JOURNAL OF MANAGEMENT AND ENGINEERING INTEGRATION

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

EDITORIAL REVIEW BOARD

REVIEWERS

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

Sandy Furterer, Ph.D., MBA
Editor-in-Chief

Ali Ahmad
Dan Zalewski
Dennis Ridley
Ewa Rudnicka
Feng Zhou
Gamal Weheba
Gary Hatfield
Gordon Arbogast
Gwen White
Hemaid Alsulami
Holger Mauch
Indra Gunawan
Jingyun Li
John Wang
J.S. Sutterfield
Masoud Shaheen
Mohammad Hamasha
Nabin Sapkota
Narasimha Nagaiah
R. Radharamanan
Ronald Shehane
Sherisse Pierre
Stephen Allen
Stephen Frempong
Sura Al-Qudah
Wei Zhan
Xiaochun Jiang
Xun Xu

TABLE OF CONTENTS

Additive Manufacturing for the Production of a Knee Prototype

R. Radharamanan[1]
Andrew P.Vilanova[1], João Paulo M. Moreira[1], Wayne de Lima[1]
[1]*Mercer University, Macon, GA 31207 USA*
radharaman_r@mercer.edu

Abstract

This paper presents the design of a right knee joint prototype, from a 3D scanner, and then obtaining an output STL file for the 3D printer. Two different types of plastic (ABS and PLA) and two models of 3D printer (MakerBot Replicator 2X and Flashforge Creator Pro) were used in achieving the goal of reproducing as accurate as possible and cheaper than the original knee prototype, purchased on the internet, made of polyvinyl chloride (PVC) plastic by a German factory specialized in making scientific prototypes. Visual quality, production time, and weight of the printed parts were compared with reference to the machinery, material types, quantity, and printing parameters. Through this hands-on project, the students were trained in emerging manufacturing technologies such as 3D scanning, 3D printing and rapid prototyping, and additive manufacturing. Some of the difficulties encountered and the learning experience from the student team are also presented and discussed.

1. Introduction

One of the most distinguishing factors that the human has different from other species is the way of displacement. Because of the human's gait, structure and position, the knee is one of the biggest and more essential joints in the human body, with a particular way of working, difficult to be analyzed by medical students. The loss of mobility in the human knee joint can happen because of injuries, deformities or illnesses due to swelling or advanced age. When this occurs, a replacement by prosthesis can be performed in order to improve the quality of life of the subject. Developing solid models of the knee is one of many steps involved in using engineering principles to solve medical problems within the human knee joint. Injuries to the knee joint are amongst the most common in sports activities and understanding the joint anatomy is fundamental to developing a better prosthesis, more adapted to the natural human gait.

The overall objective of this project is to design and make low cost knee prototypes using reverse engineering and additive manufacturing technologies within the ten weeks duration of the Mercer Summer Engineering Experience (MeSEE) academic training program. A multidisciplinary team of three students (industrial, mechanical, and production) participated in this project. They used the NextEngine 3D scanner and obtained output STL files for printing. They used different types of plastic (ABS, PLA, and NinjaFlex) and two 3D printers (MakerBot Replicator 2X and Flashforge Creator Pro), for achieving the goal of reproducing the knee joints with accuracy and low cost compared to the original knee prototype made of polyvinyl chloride (PVC) plastic by a German factory that makes this kind of scientific prototypes. In addition, visual quality, production time, and weight of the printed parts are objects of comparison regarding the machinery, material types and quantity as well, and printing parameters used in the printing processes. The results obtained are presented and discussed with conclusions and recommendations for future work related to 3D scanning and rapid prototyping.

2. Background research

2.1. Additive manufacturing

The rapid prototype process allows the fast creation of products' prototypes eliminating considerable amounts of resources and time spent on the project when compared to traditional development design methods (Fedorov, 2009). In Additive Manufacturing (AM), a model initially generated using a three-dimensional Computer Aided Design (3D CAD) system, can be fabricated directly without the need for process planning. Although this is not in reality as simple as it first sounds, AM technology certainly significantly simplifies the process of producing complex 3D objects directly from CAD data. This technology came about as a result of developments in a variety of different technology sectors. The seven main manufacturing steps of generation of an additive manufacturing process (Gibson et al, 2010) are described below:

1. Every AM process starts using any professional CAD solid model, with the obligation that the output must be a 3D solid or surface drawing. This project used reverse engineering equipment (laser scanning).
2. AM machines accept the STL file format, which every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.
3. Sometimes, when the STL file is applied in the AM machine it may need some general manipulation of the file so that it is the correct size, position, and orientation for building.
4. AM machines can work with different materials, which have different settings that would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc. To deal with it, appropriate settings of AM machine parameters such as extruder temperature, platform temperature, print speed, infill percentage, and layer thickness are necessary depending on material used to build the chosen part.
5. Building the part is mainly an automated process and the machine can largely carry on without supervision. So, it requires only a superficial monitoring during the build process.
6. Once the AM machine has completed the build, the parts must be removed. One must do this action carefully to avoid the destruction of the piece that was made.
7. After finishing all the steps above, the parts may require additional treatment before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish.

2.2. Knee joint

The knee joint is the largest joint in the human body (Platzer, 2009), which consists of four bones and many ligaments and muscles. It is the connection between the thigh and leg. Three bones come together at the knee joint, and the knee is surrounded by four major ligaments. The knee joint surface is covered by a layer of smooth cartilage, and shock-absorbing meniscus (Heesterbeek, 2010). The knee anatomy is shown in Figure 1.

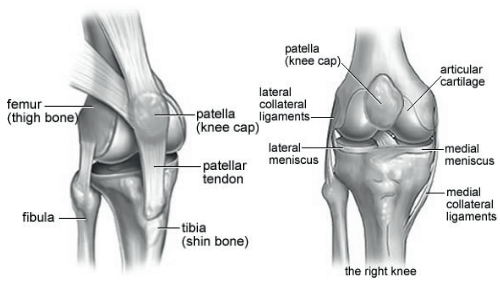

Figure 1. Knee anatomy

2.3. 3D scanner (reverse engineering)

Using a 3D scanner to obtain solid models from an existing product in order to create a new one is a process classified as a reverse engineering method. Abella et al (1994) described reverse engineering as "the basic concept of producing a part based on an original or physical model without the use of an engineering drawing". Based on this concept, reverse engineering was applied in this project through a 3D scanner. A 3D scanner is a device for creating high resolution, accurate digital 3D models from real-world objects. The scanner is built around stereo-vision and structured light projection in order to generate 3D. The scanner is controlled by 3D scanning software that runs on a computer. A 3D scanner is also capable of capturing the color map of an object. By merging the color map onto the 3D model, a color 3D digital model is created.

2.4. Types of 3D scanner

According to Vinesh (2008), 3D scanners are based on two principles: contact scanners and non-contact scanners. As their own names tell, the first type is characterized by scanning the pieces through direct contact with them. These scanners have a better precision than the non-contact type, normally with a tolerance range of +0.01 to 0.02 mm. However, they have some drawbacks. For example, some specific types of materials cannot be scanned with good accuracy or it is at least very hard to obtain a good scan.

The second type, non-contact scanner, was utilized in this research. This scanning method does not occur by touching the parts to be scanned, but by lasers that identify the shapes and surfaces of the part in the programmed range of scan. Its precision does not have a great tolerance range as contact scanners. It is within ±0.025 to 0.2 mm (Vinesh, 2008). However, the researches towards laser development and optical technology continue to grow, the accuracy of the commercially available non-contact scanning devices is beginning to improve (Boehler et al, 2001). Furthermore, another positive point is that it is the best way to scan some objects (i.e., artifacts) that need to be scanned avoiding the maximum of contact possible due to high fragility (Rutland & La Pensée, 2011).

2.5. NextEngine 3D laser scanner

The NextEngine HD 3D laser scanner (Retrieved July 17, 2015) is the scanning machine used in this project to generate some printable files of components of the prototype to be produced (Fig. 2). This scanner is classified as a non-contact scanner and it is also one of the best micro scanners commercially available. Its accuracy can reach up to 0.13 mm, and its multi-lasers can capture objects in full color. An auto drive and a part gripper are features of this scanner that allow a good fixation of the component to be scanned.

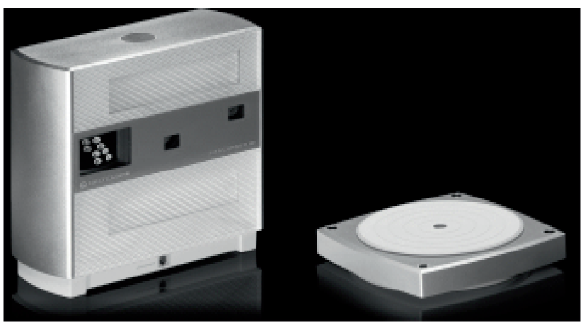

Figure 2. NextEngine 3D scanner

This machine works with the triangulation principle (Fig. 3), which is the principle that enables 3D scanning technologies to determine the dimensions and geometry of real-world objects (LMI Technologies, 2013). It can be obtained through the distances and angles between images and the projected laser creates a base of the triangle. The angle of the projected light returning to the image from the surface completes a triangle where a 3D coordinate can be calculated. By applying this principle of solving triangles repetitively, a 3D representation of an object is created (Vision Doctor - Solutions for Industrial Machine Visions, n.d., Retrieved July 24, 2015).

The software ScanStudio assists in the entire procedure, generating a point mesh for each created image. This software is essential for the machine operation, since it allows the user to select and make adjustments before and after the scanning process. For example, determining the number of divisions per round can be adjusted before starting the scanning cycle, and filling holes is a tool to be used right after the scanning process is complete.

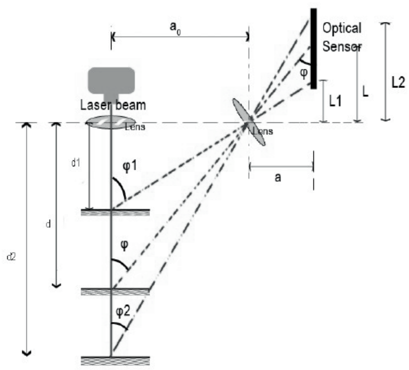

Figure 3. Triangulation principle

2.6. 3D printing

The invention of 3D printing can be traced back to 1976, when the inkjet printer was created. Since then, a variety of applications of 3D printing technology have been created across different segments and industries. 3D printers replicate not just themselves but everyday objects as well. The first 3-D printers were developed in the nineteen-eighties, by an American engineer named Charles Hull. The "ink" was an acrylic liquid that turned solid when exposed to ultraviolet light, typically from a laser beam. Makers of cars and airplanes could design complicated parts on a computer and then print out prototypes for manufacture; now they often print the part, too. Professional 3D printers can be used in 3D print shops, the copy shops of the future, and in social manufacturing services, anyone can offer the capacity of his or her 3D printer, or distribute templates to print utility or design objects. This project was executed with two models of 3D printers (MakerBot Replicator 2X and Flashforge Creator Pro). Shortly, 3D printing provokes human minds to think creatively. It inspires them to seek new ways to old solutions and improve how existing things work. Creativity should not have any boundaries, so that every individual can experiment and become an innovator.

2.7. MakerBot Replicator 2X

This is a 3D Printer that works only with ABS filaments, making snaps, living hinges, and threaded objects. In addition, this machine can control heating and cooling better with a superflat heated aluminum build plate, also helps prevent uneven cooling, shrinking and cracking. MakerBot Replicator 2X (Retrieved July 14, 2015) uses the software "MakerBot MakerWare" and it accepts input files as STL, OBJ or THING (Fig. 4). A great advantage of this machine is its small size and weight. The one that was used in this project has a size of 19.1” x 16.5” x 14.7” and weighs of 25.4 pounds.

