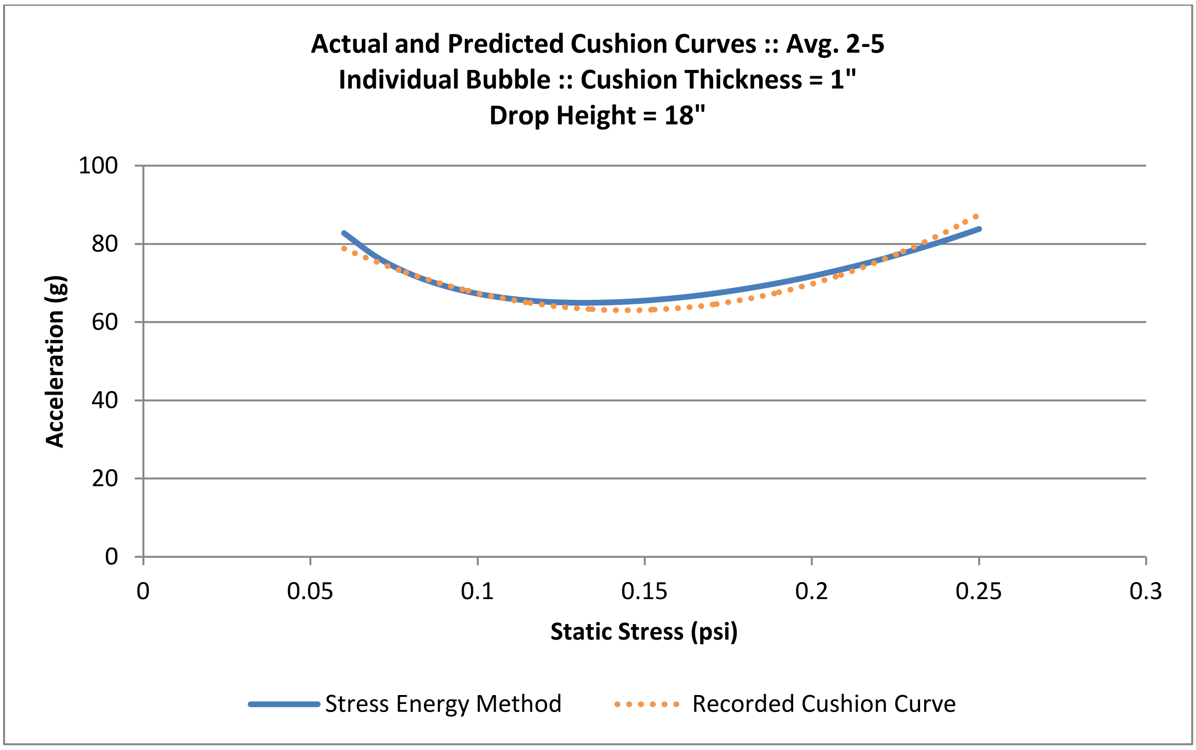

Figure 5: *Predicted stress-energy plot for Individual Bubble*

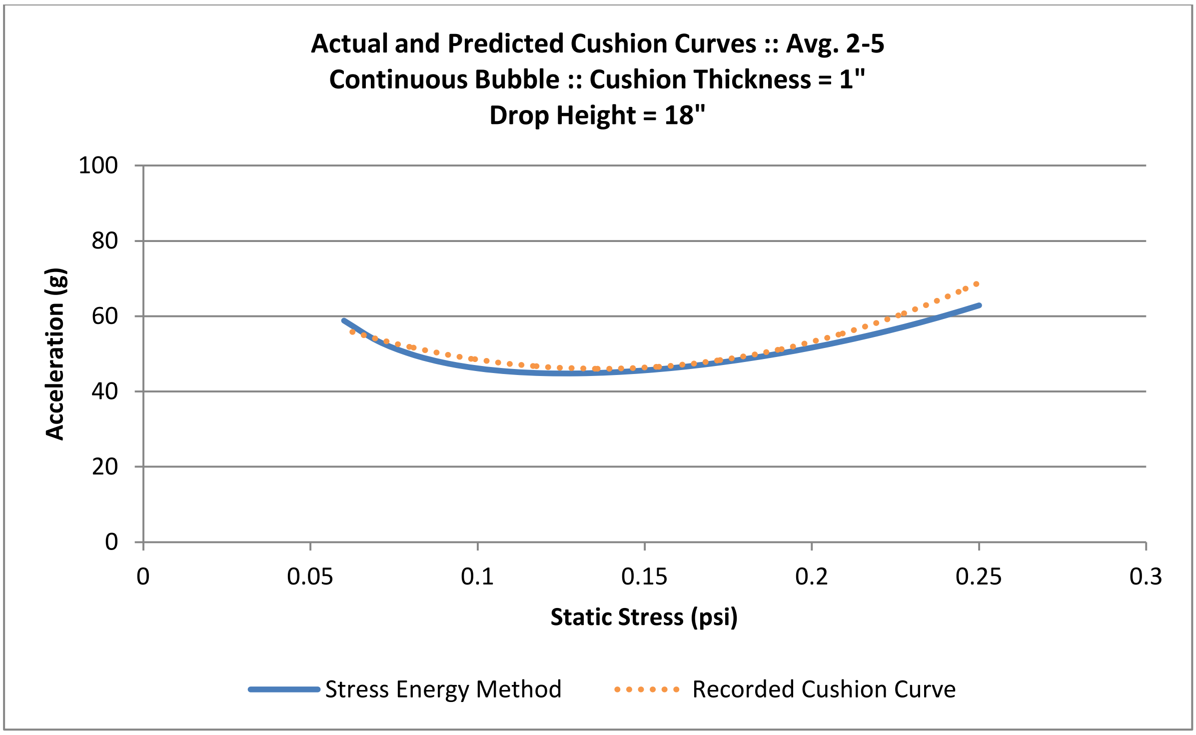

Figure 6: *Predicted stress-energy plot for Continuous Bubble*

4. Conclusions

Currently, there are no commercially available cushion curves for enclosed air cushion systems. As a result, packaging engineers and designers are required to make assumptions based on experience or trial and error. These scenarios can lead to under- or over-packaged products resulting in an increase in product damage or packaging material, both of which are costly.

Developed from this experiment were equations designed to predict the cushion performance of two commonly employed enclosed air cushion systems. As with closed cell foams, enclosed air cushion systems rely on the displacement of air for cushioning properties. Because of this relationship, the data were examined using an exponential curve fit to generate the stress-energy equations. Both of the equations produced from the data showed high correlation, having an R^2 value greater than 95%. Additionally, the average of the predicted values generated from the stress-energy equations were within ± 10% of the actual values recorded. Based on these findings, the equations can develop cushion curves for use by packaging engineers or designers to determine the optimum static load required to prevent product damage.

This paper provided a preliminary investigation into using the stress-energy method to predict the performance of enclosed air cushion systems. This method was chosen due to the collection technique and reduced time associated with using the stress-energy method. Although a high correlation was obtained from the samples used for this study, it is recommended to perform this type of testing on the various other types and grades of air cushion systems.

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