Figure 4. MakerBot Replicator 2X

2.8. Fleshforge Creator Pro

This is a 3D Printer that works both with ABS or PLA filaments. Flashforge Creator Pro (Retrieved, July 14, 2015) has a dual extruder that has no limits (Fig. 5). In stock form, Flashforge Creator Pro prints ABS, PLA, nylon, dissolvable filament, and even composite materials such as wood and metal. The extruders can be modified to print flexible and other composite materials that may come out in the future. The Flashforge Creator Pro uses the software “MakerBot MakerWare” as well and it accepts input files as STL, OBJ or THING. A great advantage of this machine is also its small size and weight. The one that was used in this project is of 18.7” x 15” x 13.1” size and weighs 23 pounds.

Figure 5. Flashforge Creator Pro

3. Methods and materials

3.1. Creating the project

A knee joint prototype, 3B Scientific A82/1 Deluxe Functional Knee Joint Model, was purchased from a website in order to be the basis to start the project. It is the reference measurements for the CAD drawings as well as the model used in the reverse engineering (3D scanning) and assembly process. A picture of the full object is shown in Figure 6 with each component indicated separately (Vilanova et al, 2015):

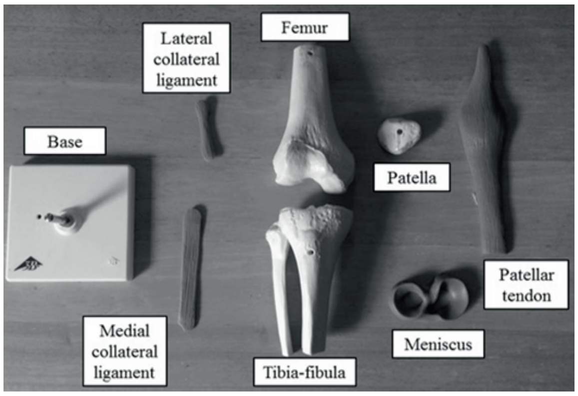

Figure 6. 3B Scientific A82/1 knee joint

3.2. Computer aided design (CAD)

The patellar tendon, lateral collateral ligament, and medial collateral ligament were designed using the software Pro-Engineer (student version), best known as Creo^{TR}. From a knee prototype bought on the market, a digital caliper (Vernier Caliper 150mm/6inch Micrometer) was utilized for getting its measurements. The patellar tendon required a central attention. Due to its complex design, tools such as sweep blend, sweep, and extruder were used for its bumpy form. Also, for the purpose to obtain a union with the patella, the tool revolve was used for removing material from the patellar tendon. Furthermore, basic tools such as, line, circle, and mirror were utilized for getting the lateral and medial collateral ligament. Finally, the round tool was selected for better finishing, removing their sharp edges.

Additionally, the base for the knee prototype (Fig. 7) was projected with some modifications. The team members' names and the University logo were customized in order to have a better identification. Then, the drawings were transformed in a binary Stereolithography (STL) file and exported to MakerBot software (Vilanova et al, 2015).

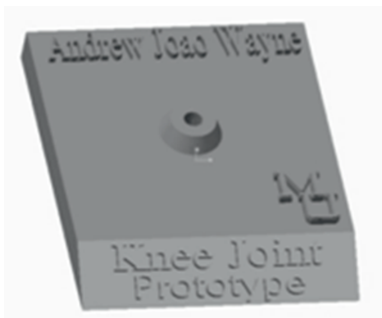

Figure 7. Final base designed by Creo^{TR}

3.3. 3D scanner (reverse engineering)

The Tibia-Fibula, Patella, Femur, and Meniscus were scanned using the NextEngine 3D scanner (Fig. 8). The already mentioned part gripper of the scanner was the base to put and hold these parts during the scanning process.

After scanning the part as many times as necessary the trim command was used to remove undesirable features shown at the scanned model. Then, the align tool was used in the following way: three reference points between each pair of scanned models - aligning and combining them into one until getting the final model (Fig. 9). After using the trim and align commands, the buff and remesh tools were utilized respectively. The buff command was utilized for getting a better finish, thus removing imperfect shapes and/or spots on the model surface. In sequence, the remesh tool was used for the purpose to fill all holes and/or open surfaces that were generated during the scanning process. Finally, once a completely solid model was created the next step was to save the drawing in a supported 3D printing format. In that case, the format used was the Stereolithography (STL) file. By then, the part was ready to be printed (Vilanova et al, 2015).

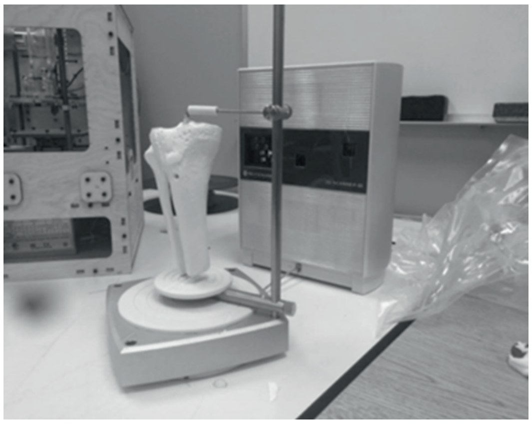

Figure 8. Scanning procedure

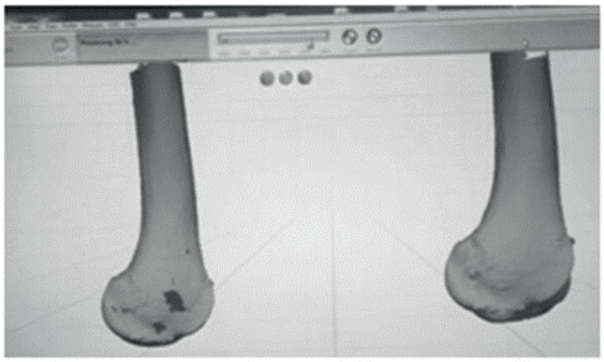

Figure 9. Align command processing

3.4. Project execution

After the femur, tibia-fibula, patella, patellar tendon, meniscus, medial and lateral collateral ligament were designed, they were manufactured using two 3D printers, the MakerBot Replicator 2X and the Flashforge Creator Pro. Basically, their operations are pretty similar and have the same purpose. First of all, using the MakerBot software, completed STL files were adjusted. Positions, angles, and rotations were the main tools for their adjustment; also, a lay flat was required for a better printing, avoiding troubles during the process. Settings were adjusted according to the kind of material; raft and support were selected for a better fixation in the platform. Finally, an extruder was selected. The adjustments made to the femur model are shown in Figure 10 (Vilanova et al, 2015).

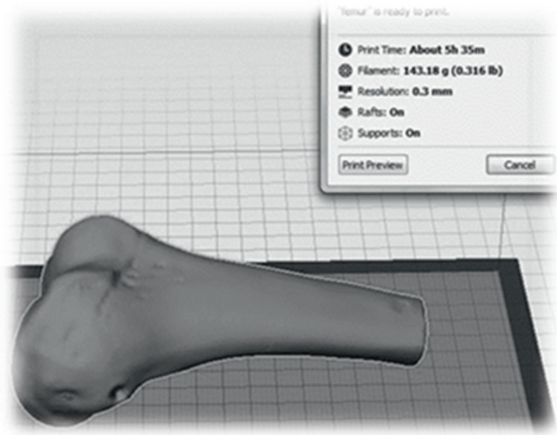

Figure 10. Adjusting the femur model

Once adjusted, the filament plastics were fitted at the nozzles' extrusion. A load extrude command was selected after this process, and the sound alert sounded when it was completed. Returning to the software, those STL files were reviewed and printed using the print button. This procedure was repeated for each piece printed.

3.5. Plastics

Three types of plastic were used for printing the objects: the Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), and NinjaFlex filament. As previously mentioned, each one of them has its own print settings, and this factor created the necessity to do some research to find proper adjustments for print settings. The PLA and ABS plastics were used for manufacturing the bone parts (femur, tibia-fibula, and patella) and the prototype base. The PLA parts were printed using the Flashforge Creator Pro, and the ABS parts were printed using the MakerBot Replicator 2X, due to technical recommendations. For the purpose of getting flexible parts, the NinjaFlex was used to achieve the ligament models' flexibility. The manufactured parts by this type of plastic were the patellar tendon, the meniscus, the lateral collateral ligament, and the medial collateral ligament. About the others parts, the ABS and PLA models were printed using two brands: for printing the test pieces and the patella, MakerBot white filament was used; for the prototype base, MakerBot yellow filament was chosen; and for the skin color parts, the filament brand BuMat Elite was used (the parts destined for the final assemblies).

3.6. Final assembly

The two final assemblies (PLA and ABS) were composed each by the femur, tibia-fibula, patella, patellar tendon, lateral collateral ligament, medial collateral ligament, meniscus, and knee prototype base. Both assemblies were made in the same way as described in the following steps. The first step was to obtain a better surface finish on non-flexible parts which had some supports' fragments from the printing process. An electric sander was utilized in the polishing procedure.The parts were assembled using super glue (Loctite) and it was based on the original assembly of the 3B Scientific A82/1 Deluxe Functional Knee Joint Model (Fig. 6). The first step for getting the final assembly was to gather the tibia-fibula and meniscus together. Thus, allowing a better mobility for the femur, reaching the objective of getting a real knee movement. Secondly, the base part of the tibia-fibula was glutted in the middle of the customized base, which has a support designate to fix the fibula standing. Meanwhile, the patella was glutted in a tendon cavity, just like the knee joint model was manufactured. Finally, the patellar tendon, lateral collateral ligament, and medial collateral ligament were assembled.

4. Results and discussions

4.1. CAD drawings

The drawings obtained from the CAD software were adjusted to better apply to the project, thereby being different than the original parts as a consequence of applied customization and some existent constraints. The customization can be verified in the base of the knee prototype where the team members' names and the University logo were inserted. As a consequence, the length of the base needed to be increased in order to accommodate the modifications. Regarding the constraints, the first limitation to generate the drawings from CAD software was the level of complexity of some parts. These parts (the patellar tendon, the lateral collateral ligament, and the medial collateral ligament), flexible and difficult to hold and scan using the NextEngine scanner, require a high level of expertise in CAD software to design and obtain more accurate results regarding shapes and surfaces. Additional training is needed in CAD for the students to successfully design these parts. Only 2/3 of the students trained (8 out of 12) were able to successfully design and print these parts. The other constraint is the maximum printable area of the printing platform that can limit the sizes of the parts to be printed. Due to this constraint, the patellar tendon needed to be reduced 40 mm on its total length. Even though all of those modifications were made, one point that needs to be addressed is that all of the models created from CAD software maintained the most important shapes and sizes needed for creating the final assembly.

4.2. 3D scanned drawings

Among all the available resources for creating solid models to be printed, the NextEngine 3D Scanner was the most accurate and easiest to use. Also, it was the fastest tool too. In comparison, drawings made from a CAD software, simple to complex parts, took 1 hour to 4 hours (the time spent to manually obtain the necessary measurements of the parts is counted), while a complete scanning process of simple to complex parts took 30 minutes to 2 hours until the final solid model was generated. Another point to be considered is that the complexity of the scanned parts is much higher than the solid models generated by the CAD software. However, it had a drawback. The most flexible parts could not be scanned because it was not possible to fit and hold those parts into the scanner plate. But besides that problem no other issues were identified.

4.3. 3D printers

In the process of printing all of the necessary components for the assemblies, different results were achieved regarding printing time, part weight, and finish quality. Those variations occurred because combinations of different print settings with different materials were tested. Table 1 shows the different materials used and their proper print settings that impact the printing time and weight values. As an example, the infill configuration used for the base in PLA had a considerable variation in the part weight compared with the same part printed in ABS. In addition, the type of material's brand used affected the outcomes as well. As an example, the parts printed with BuMat filament (both ABS and PLA) showed to be heavier than the parts printed with MakerBot filament. Furthermore, using that same material, the surface smoothness was not good at the bottom of the parts (where the support is created) and some layers did not adhere properly with their previous layers during the printing process, occasioning some fissures in the finished part. In a different way, the NinjaFlex filament worked as expected, resulting in good quality parts and presenting just some settings issues. Analyzing the parts separately, the prototype base was the only component that showed similar problems while printing in both PLA and ABS materials. As mentioned previously, for the prototype base MakerBot yellow filament was used, but the print outcomes were not as expected. For unknown reasons, the upper surface finish was never satisfactory, always showing very noticeable imperfections, such as missing layers. The best, but still not good, two outcomes of this part was destined to the final assemblies. Regarding the printers, no considerable differences were encountered comparing the printing results of both machines. Support material removal and cleaning time on average for the larger parts such as base, femur, and tibia-fibula was between 20 to 30 minutes where as for the smaller parts it was between 10 to 15 minutes.

Table 1. Results of 3D printed parts

Part Name	Printer Settings				
	Extruder Temp. (°C)	Platform Temp. (°C)	Print Speed (mm/s)	Infill (%)	Layer Height(mm)
Tibia-fibula, ABS	230	110	90	50	0.3
Tibia-fibula, PLA	220	60	90	50	0.3
Femur, ABS	230	110	90	50	0.3
Femur, PLA	220	60	90	50	0.3
Patella, ABS	230	110	90	50	0.3
Patella, PLA	220	60	90	50	0.3
Meniscus, NinjaFlex	240	40	15	50	0.3
Patellar tendon, NinjaFlex	240	40	15	50	0.3
LCL, NinjaFlex	240	40	15	50	0.3
MCL, NinjaFlex	240	40	15	50	0.3
Base, ABS	230	110	90	50	0.15
Base, PLA	220	60	90	25	0.15

Part Name	Printing Time	Weight (g)	Weight Decrease (PLA Compared to ABS)
Tibia-fibula, ABS	5h 26m	94.29	-
Tibia-fibula, PLA	5h 25m	76.17	19.22%
Femur, ABS	5h 33m	102.87	-
Femur, PLA	5h 35m	84.75	17.61%
Patella, ABS	0h 32m	7.12	-
Patella, PLA	0h 30m	6.96	2.25%
Meniscus, NinjaFlex	2h 9m	10.40	N/A
Patellar tendon, NinjaFlex	5h 12m	19.21	N/A
LCL, NinjaFlex	0h 35m	1.62	N/A
MCL, NinjaFlex	1h 44m	4.61	N/A
Base, ABS	8h 17m	89.49	-
Base, PLA	7h 4m	44.64	50.12%

4.4. Assembly

The creation of the final assembly did not present any major issue. As commented before, the original prototype was the basis for assembling the new knee joint prototype, being an excellent support to avoid errors while joining the components. It was an easy process that required approximately just 30 minutes to finish each assembly. The final assemblies (ABS and PLA) are shown in Figure 11 (Vilanova et al, 2015).

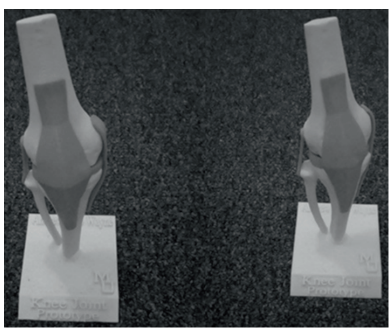

Figure 11. Final assemblies: ABS (left) / PLA (right)

4.5. Material quality

PLA samples were stronger than ABS samples for manual breaking. Using clamps, a vice, and a weighed system, tensile test experiments conducted on ABS printed samples indicated that the samples failed for the 20 pound weight whereas PLA samples did not fail for the 20 pound weight. PLA samples failed when 30 pound weight was used. The ABS part gave in gradually with compression. The PLA sample was the same as ABS but did require additional force at the end. Published data indicate that PLA has approximately 1.4 times greater tensile strength and 2.4 times greater compressive strength than ABS.

4.6. Prototype cost

The cost of 1000 grams of ABS/PLA filaments used is $23 ($0.023/gram). The cost of 500 grams of NinjaFlex filament is $40 (0.080/gram). The cost of material from Table 1 data for ABS prototype is $9.64 and that of PLA prototype $7.78. Hence, the material cost of a prototype is approximately $10.

The scanning, printing, assembly and machine utilization cost is approximately $20/prototype. The total cost of a prototype is approximately $30. With 50% profit a prototype selling price is approximately $45.

The purchase price of similar prototype in the market is from $128 to $175. Therefore, the prototype made can be sold 3 to 4 times cheaper than the market price of similar prototypes. If the prototype is sold for 100% profit ($60/prototype), it is still 2 to 3 times cheaper than the market price for similar products. The knee joint prototype, 3B Scientific A82/1 Deluxe Functional Knee Joint Model purchased for this project was $180 (including the shipping cost).

5. Conclusions and recommendations

After all the steps taken to perform this project, some conclusions and recommendations can be drawn regarding the set of variables involved in an Additive Manufacturing process. The engineering method was essential in achieving solid models of the most complex parts. However, as some parts could not be scanned, the CAD software used (Creo™) was a very important additional tool. Then, different tools were combined while creating solid models to be printed; this was the best approach to complete the project. Second, even though two 3D printers were used, all the printed parts could be obtained just using the Flashforge Creator Pro which accepts many different types of plastic filaments. However, printing components simultaneously using two printers revealed to be a great increase in time performance. As the last point, regarding the materials used, MakerBot filaments would be chosen for future projects instead of BuMat filaments for reasons already discussed in this paper. Also, for better aesthetic results, PLA filaments would be selected as the main material for solid non-flexible parts. However, due to mechanical properties ABS plastic would have preference for more applicable parts (i.e., prosthesis). Overall, this project was successful and had achieved the goal of creating as accurate as possible a low cost knee joint prototype using additive manufacturing concepts and tools.

5.1. Challenges and lessons learned

Initially, the student team needs to be trained in CAD, 3D Scanning, and 3D printing using the available lab facilities. They need to learn about human anatomy, the knee joint, and its functions. Some problems arose during the process, like delay in the arrival of some materials, problems with the 3D printer, assembly errors, sizing issues, software incompatibility, among others. These problems were solved referring to resources such as the internet, reference manuals, and books as well as watching online tutorials and reading related articles. Focus and dedication of the student team was the key to successfully completing the project and assembling the knee prototypes.

5.2. Recommendations

From the outcome of this project evaluation, it is noted that the students need additional training in CAD and 3D scanning. They are encouraged to read related materials (reference manuals, books, articles, internet resources, etc.) and watch online tutorials and YouTube videos on CAD, 3D scanning, AM processes, and related topics.

As a recommendation for the students who like to work on hands-on manufacturing and rapid prototyping projects the following suggestions are made: Take proper training in CAD and use of 3D printers; conduct background research on CAD, 3D scanning, and rapid prototyping technologies; read carefully the related materials (reference manuals, books, articles, internet resources, etc.) and watch online tutorials; and take proper safety measures while using lab machines and equipment.

6. Acknowledgements

This project was funded by the Mercer Summer Engineering Experience (MeSEE) program of Mercer University School of Engineering during the Summer Semester of 2015.

7. References

Abella et al. (1994). *Introduction to reverse engineering*. Chapter 1, Springer, pp 5.

Boehler, W., Heinz, G., & Marbs, A. (2001). *The potential of non-contact close range laser scanners for cultural heritage recording.* XVIII CIPA Symposium, Potsdam, Germany.

Fedorov, A. (2009, April 4). *Rapid prototyping versus traditional development*. Fresh Tilled Soil. Retrieved July 21, 2015.

"Flashforge Creator Pro 3D Printer User Manual". Retrieved July 14, 2015 from www.flashforge-usa.com/ creator-pro/.

Gibson, I., Rosen, D., & Stucker B. (2010). *Additive manufacturing technologies, 3D printing, rapid prototyping, and direct digital manufacturing.* New York: Springer.

Heesterbeek, P. (2010). *Mind the gaps! Clinical and technical aspects of PCL-retaining total knee replacement with balanced gap technique.* S. l.: Heesterbeek.

LMI Technologies, (2013). *A simple guide to understanding 3D scanning technologies.* First Edition. Retrieved July 23, 2015, from http://www.lmi3d.com/sites/ default/files/EBOOK_A_Simple_Guide_To_3D.pdf

"MakerBot Replicator 2X User Manual". Retrieved July 14, 2015 from www.makerbot.com/Replicator2X.

NextEngine 3D Laser Scanner. (n.d.). Retrieved July 17, 2015 from http://www.nextengine.com/products/ scanner/specs.

Platzer, W. (2009). *Color atlas of human anatomy.* (6th rev. and enlarged ed.). Stuttgart: Thieme.

Principle of triangulation: basics for machine vision. (n.d.). Vision Doctor - Solutions for Industrial Machine Visions. Retrieved July 24, 2015 from http://www.vision-doctor.co.uk/laserillumination/ principle-of-triangulation.html.

Rutland, F. P., & La Pensée, A. (2011). *Non-contact 3D laser scanning as a tool to aid identification and interpretation* *of archaeological artifacts; the case of a Middle Bronze Age Hittite dice.* National Museums.

Vilanova, A. P., Moreira, J. P. M., and Lima, W. D. (2015). *Additive manufacturing for the production of a knee joint prototype.* Project Report, Mercer Summer Engineering Experience (MeSEE) 2015, pp. 1-45.

Vinesh, R. (2008). *Introduction to reverse engineering, in reverse engineering: an industrial perspective.* Vinesh, R., Kiran F.J, Eds.; Springer-Verlag: London, UK, pp.1-11.

Business Intelligence- Success Through Agile Implementation

Matthew Williams[1]
Thilini Ariyachandra[1] , Mark Frolick[1]
[1]*Xavier University*
williamsm44@xavier.edu; ariyachandrat@xavier.edu; frolick@xavier.edu

Abstract

As organizations continue to realize increased value of Business Intelligence (BI) systems, being able to deliver these systems faster and at higher quality continue to grow in necessity. How projects are approached and managed is one means of achieving these goals. BI implementations within organizations face some of the hardest challenges seen in Information Technology projects. The scope, timeline, and number of groups involved in BI projects all create factors that can compromise the success of an implementation. Strategic value of the project must be defined and infrastructure and development needs must match. This can be easier said than accomplished especially given high failure rates of BI implementations. However, BI implementations can benefit from following an agile approach. Agile approaches can better align BI implementation efforts with the objectives of the organization by better hearing key stakeholder input and focusing technical expertise simultaneously. Senior leadership should identify these high risk and complex projects as true agile candidates and organization resources appropriately. Improved results will follow. This research attempts to discuss the benefits, challenges and issues of using an agile development method for the implementation of a BI system. While the agile development methodology in its purest form may not fit the development of BI infrastructure, enterprise level design and development of BI infrastructure requires a hybrid approach of development. Unlike conventional IT implementations, as BI projects are infrastructure projects, a unique perspective of agile methods are required for BI implementations.

1. Introduction

Business Intelligence (BI) implementations within organizations face some of the hardest challenges seen in Information Technology projects. The scope, timeline, and number of groups involved in BI projects all create factors that can compromise the success of an implementation. Strategic value of the project must be defined and infrastructure and development needs must match. This can be easier said than accomplished. For example, the following findings represent the failure rates of IT projects. For IT projects in general, the average cost overrun is 27%. Fifty seven percent of IT projects fail from poor communications (Threlfall, 2014). In 2007, data suggested data warehouse implementation failures could be as high as half of all projects (Hill, 2011).

BI projects are not immune to these trends and arguably more impacted because of project complexity. Gartner predicts BI projects have a failure rate of 70 to 80% (Kernochan, 2011). A key means to changing success rates for projects is modifying the methods by which they are completed. The traditional waterfall method for implementing BI projects are wrought with challenges (see Figure 1).

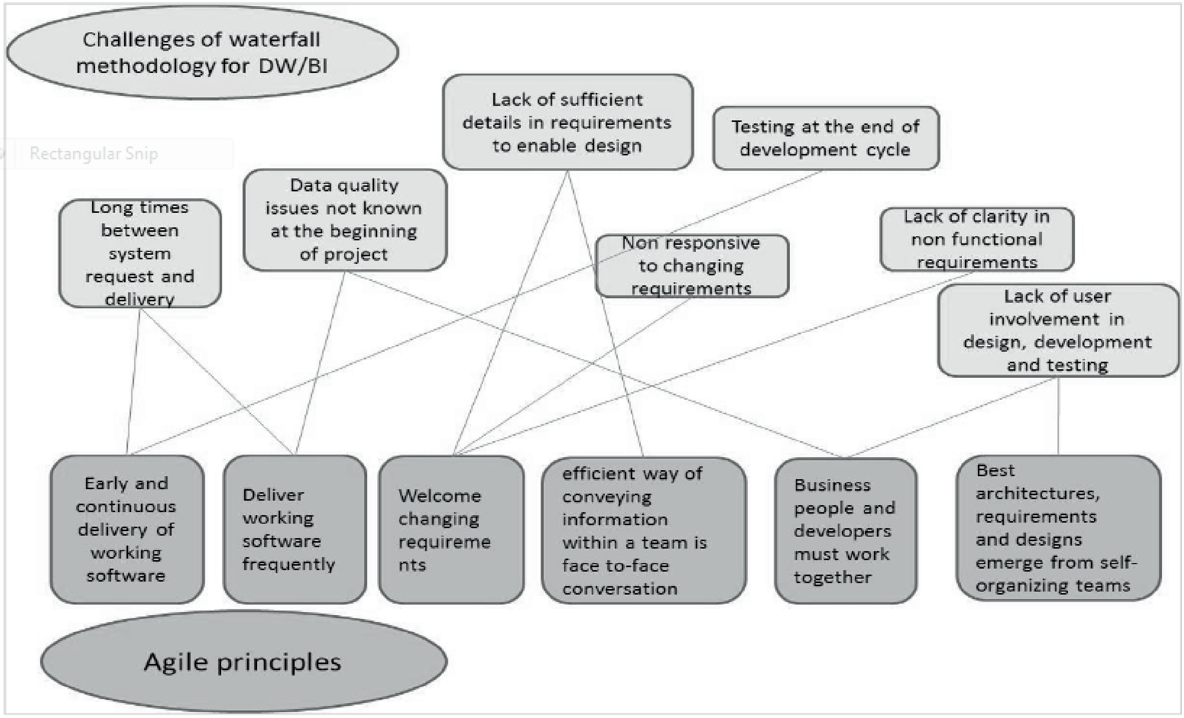

Figure 1. Challenges faced by BI projects due to Waterfall (Adopted from Deshpande & Desai 2015)

BI implementations can benefit from following an agile approach. In the sections that follow, this paper first introduces a BI system. Then it discusses the key approaches to systems development, identifies the value of agile methods and discusses the issues and challenges in using an agile approach to BI implementations. In so doing, the paper presents an approach to how agile can be adopted for BI implementations in a manner that could lead to the success of more BI implementation projects.

2. Business Intelligence

Business intelligence, or BI, is an umbrella term that refers to a variety of software applications used to analyze an organization's raw data. BI as a discipline is made up of several related activities such as data mining, online analytical processing, querying, and reporting. Companies use BI to improve decision making, cut costs, and identify new business opportunities. BI is more than just corporate reporting and more than a set of tools to coax data out of enterprise systems. CIOs use BI to identify inefficient business processes that are ripe for re-engineering. With today's BI tools, businesses can jump in and start analyzing data themselves, rather than wait for IT to run complex reports. The access to this shared information helps users back up, with hard numbers, business decisions that would otherwise be based only on gut feelings and biased opinions.

Business intelligence systems have evolved from narrowly focused query and reporting tools to enterprise-wide platforms. The resulting single source offers not only current, but also historical and predictive views of operations. The continued evolution of the BI software category includes new trends, including self-service techniques, and ongoing acquisitions that represent a major market consolidation. As organizations embrace technologies such as social media, and new data sources (e.g., sensors, RFID), they also face new challenges related to analyzing and leveraging data characterized by large volume, velocity, and variety – typically referred to as 'Big Data'. Implementation BI solutions that can accommodate big data involve dealing with multiple technologies to integrate different data types and a considerable investment of resources both in time and money. A waterfall methodology is clearly inappropriate for this as the time and effort needed to implement a consistent enterprise wide solution in a manner that would meet market demands is not possible. Agile provides a more reasonable methodology that can enable an organization to implement while meeting ongoing demands for decision making.

3. Why agile?

First a discussion what an Agile approach is and how this different from traditional approaches is needed. A common traditional approach would be the waterfall methodology (Muntean, 2013).

A waterfall approach has the following characteristics (Muntean, 2013):

- The requirements for the project are well known up front.
- This implies the customer is fully aware of their requirements, and there is no intention to change them throughout the project.
- User input is provided at the beginning of the project and primarily only at this time.
- The project team works through well-defined phases, not repeating each of these phases (such as design, development, or testing).
- The results of the project are delivered to the user at project completion.

An Agile approach is very different with user interaction occurring frequently throughout the project and requirements changing or adapting on a regular basis. Planning therefore occurs during the actual project, with 80% of planning even occurring during deployment (Kenney, 2015). How can this lead to increased success one may ask.

The best way to demonstrate the value of this newer approach is a specific agile methodology as an example. For instance, some leading Agile development methodologies include Extreme Programming, Adaptive Software Development, Feature-Driven Development, and Scrum. Scrum specifically is defined as “a team-based approach for controlling the chaos of conflicting interests and needs to iteratively, incrementally develop systems and products when requirements are rapidly changing” (Meso, 2006).

4. A background on Scrum

Focusing on Scrum, it will be beneficial to define some of the roles and features of this approach. The key roles are the ***Product Owner***, ***Scrum Team***, and ***Scrum Master***. The critical items to note are the Product Owner is responsible for maximizing the ROI on the project, the Scrum Team determines how commitments can be reached, and the Scrum Master knocks down blockers (James, 2014).

The Product Owner is typically a functional owner or member from the business seeking the BI tool or product. They understand why the project is occurring and how it aligns to and will enable business strategic goals. Upper management support of the BI project is very important for success. Employees’ focus and motivation will be drawn to where leadership directs their attention (Hobeck, 2009). A Product Owner that is senior themselves or visibly supported by management is critical. They determine where the Scrum Team will focus efforts and accepts (or rejects) products produced by the team. The Scrum Team consists of cross-functional members such as architects, developers, data owners, and technology experts (Heizenberg, 2013). They understand what they are capable of producing within a Sprint and work with the Product Owner to align priorities. The Scrum Master focuses on keeping the team on track with the Scrum process. This includes removing external distractions, escalating any potential blockers to success, and ensuring a collaborative environment remains available to the Team.

Equally important to the roles within the Scrum Team is the frequency and types of interactions they conduct. The team operates within Sprints. These are typically 2 week time periods, though they can be slightly shorter or longer as determined by the Team at the beginning of the project. Once the project starts the time period stays the same length and each of the following working sessions occurs within a sprint (James, 2014), see Figure 2:

- Sprint Planning (and Backlog Refinement) Meeting
- Daily Scrum
- Sprint Review Meeting
- Sprint Retrospective Meeting

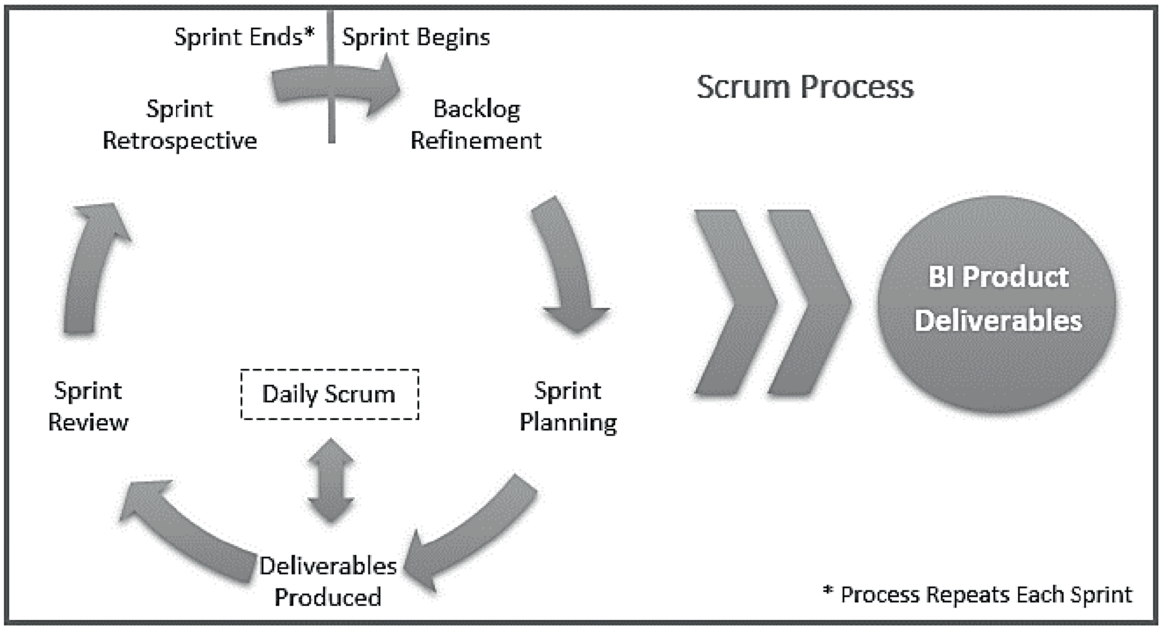

Figure 2. Scrum process

What is unique to this agile approach when compared to traditional approaches is the Team "resets" priorities each Sprint. During Sprint Planning the Product Owner reviews the Backlog which contains all possible needs for the project. These needs have been estimated by the Scrum Team to take, at a maximum, 2-weeks to deliver. If a longer time is estimated, the requirement should be broken down to Sprint length to ensure it can *possibly* be delivered within one Sprint. This allows the focus of the Team to be very adaptable. If the Product Owner decides priorities should adapt to new requirements, this can be accomplished by pulling the most pressing requirements off of the backlog for the current Sprint.

At the end of a Sprint, the Scrum Team has a chance to showcase their efforts during the Sprint Review Meeting. During this meeting features and/or completed requirements of the project are shown to the Product Owner and other key stakeholders as determined by the Product Owner. Initially these features may be small, but this gives the Product Owner the opportunity to provide feedback to the Team and continuously see progress. The Product Owner then also determines if the requirement is met or should go back in the Backlog for future Sprints.

The Retrospective Meeting typically occurs shortly after or just after the Review Meeting, and gives the Team a chance to provide honest and open feedback on how the Sprint executed. Is the Team seeing challenges in certain areas? What did they do well? What didn't they do well? The idea is not to dwell on issues but provide continuous improvement to the Team with each Sprint.

Finally, a key ingredient to success is how the Team interacts. The Team should be provided with collaborative communication tools and typically will work in a collaborative space, the same room or space for example. The Team also conducts Daily Scrums. During these 15-minute, once a day meetings each team member states (Lovell, 2014): (1) What they accomplished the day before, (2) What they intend for the current day and (3) What, if any, impediments stand in their way.

This allows the Team to know what progress each member has made and how the Team is executing as a whole. The Scrum Master can also identify issues and help the Team push through them. See Figure 2 for an overview of the flow Scrum meetings.

5. Applying Scrum to Business Intelligence

Now that the background has been provided on an Agile approach using the Scrum framework specifically, a focus on how this improves the success of BI projects can be presented at greater depth. The Agile Manifesto contains twelve principles that drive Agile approaches including Scrum. The full list of the principles can be reviewed at agilemanifesto.org, but this list can be broken down into four key success criteria. Each of these four criteria may sum up one or more of the twelve principles, but more importantly a focus on these criteria is how Agile approaches provide value to BI implementations.

1) Customer Satisfaction
2) Results Delivered in Frequent Iterations
3) Simplicity
4) Continuous Improvement

5.1. Customer satisfaction

By design, an agile approach focuses more on the Customer than a traditional approach. In a waterfall approach the user defines requirements for the IT group at the beginning of the project, and the IT function executes on these requirements. A product is then provided at the end. Certainly touch points can be built in for interaction between the IT and business functions, for example, at the completion of design or development. However, these interactions may simply be a sign off on the phase or an ask for complete rework of a phase if requirements need modification.

There is not continuous interaction between all parties involved with the BI effort in a traditional approach. BI projects span many business units, many IT systems, and require both technical integrations and procedural crossover. Further, because of this scope BI projects can span many years (or even be viewed as not having an end date). The only way to produce valued and effective deliverables is by including the “customer” in the process.

With Scrum the customer is the Product Owner. At a *minimum* the Product Owner is interacting with the Scrum Team twice per Sprint, once at Planning and once at Review. These meetings improve customer satisfaction because the customer is determining areas of focus for the team and signing off on what meets expectations. This helps ensure integration between technical efforts and the business defined strategy for the organization. Multiple stakeholders in addition to the Product Owner can attend the Sprint Review as well (James, 2014)!

5.2. Results delivered in frequent iterations

Senior leadership buy-in is critical to BI project success. Many parts of the organization are touched and costs are high. Frequent touchpoints showing project progress can demonstrate wins, show desired results are being achieved, and keep on leadership’s radar how the project aligns to company goals. They can see how ROI is being achieved throughout the project timeline.

Obviously projects can and do go “off-track” sometimes. Frequent releases provide multiple opportunities to drive the Scrum Team back on track. IT isn’t simply translating requirements in a system as they see is best. Both the business and IT are achieving results together.

Small releases of features also can provide a means for improved training or at least identify more detailed needs for training early on. Instead of full system turnover upon completion, functional owners see how the system, reports, and tools are coming together. Better insight on how features can truly be used is gained throughout development. Therefore how the end user can best utilize the system and be trained to do so can develop simultaneously with the BI tool itself.

5.3. Simplicity

To a newcomer it may sound as if an iterative process may complicate an already difficult project management process. However just the opposite is achieved with an Agile approach. Because the Scrum Team and Product Owner align on priorities for each Sprint, the Team has a very clear picture of only a few items to focus on in the next couple of weeks. The Scrum Master is also involved to ensure that these priorities are where all efforts are focused. Distractions from items outside of the project or even items from previous Sprints should not be worked if they are not within the defined, prioritized list for the current Sprint.

Additionally BI engagements can be very lengthy in time or simply a planned on-going effort. A focus on a potentially changing project end date is avoided. Only the current Sprint is the focus, and the Team can repeatedly deliver results.

The Product Owner is simultaneously working with stakeholders to determine needs from the project and then align the team priorities to the BI strategy. It should be expected that requirements will change repeatedly throughout a project, especially one that is multiple years. As Gartner analyst James Richardson put it, “BI is the art of trying to hit a moving target. About half of the BI requirements change in the first year of the project” (Banks, 2011). A Scrum rhythm allows efforts to align with *current* requirements.

Table 1. Key agile factors improving BI success

Agile Approaches Provide Value to BI Implementations via 4 Key Factors	
Customer Satisfaction	The customer is placed first in Agile approaches. Typically the business can prioritize what is needed from the BI system to align with strategic goals.
Results Delivered in Frequent Iterations	ROI can be seen early on in the project and project successes/wins are demonstrated on an ongoing basis.
Simplicity	True priorities for project success are broken down into manageable pieces and focused on.
Continuous Improvement	The Scrum Team frequently reviews what is working and what is not to improve process and BI deliverables. Stakeholders are given a critical voice in improving the results of the project.

5.4. Continuous feedback

A critical component to any project’s success, specifically if there are many stakeholders, is communication. Daily Scrums ensure the Scrum Team meets every day at a minimum. Sprint length guarantees larger stakeholder interaction every couple of weeks. At these interactions feedback is provided on product features improving the overall final system produced.

Continuous feedback also helps create employee and end user buy-in. Stakeholders have a true say in what features will be beneficial and why. “Employees will be more likely to accept a new technology initiative if they can see how they will be able to impact the organization and personally benefit from the new tools at their disposal” (Hobeck, 2009). At the same time the Scrum Team can articulate any realistic hurdles or concerns with producing a desired deliverable. This cross-functional effort helps create an achievable project scope. Individuals also get to see the results of their ideas or efforts quickly increasing buy-in of the new tool or a change to the current process. Impacts of their decisions are seen much sooner with an Agile approach. See Table 1 for a high-level overview of each of the four key factors that provide value to BI implementations.

6. Potential challenges

Modifying project management approaches is both a mindset and a culture shift for organizations. Small businesses to enterprise-size companies can face many of the same obstacles (Frye, 2012), so what is the best way to move towards an Agile framework?

Simply put, implement the projects that will benefit from an Agile approach using an Agile methodology. Otherwise a traditional approach may still be suitable and potentially better. Agile projects should be those projects that have frequently changing requirements and large amounts of risk and uncertainty (Vinekar, 2006), in other words… many BI projects.

It is likely however because of how many parts of an organization are need for BI success, there will be an overlap of approaches. For example, Compliance or Infrastructure Sourcing groups may need to stick to more traditional approaches purely because of external factors or large lead times on sourcing items. Even options in these areas are changing as Cloud providers tackle compliance certifications and the processing needs of BI systems (Muntean, 2013). The development of BI tools, integrations, data modeling, and creation of architectures can benefit from Agile approaches and begin doing so right away.

Another area of consideration could be sizing teams appropriately. Typically Scrum Teams are 5 to 7 persons in size (Radigan, 2016). Moving beyond this number brings in communication and prioritization challenges. Many organizations have more than 5 to 7 IT persons who can contribute to a BI effort however, sometimes hundreds more. This is where the “scrum of scrums” idea can be beneficial (Vinekar, 2006). Overall objectives of the BI initiative would be split among Scrum Teams allowing the benefits of a smaller team size while still leveraging a larger headcount of employees.

7. Conclusions

As organizations continue to realize increased value of Business Intelligence systems, being able to deliver these systems faster and at higher quality will grow in necessity. How projects are approached and managed is one means of achieving these goals. Agile approaches can better align BI implementation efforts with the objectives of the organization by better hearing key stakeholder input and focusing technical expertise simultaneously. Senior leadership should identify these high risk and complex projects as true Agile candidates and organize resources appropriately. Improved results will follow.

7. References

Agile Alliance. (2015). What is Agile Software Development? Retrieved April 23, 2016, from https://www.agilealliance.org/agile101/what-is-agile/

Banks, L. Business intelligence needs CFO, COO support to be agile: Gartner. (2011). CIO (13284045), 3.

Deshpande, K., & Desai, B. (2015) Model for Assessment of Agile Methodology for Implementing Data Warehouse Projects. Volume 9–No.8, October.

Dimensional Insight, Inc. Agile Business Intelligence: Impact Profitability, Optimize Performance and Drive Business Value. (2009). Information Management (1521-2912), 19(7), 35.

Delphix. Analytics Aren't Agile. (2014). Database Trends & Applications, 28(1), 19.

Frye, C. (n.d.). Implementing Agile in very large enterprises. Retrieved April 23, 2016, from http://searchsoftwarequality.techtarget.com/feature/Implementing-Agile-in-very-large-enterprises

Heizenberg, J., Berk, A. V., & Feitsma, R. (2013). Agile Business Intelligence - How to make it happen. Retrieved February 28, 2016, from https://www.nl.capgemini.com/resource-file-access/resource/pdf/1b-032.13_whitepaper_new_vi_agile_bi_17th_oct13_final_web_secured_1.pdf

Hill, A., Ariyachandra T., and Frolick, M.. 10 Principles to Ensure Your Data Warehouse Implementation is a Failure, International Journal Of Business Intelligence Research, Vol. 2, No. 2, April-June 2011, 37-47.

Hobeck, R., Ariyachandra, T., and Frolick, M.. The Importance of Soft Skills in Business Intelligence Implementation Efforts, Business Intelligence Journal, Vol. 14, No. 1, 1st Quarter 2009, 28-36.

James, M. (2014). Scrum Reference Card. Retrieved April 23, 2016, from http://scrumreferencecard. com/scrum-reference-card/

Jourdan, Z., Rainer, R. K., & Marshall, T. E. (2008). Business Intelligence: An Analysis of the Literature. Information Systems Management, 25(2), 121-131.

Kenney, T. (2015). How to achieve Agile business intelligence success. Cio (13284045), 1.

Krawatzeck, R., & Dinter, B. (2015). Agile Business Intelligence: Collection and Classification of Agile Business Intelligence Actions by Means of a Catalog and a Selection Guide. Information Systems Management, 32(3), 177-191.

Lovell, J. (2014). Agile Business Intelligence: A Practical Approach. Business Intelligence Journal, 19(1), 15-21.

Meso, P., & Jain, R. (2006). Agile Software Development: Adaptive Systems Principles and Bast Practices. Information Systems Management, 23(3), 19-30.

Moss, L. (2009). Beware of Scrum Fanatics On DW/BI Projects. Enterprise Information Management Institute, 3(3). Retrieved February 28, 2016, from http://www.eiminstitute.org/library/eimi-archives/volume-3-issue- 3-march-2009-edition/beware-of-scrum-fanatics-on-dw-bi-projects

Muller, R. M., Linders, S., & Pires, L. F. (2010). Business Intelligence and Service-oriented Architecture: A Delphi Study. Information Systems Management, 27(2), 168-187. doi:10.1080/10580531003685238

Muntean, M., & Surcel, T. (2013). Agile BI - The Future of BI. Informatica Economica, 17(3), 114-124. doi:10.12948/issn14531305/17.3.2013.10

Radigan, D. (n.d.). A brief introduction to scrum. Retrieved April 23, 2016, from https:https://www.atlassian.com/agile/scrum//www.atlassian.com/agile/scrum

Thamir, A., & Poulis, E. (2015). Business Intelligence Capabilities and Implementation Strategies. International Journal Of Global Business, 8(1), 34-45.

Threlfall, D. (2016, July 21). Seven Shocking Project Management Statistics and Lessons We Should Learn. Retrieved April 23, 2016, from http://teamgantt.com/blog/seven-shocking-project-management-statistics-and-lessons-we-should-learn/

Vinekar, V., Slinkman, C. W., & Nerur, S. (2006). Can Agile and Traditional Systems Development Approaches Coexist? An Ambidextrous VIew. Information Systems Management, 23(3), 31-42.

Wayne, K. (2011, May 2). Why Most Business Intelligence Projects Fail. Retrieved April 23, 2016, from http://www.enterpriseappstoday.com/business-intelligence/why-most-business-intelligence-projects-fail-1.html

Big Data, Ethics, and Social Impact Theory – A Conceptual Framework

Gwen White[1]

Thilini Ariyachandra[1], David White[1]

[1]*Xavier University*

whiteg@xavier.edu

Abstract

Decisions made using big data, impact ethical issues like privacy, security, ownership, and decision making. In addition, those same decisions can have a positive or negative social impact. This paper proposes a framework that explains how decisions made using big data impacts ethics and social impact theory. A broad literature review explored how big data and ethics can have a social impact on society. The proposed framework of big data, ethics and social impact is illustrated through three examples. Insurance companies manipulate big data to impact sales. The Center for Disease Control examines big data to determine the location of the next outbreak. Companies analyze big data in predictive analysis to increase marketing or determine a new trend. It was found that these uses of big data directly affects ethics which has a positive or negative social impact. Simple decisions can change the outcome for one or millions.

1. Introduction

Big data is a disruptive technology where it changes an existing industry or starts something completely new (Wessell, 2016). Big data is found in many industries like finance, education, government and even retail. (Disruptive Technology Reconsidered: A Critique and Research Agenda, 2004). There are many types of big data which include mobile, pictures, social media, video, machine generated and audio. These new types of media will make up 85% of data sources for big data consistently increasing the size of the big data cache (Bearden, 2014). Within the past ten years, ethical problems associated with big data have increased. Big data affects the ethical principles of privacy, security, ownership, and decision making. Many organizations use the results from big data analytics to make major decisions. Those decisions directly influence ethics and in turn play a role on the social impact of its outcomes. This paper proposes a framework that explains how big data, ethics and social impact theory are interrelated.

2. Big data and ethics

There is a rapidly growing volume of literature that combines big data and ethics. Between 2001 to 2016 big data usage has increased along with the instances of actual and perceived ethical violations. Ethical themes evolved including privacy, security, ownership, and decision making. According to Zwitter (2014), industry is moving towards "changes in how ethics has to be perceived away from individual decisions with specific and knowledgeable outcomes towards actions by many unaware that they may have taken actions with unintended consequences for anyone". There are four themes that have emerged in relation to ethics and big data: privacy, security, ownership, and evidence based decision-making.

Privacy is the non-disclosure of personal information to the public (Davis, 2016). Big data can contain private information that might be exposed unintentionally or intentionally. States normally develop their own privacy requirements which echo federal laws (Thorpe & Gray, 2015). Normally data should be de-identified to protect it. Since so many people are connected through a variety of data networks, the ability to generate and share data increases daily (Tene & Polonetsky, 2013). There are situations where consent is not possible. "Protecting privacy will become harder as information is multiplied and shared ever more widely among multiple parties around the world. As more information regarding individuals' health, financials, location, electricity use and online activity percolates, concerns arise regarding profiling, tracking, discrimination, exclusion, government surveillance and loss of control" (Tene & Polonetsky, 2013, pg. 2).

Security is designed to protect data from others who do not have access permission. As more data is produced, there are more opportunities for data breaches. The various software servers and locations are vulnerable to hacking because many processors are located outside the jurisdiction of the company that requested the information (Thorpe & Gray, 2015). The overwhelming amount of big data makes it hard to protect and the protections are not always sufficient. The lack of protection for data is a violation of ethics because it affects more than just security. The public wants to feel confident their data is protected and secure.

Data ownership is a feeling of control but most people do not own their data, although they think they do. Big data is harvested from a variety of locations and organizations that receive the data and who assume it has been responsibly acquired. Just because the form has an opt in or opt out checkbox, does not mean it will be respected. The individual does not own the data. It is just a mere pit stop before hitting the super highway of data transmission known as big data.

Organizations use data to make decisions about populations regarding what they should receive or not receive. Many times, algorithms are used to determine needs but at the same time these decisions can affect a population because personalization is removed. Predictive analysis, making decisions based on a set of parameters, is common but are these decisions appropriate? "The wealthy and well-educated will get the fast track; the poor and underprivileged will have the deck stacked against them even more so than before" (Tene & Polonetsky, 2013, p. 254). Decisions based solely on numbers can be problematic and lead to discriminatory practices by ignoring the personal aspects of the data.

Ethics and big data are intertwined and in combination they have a social impact. New ethics rules are starting to emerge that will help organizations and individuals with responsible use of big data, however there are social consequences that are evidenced in social impact theory.

3. Big data and social impact

Big Data can be used to help address various social problems related to societal issues such as hunger, disease, poverty, and social inequity. Social problems are often what are called "wicked" problems (Ritchey 2011). Not only are they messier, they are also more dynamic and complex than technical or business problems as the number of stakeholders involved is high. While nonprofits and government agencies may take part in resolving social problems, collaboration and data sharing is often the exception rather than the norm. During social crises, the data collected may not be effectively integrated to serve all effected constituents immediately. The majority of big data used in the context of social crisis and disasters is called big crisis data (Castillo 2016). The data driven decision making resulting from the analysis of big data can result in far reaching societal impacts.

Social impact is a nebulous concept that over the years has been conceptualized in multiple ways (Epstein et al 2014). A popular definition of social impact presented by Clark et al. (2004) is a portion of the total outcome that happened as a result of a decision or activity of an organization, above and beyond what would have happened anyway. Positive social impacts resulting from big data insights can range from 'better health, greater financial inclusion, and a population that is more engaged with and better supported by its government.' (LaValle et al 2011).

While the vast quantity of data gathered during a crisis can be very useful if subjected to instant analysis and recommendations to enable effective responses, it can also be paralyzing as most humanitarian organizations lack the infrastructure and the capability to conduct big data analysis. In addition to the large quantity of data collected, big data analyzed to create a positive social impact suffers from authenticity issues. Misinformation and disinformation generated on social disasters can influence analysis and recommendations from big data. Digital humanitarianism suffers from the collection of disingenuous data but also reveals the power of data by giving organizations the ability to create solutions for social problems that were previously not viable.

In addition, large historic data sets could lead to false confidence in predicted outcomes that may result in significant errors (Ganore 2012). Individual agendas of corporations or governments could lead to manipulated findings that in turn suggest the use of skewed recommendations for the selfish benefits of a few. Social impact theory provides a lens to consider how big data insights could lead to positive or negative social impacts and the ethics behind it.

4. Social impact theory

Social impact theory was created by Bibb Latané in 1981 at The Ohio State University. This theory was defined as "any of the great variety of changes in psychological states and subjective feelings, motives and emotions, cognitions and beliefs, values and behaviors, that occur in an individual, human or animal, because of the real, implied, or imagined presence or actions of other individuals" (Latané, 1981, p. 343). The theory uses mathematic equations to determine the various levels of social impact based on the situation.

The social influence that is predicted will have a proportional multiplicative influence and the number of people involved in the social influence will have an inverse proportional influence on the number of people influenced (Latané,1981). People's actions affect others in social situations and the impact of their actions can be measured visually along with measures that include three laws: social forces, psychosocial law, and multiplication/division of impact (Table 1).

Table 1. Social Impact Theory

Social Force	• Strength of the message • Immediacy • Number of people/target influence
Psychosocial Law	• First source influence most important
Multiplication/Division of Impact	• Smaller impact less dispersion • Larger impact more dispersion (Latané, 1981)

Social force is a pressure that is put on people to change their behavior. The concept of social force is divided into three sections: strength of the message, immediacy and numbers of people exerting force on the group (social force = *f*(S*I*N)) (Latané, 1981). The strength of the message is based on the level of power and influence perceived by the target. Immediacy concerns how recent the event occurred and if there were other factors involved. The number of people include the total number of influencers on the target. Psychosocial law explains that the first source of influence is the most potent. Multiplication/divisions of impact emphasizes that the force directed at one person will have a large impact and if there are two or more people the impact splits proportionally (two people = impact split in half). This theory along with big data and ethics is applied to a conceptual framework that describes social impact based on decisions that use big data.

5. Big data, ethics, and social impact

Decisions using big data affect ethics and social situations. It is important to consider how and who is affected by decisions. Does the decision affect the public, is it detrimental, is it beneficial and does it create group dynamics? We propose that the use of big data has a direct effect on social impacts and ethics. The big data, social impact, and ethics conceptual framework is explained and represented in Figure 1. An organization gathers big data from sources. The big data is then delivered to a group or individual which processes the data by absorbing the data. That big data has an influence on the group or individual which can be positive or negative. Once the influence is determined, social impact is assessed. The level of social force, psychosocial law and multiplication/division of impact is assessed to determine the social impact. The level of social impact is directly compared to ethics to determine if the social impact was ethical and its end effect on society.

Depending on how the big data is used, it could create fear or euphoria. The fear or euphoria can be used to initiate obedience and a need for immediate action. The action can either grow or reduce the numbers of people involved and be responsible for behavioral changes in the affected groups. The impact of the behavioral changes applied directly affects social impact and ethics of the situation. The big data, social impact and ethics framework conceptual model will be applied showing how these concepts are related.

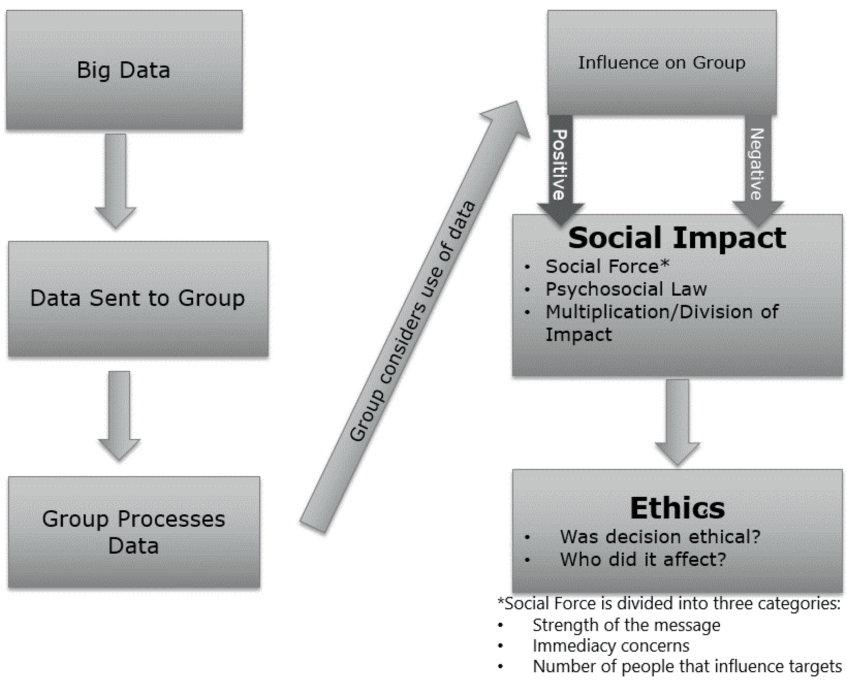

Figure 1. Big data, social impact, and ethics conceptual framework

6. Application of big data, social impact, and ethics

Big data is powerful and unpredictable. Important trends and new connections can be discovered when evaluating big data. In combination with predictive analysis, big data is an important tool for discovering new trends, new products and preventing disease. However, one must be careful when using big data because of ethical implications and its social impact. It is important to use big data responsibly. Three applications of big data, ethics and social impact are summarized next.

Insurance companies use tornado data to predict the likelihood of recurring storms in the same location. The data generated from the National Oceanic and Atmosphere Administration (NOAA) tracks various weather incidents throughout the United States. Moore, Oklahoma is a hotspot for tornadic activity. Moore has been impacted by ten tornadoes from 1998 to 2015. Since the city is in tornado alley, it is vulnerable to repeat incidents. Insurance companies determined that since Moore was a likely target, it was important to explain the need for homeowner's insurance coverage for protection from a potential tornado. The direct impact of the big data helped insurance companies deliver a message of safety, importance, and vigilance (Palmer, 2013). The insurance companies decreased cases of fraud, enhanced security and encouraged the community to help rebuild, make donations, and provide emotional support to the victims of the latest tornado. Their consumers were prepared for the next tornado. Social impact theory was applied through social forces (the significant influence of the insurance company), immediacy (the past tornadoes occurred in Moore) and the multiplication/division of influence (many people were informed of the insurance companies warnings). Their direct influence on groups of people made the community come together and help each other even more than before (Palmer, 2013). Ethically social impact was positive because the perspective of insurance companies in this case was changed from negative to positive.

The Centers for Disease Control (CDC) use big data to predict the spread of the flu. The review of data determines where the next outbreak might occur. These predictions can help doctors prepare for the flu outbreak and in addition encourage individuals to get flu shots for preventative measures. The use of big data in this case saves lives. Social impact theory was applied through social forces (the CDC had a significant influence on the community), immediacy (the importance of the flu epidemic) and the multiplication/division of influence (impact of many people who could be affected by the flu). The CDC has a strong influence over the public, therefore any messages delivered by the organization are impactful and important. Decreasing the spread of disease is ethical and necessary (Silva, 2006). It is vitally important to maintain the public trust, especially when lives are at stake.

Big data is used to recommend products to consumers through predictive analysis. However, companies should be careful when recommending a product due to the sensitivity and ethical problems. An e-cigarette company can have strong influence on the consumer (Zhu, et al., 2014). The e-cigarette company can make recommendations which are both positive and negative, potentially creating an ethical dilemma. For example, big data has been used to determine if smokers might be interested in e-cigarettes. Unfortunately, smoking has caused many deaths (Center for Disease Control, 2016). However, the e-cigarette companies see e-cigarettes as a safer alternative for their customers. Social impact theory was applied through social forces (the e-cigarette companies have a strong influence on the existing smoking customer base), immediacy (a brand-new product was introduced as an alternative to tobacco cigarettes) and multiplication/division of influence (the information was shared with a large customer base who influenced each other to purchase a new product). Due to the strong influence of the company, people made the change and in some cases the consumers convinced others to change based on the message from the company. In this case, the promotion of a negative behavior in a positive light is questionable and depending on the audience, violates ethical principles.

7. Conclusion

Big data usage has increased and we should watch for ethics violations and negative social impacts. This article examined how big data, ethics and social impact are interrelated using a conceptual model. It is important that organizations be respective when using big data to make decisions because it directly impacts individuals and society. The framework was supported through three different examples that indicated big data can be used to manipulate ethics and social impact. Organizations must make the right decisions, honor established ethical principles and make positive social impacts. A simple decision is enough to change the outcome for thousands, even millions.

8. Future Work

Further examination of the Big Data, Ethics and Social Impact Framework is needed to determine the exact impact. The next step is to evaluate the validity of the big data, ethics, and social impact framework through semi-structured interviews with data analytics managers and consumers, along with empirical survey research will statistically validate the conceptual model.

9. References

Bearden, R. (2014). Hadoop Summit. *CEO Keynote Conference Speech.* San Jose, CA: Hadoop Summit.

Center for Disease Control. (2016). *Smoking and tobacco use.* Centers for Disease Control.

Davis, J. (2016, January 4). *Big data predictions for 2016*. Retrieved May 5, 2016, from Information Week: http://www.informationweek.com/big-data/big-data-analytics/big-data-predictions-for-2016/d/d-id/1323671

Disruptive technology rconsidered: A critique and research agenda. (2004). *Journal of Product Innovation, 21*, 246-258.

Ganore, P. (2012, October 1). *Need to know what Big Data is?* Retrieved April 2, 2017, from ESDS Enabling Futurability: https://www.esds.co.in/blog/need-to-know-what-big-data-is/#sthash.PQpIh0YO.dpbs

Johnson, D. (1985). *Computer ethics.* Englewood Cliffs, NJ: Prentice-Hall.

(2014). *Joint Statistical Meetings.*

Latané, B. (1981). The psychology of social impact. *American Psychologist, 36*(4), 343-356.

LaValle, S., Lesser, E., Shockley, R., Hopkins, M. S., & Kruschwitz, N. (2011). Big Data analytics and the pathfrom insights to value. *MIT Sloan Management Review, 52*(2), 1-15.

Needham, J. (2013). *Disruptive possibilities: How Big Data changes everything.* Boston, MA: O'Reilly Media.

Olumoye, M. Y. (2013). Ethics and social impact of information systems in ethics and social impact of information systems. *International Journal of Science and Research (IJSR), 2*(11), 154-158.

Palmer, J. (2013, May 22). *Oklahoma tornadoes: Insurance companies set up in Moore, in it for the long haul*. Retrieved March 31, 2017, from The Oklahoman: http://newsok.com/article/3828511

Richards, N., & King, J. (2014, May 19). Big Data ethics. *Wake Forest Law Review, 49*, 393-432.

Silva, M. L. (2006, November 6). What would you do? Ethics and infection control. *Online Journal of Issues in Nursing, 12*(1), 1-3.

Tene, O., & Polonetsky, J. (2013, April). Big Data for all: Privacy and user control in the age of analytics. Northwesten Journal of Technology and Intellectual Propery, 11(5).

Thorpe, J. H., & Gray, E. A. (2015, March-April). Big Data and public health: Navigating privacy laws to maximize potential. Law and the Public Health, 130, 171-175.

Wessell, M. (2016, January 27). How Big Data is changing disruptive innovation. Retrieved May 6, 2016, from Harvard Business Review: https://hbr.org/2016/01/how-big-data-is-changing-disruptive-innovation

Zakir, J., Seymour, T., & Berg, K. (2015). Big Data analytics. Issues in Information Systems, 16(II), 81-90.

Zhu, S.-H., Sun, J. Y., Bonnevie, E., Cummins, S. E., Gamst, A., Yin, L., & Lee, M. (2014). Four hundred and sixty brands of e-cigarettes and counting: Implications for product regulation. Tobacco Control, 23(3), 3-9.

Zwitter, A. (2014). Big data ethics. Big Data and Society(July - December), 1-6.

Teaching Ethics in an Engineering Program

Andrzej J. Gapinski, Ph.D.[1]

[1]*The Pennsylvania State University-Fayette*

ajg2@psu.edu

Abstract

The article discusses the issues an instructor should consider in teaching ethics in an engineering program. The historical backgrounds of ethics and ethics in the context of professional responsibilities are discussed. Teaching of ethics in engineering and other areas such as a business program is analyzed and compared. The contents, teaching frameworks, delivery methods, and assessment of effectiveness of teaching ethics are addressed. The role of ethics in the decision-making process and its models as encountered in engineering are reviewed. Guidelines for solving ethical issues and the assessment methods are provided, and illustrated in an example ethics course for engineering and science students.

1. Introduction – Historical Background

Engineering and technology played a significant role in the development of civilization throughout the millennia. The ancient collegia, followed later by the crafts and guild systems, were formed to maintain control over the profession, product standards, and professional ethics (Newberry, 2005). Occasional failures in engineering endeavors of the past millennia were caused mainly by erroneous designs that exceeded the permissible technical limits (Rogers, 2014). Rogers (2014) writes that the founders of giant construction works often exhibited big ambitions, which "led to taking big chances, which often resulted in faulty construction and, occasionally, deadly collapses."

Through the centuries, engineering was exercised by trial and error and as such always had an intuitive underpinning. In order to maintain craftsmanship and proficiency standards, the adepts of the engineering professions were usually subject to long training periods before they were allowed to work independently. Master builders in antiquity built canals, public water supplies, harbors, roads, bridges, and other massive structures using structured learning processes where crafts and guilds, and later the apprenticeship programs of medieval times, educated and trained the next generation of engineering professionals (Baker, 2004). The quality of work and individual responsibility were essential attributes of the engineering profession. Cicero's Creed (Mitcham, 2005) "Salus populi suprema est lex" ("the safety of the public shall be the highest law") expressed engineering ethics' key principle and was explicitly identified and incorporated in the ethical codes of professional engineering societies beginning with the Corps du Genie in 1672, France, and followed by other professional societies across the European and American continents in the nineteenth century (Baker, 2004). On other continents such as Asia and Australia, Japan formed its first professional society in 1914, Australia in 1919, and India in 1920 (Baker, 2004).

One may consider Cicero's Creed as the equivalent to medicine's "primum non nocere" ("first, do no harm").

The Western school of thought developed three distinct moral theories. The first one, developed in antiquity by the Greek philosopher Aristotle, is virtue ethics, where "morally right actions are virtuous actions" (Newhard, 2004). Virtue ethics centers on a concept of virtue, which is understood as a "morally valuable character trait" (Hursthouse, 2013). In this approach, a virtuous action performed by a person is an ethically and morally sound endeavor and its intentions and consequences play a less important role. It is important to realize that the ancient Greeks' approach to a virtuous life placed a significant role on learning and an educational process to develop a virtuous person. The role of learning has resurfaced in current ethics education.

The remaining moral theories are from the modern era. The second one, developed by the German philosopher Emmanuel Kant, is the good intentions approach, where "morally right action is done with intentions which every rational person would approve," and it gained significance beginning in the nineteenth century (Newhard, 2004). The third theory, Utilitarianism, developed by John S. Mill, is based on "utility" – a composite notion consisting of "happiness, health, and well-being" (Newhard, 2004). In this light, a moral or ethical action is one which maximizes overall utility.

These three theories are not mutually exclusive and are discussed throughout the ethics coursework. Professional codes of conduct have mostly adopted the concept of utility in assessing the ethics of behavior and actions. Some elements of Aristotle's virtue ethics and Kant's duty ethics can be found in these codes as well (Newhard, 2004).

Throughout history, engineering designers and builders were left predominantly to their own sense of mastery of the subject matter to ensure quality, but it was not so in other areas. Historians, for example, point to the medical field where Roger of Normandy in 1140 required doctors to prove competency (Michels, 2013).

Can virtues be taught? Philosophers have debated this question for centuries. Even if virtues may not be taught, Greek philosophers realized that persons can learn to reason and consequently there is a role to be played by learning in shaping one's character and inducing virtuous behavior. Baker (2004) writes that there is a "strong relationship between the teaching of ethics and the development of moral behavior." Thus, according to Baker (2004), the objective of ethics education is to develop "moral imagination" and "conscious rationality when appraising and judging ethical dilemmas" through the educational process. Consequently, through learning students will develop ethical sensitivity and skills helpful in recognizing and finding solutions to ethical problems.

Similar to the ancient Greek philosophers, modern educators and researchers tend to assign an important role to education in bringing about moral, virtuous behavior in general as well as in professional settings.

2. The Ethics Landscape: Professions, Licensure, and Social Responsibility

Since we are concerned with professional ethics it is worthwhile to mention that the term "professional ethics" was coined by Thomas Percival (1740-1804), a philosophically trained English physician (Baker and Linda, 2000). Various professional organizations were concerned with professional skills and competencies including moral traits. Many studies on professional skills, ethics, and expectations of moral conduct were conducted in the medical field, including nursing (Savulescu, Crisp, Fulford, and Hope (1999), (Scanlon and Glover, 1995), (Wright, 1987), and business (Singer and Singer, 1997), (Mele, 2013). Moral competence in nursing, for example, requires "familiarity with and commitment to nursing personal, professional and social values" (Jormsri, Kunaviktikul, Ketefian, and Chaowalit, 2005). Moral competence is seen "as a combination of three dimensions: (1) moral perception as an affective dimension requires the individual's awareness of values and the expression of those values in clearly communicated messages about the same; (2) moral judgment as a cognitive dimension entailing the individual's choice of one value over another based on logical reasoning and critical thinking; and (3) moral behavior as a behavioral dimension involving the individual's application of values to action by being willing to receive public affirmation for the choice, and consistent repetition of the same" (Scanlon and Glover, 1995) . Moral competence in terms of specific characteristics or traits is understood in the nursing practice as: “loving kindness, compassion, sympathetic joy, equanimity, responsibility, discipline, honesty, and respect for human values, dignity and rights” (Jormsri, Kunaviktikul, Ketefian, and Chaowalit, 2005).

In many professions, ethical conduct is so critical that it found its way well beyond professional codes and into licensure policies. Currently, many professions, including engineering, are subject to professional licensing, which is handled in the USA at the state level. Often, the expectations and even requirements for ethical and moral conduct go beyond the professional settings and reach personal life and conduct (Savulescu, Crisp, Fulford and Hope, 1999). Gapinski (2016) investigated professional licensure policies in light of ethics and public welfare.

Companies are not immune to external societal pressures. Consequently, one has to consider external factors, which affect companies’ inner cultures and their promoted ethical climate. These factors drove the development of Corporate Social Responsibility (CSR) as a response to maintain marketability, sustainability, and economic viability. One can claim that this is not exactly new since corporations had to address the concerns of stakeholders in the past, but current society’s expectations brought CSR to the forefront. CSR covers “three kinds of responsibility: economic, environmental, and social, covering issues of the workplace, human rights, the community and the marketplace” (Schreiber, 2014). CSR even found its way into international guidelines (not standards) such as ISO 26000, which provide guidelines for businesses and organizations for operations in a socially responsible way (Chandra, 2014).

The above described ethical concerns related to the individual, professional, and social responsibilities were described as “microethics” and “macroethics” by Herkert (2005).

3. Ethics in Engineering Education: Historic View, Goals, and Delivery Frameworks

In the last few decades, ethics was a subject of extensive research mostly in the context of business ethics and the decision-making process. Even though professional engineering societies adopted ethical codes of conduct in the nineteenth century in the USA, academic engineering programs began to address the issue only in the 1970s (Michels, 2013). Here, it is assumed that engineering ethics, after Martin and Schinzinger (2005), is “the study of the moral values, issues and decisions involved in engineering practice.” Furthermore, most educational programs assume that the engineer is a moral agent, after Pinkus, Shuman, Hummon and Wolfe (1997), and as such is “competent, responsible, and respectful of the public.” Recent interpretation of professional ethics, however, gives rise to additional traits, which are addressed in a separate section.

Weil (1984) provided excellent background information on engineering ethics in the last few decades of the twentieth century. Unger (1994) gave a detailed analysis of the role of an ethical engineer vis-a-vis well publicized and lesser known technological achievements and disasters of the last few decades. How universal is ethics education in engineering programs? Herkert (2000) reported that as of circa 2000 “nearly 70% of the institutions did not have ethics related course requirement for all engineering students.” Based on anecdotal evidence and available literature, the situation has improved, but to what extent is unknown to the author at the time of writing. Naturally, ABET, with its Engineering Criteria 2000 where an ethics requirement has been added, prompted many engineering programs seeking accreditation to add ethics instruction to their engineering curriculum (Herkert, 1999).

According to Herkert (2000), current pedagogical trends encompass dedicated stand-alone ethics courses, case methods, across-the-curriculum initiatives, the use of internet resources, and a preference of an integrated approach that combines ethics with science, technology and society (STS).

Cantwell, Lam, Reyer, and Rafferty (2014) provided more recent information and in depth analysis of ethics education in engineering. Interestingly, the authors (Cantwell et al., 2014) of the publication provide an Engineering Ethics Education Handbook that contains a practical guide and useful suggestions for instructors on how to incorporate ethics “into an engineering curriculum in an effective and engaging manner."

According to Davis (1999), there is a general consensus on sought-after outcomes of engineering ethics education: "a. increased ethical sensitivity, b. increased knowledge of relevant standards of conduct, c. improved ethical judgement, d. improved ethical will-power."

A recently published report by the US National Academy of Sciences (2016) lists a variety of exceptional programs for "improving engineers' understanding of ethical and social issues" and furthermore provides "a resource for those who seek to improve the ethical development of engineers at their own institutions." The report describes the activities and best practices employed by universities and engineering programs that "connect ethics to technical engineering content and assessment." The reported activities encompass a variety of initiatives at the undergraduate and graduate level, with a varied timespan from a short time activity inserted in engineering courses to long multi-year engagements and extracurricular experiences. The report (US National Academy of Sciences, 2016) also lists some challenges as encountered by pedagogical innovators that successful implementations must overcome: "a lack of interest among students, resistance from faculty, lack of consensus on topical and methodological approaches." To address these obstacles the report (US National Academy of Sciences, 2016) suggests some solutions such as the use of real-life and relatable examples in interactive activities to increase students' interest and providing adequate training and support for instructors.

Herkert (2006) gave an overview of the progression of engineering ethics education from elements of ethics introduced through curriculum, a dedicated required course, and an across-the-curriculum approach. Herkert (2006) pointed out that the last option "may lack depth and continuity" and consequently suggested that the ideal solution may be offered by "a combination of methods – a required course in engineering ethics and an engineering curriculum that recognizes the importance of ethics throughout," and, furthermore, suggested to imbed ethics education into the STS educational framework.

Few researchers investigated the role of culture in ethical reasoning. Qin Zhu, Feister, Zoltowski, Buzzanell and Oakes (2014) investigated the role of culture in individual ethical reasoning on multidisciplinary engineering projects in the academic environment, where various factors affecting students' reasoning including primary language, ethnicity, and gender were analyzed. Results pointed out the differences in understanding and application of ethics by the studied subjects as related to an individualistic or a communitarian approach to ethics and either a dogmatic, principle-based ethics or a more relativistic understanding of ethics.

4. Ethics and the Decision Making Process

The role of ethics in decision-making in engineering endeavors was the subject of research by Unger (1994), Davis (1991), Fan and Fox (2009), and Cook (2008) among others. These investigations were mainly *post factum* and focused on the analysis of engineering failures that include the Chernobyl and Challenger disasters and obligations of engineers from an ethical stand point.

Recently, Rudnicka, Besterfield-Sacre, and Shuman (2013) studied the *process* of ethical considerations in decision-making activities for engineering problems while the decisions were being made. Namely, Rudnicka et al. (2013) reported on an empirical study of ethical decision-making based on behavioral observations of individual engineering students and engineering teams *while* they were analyzing ethical engineering problems and making ethical decisions. A comparative study was performed for both type of subjects with and without a formal ethics instruction (Rudnicka et al., 2013).

Essentially, researchers developed two categories of ethical judgement models for ethical decision-making: descriptive and prescriptive or normative. As per Rudnicka et al. (2013), descriptive models "are based on the cognitive processes that individuals use in making ethical decisions" and the normative models are based on "absolute truth about appropriate decision-making." Rudnicka et al. (2013)

provided a review of existing decision-making models as applied to ethics and, furthermore, proposed a synthesized model to assess ethical engineering reasoning and the decision-making process. The regression analysis performed by Rudnicka et al. (2013) on gathered data indicate that in the case of the ethical problems of lower level moral intensity "teams performed better than individuals and teams whose members had been through an engineering ethics course were better able to resolve the ethical dilemma than teams without benefit of that instruction." For higher moral intensity cases, the results (Rudnicka et al., 2013) show that "an introductory ethics course may help, but isn't sufficient." As reported in Rudnicka et al. (2013), the performed experiment validates the importance of "working in teams and having an engineering ethics course" for successful ethical engineering decision-making.

5. Multifaceted Aspects of Engineering Ethics

In the wake of the financial scandals of late 1990s, Congress passed the Sarbanes-Oxley Act of 2002 to improve accountability of both the private sector and of government (Pautz and Washington, 2009). Given the technical disasters of the last decades and exposed unethical, if not maleficent, activities in various sectors of the economy, an increasing number of universities recognized the importance of incorporating ethics in the curriculum. The technological disasters of recent decades including India's Bhopal, Chernobyl, and the Challenger Disaster brought into the forefront the decision-making process in business and ethics' place in it. Broome (1986) points out that Cicero's Creed of keeping the safety of the public as a primary consideration of any engineering endeavor have been bluntly violated in these cases. Many even feel that the unspoken trust between society and the engineering profession has been affected if not broken. Broome (1986) attempts to provide a clarification of the ethics of engineering in the context of the interdependencies among various stakeholders such as society, engineers' employers, and engineers themselves. He points out that engineering societies such as the Institute of Electrical and Electronics Engineers (IEEE) in its code, in addition to reflecting Cicero's Creed, provides three opposing imperatives without an attempt to resolve the conflicts (Broome, 1986). These are: a contractarian approach where "deference is given to the contract imperative, rather than to the public," the "personal-judgement" imperative where it is assumed that the "interests of business, government, and public are not in conflict," and that "engineering is neither an applied science nor any other kind of science." These possibly contradicting imperatives leave room for interpretation by the possibility of violating Cicero's original Creed and putting the public at risk.

The solution, to at least minimizing the ill effects, lies in what Broome (2004) calls "a good engineering" which combines professional competence with good moral character of actors. But, in many instances of ethical violations, the causes are found outside of the engineering domain, made by decision makers such as managers or politicians. Engineers provide solutions to technical problems with clearly defined risks for decision makers who should take full responsibility for further actions. The case of the Challenger Disaster (Smith and Harper, 2004), (McDonald and Hansen, 2012), already well documented in literature, is an example where engineering and management interests collided with respect to responsibilities and ethics.

6. Ethics in Other Disciplines: Business

In most academic degree programs in the USA prior to 2000, ethics was a non-compulsory, humanities-related elective usually covered by the philosophy faculty. Herkert (2000) wrote in 2000 that "nearly 80% of engineering graduates attend schools that do not have an ethics-related course requirement for all students" and that "while 17% of institutions and 8% of graduates do have one or more required courses with ethics-related content, these courses are usually not courses in engineering per se, but rather courses in such areas as philosophy or religion." The situation has improved since then as many engineering programs across the nation introduced ethics instruction as part of the requirements and furthermore many institutions engaged innovative approaches in teaching ethics (National Academy of Engineering, 2016).

Since business programs deal with the human element in the decision-making process, it is only natural that business was and still is in the forefront of ethics education. De George (2015) stated that business ethics as a separate academic field emerged in the 1970s. Consequently, business academic programs adopted an ethics course early on as part of the curriculum requirements relative to other disciplines.

One can mention the business program at the University of Pittsburgh at Greensburg (UPG) as an example. In this business program, students are required to take the Business Ethics course (PHIL 1380 Business Ethics) offered by the philosophy department. To deepen students and future managers' understanding of ethical issues, the business course instructor introduced an ethics component in the Operation Management (OM) (MGMT 1820) course (Rudnicka, 2005). The goal of the ethics component in the OM course was "to refine the skills used in ethical problem solving" (Rudnicka, 2005). The course examines moral and ethical issues and dilemmas caused by the nature of business [40]. The course helps students to "improve their managerial decision-making ability" and to address the current business environment where globalization plays an increasing role (Rudnicka, 2005). Aspects of globalization expose students to different standards of moral behavior in various cultures. Initially, students in the OM course are introduced to codes and guidelines of ethics of various professional societies, such as the National Society of Professional Engineers (NSPE) and the Guidelines for Facilitating Solutions to Ethical Dilemmas in Professional Practice followed by ethics case analyses (Rudnicka, 2005). The ethics component of the OM course is being taught using two types of assignments: short critical thinking exercises to identify and analyze ethical dilemmas done individually and long business ethics case studies done in groups. The Pittsburgh-Mines (P-M) Engineering Ethics Assessment Rubric is used by a course business instructor to assess the level of ethical problem recognition, analysis, and solutions provided by the students (Rudnicka, 2005).

7. Ethics Course

At Penn State University – Fayette, engineering students were exposed to ethical professional issues in various classes through dedicated segments devoted to specific ethical problems or via extracurricular activities through seminars, guest presentations, etc. The activities were designed to provide students with the vital skills to satisfy the National Society of Professional Engineers (NSPE) (www.nspe.org, 2016) and the Accreditation Board for Engineering and Technology (ABET) (www.abet.org, 2016) recommendations for the teaching of ethics in engineering. However, during one of the ABET accreditation visits, ABET assessed the learning of ethics without a dedicated course as insufficient. To remedy the weakness, the Electrical Engineering Technology program incorporated the Ethics and the Design of Technology course (STS 233) (http://bulletins.psu.edu/udergrad/courses/S/S%20T%20S/233, 2016) as a required humanities course. STS 233 covers ethics in general and professional ethics.

The major topic of the course is ethics, but it covers other subjects as well (http://bulletins.psu.edu/udergrad/courses/S/S%20T%20S/233, 2016). STS 233 is also offered for science and engineering PSU majors as an elective humanities course. The course used *Engineering Ethics: Concepts, Viewpoints, Cases and Codes* by J.H. Smith, P.M. Harper, and R. A. Burgess (2008) and covered the following topics:

- Historical review of the concept of morality and ethics including Greek philosophers and the Greek school of thought, Kant's duty ethics, and Mill's utilitarianism;
- Moral theories;
- Group decision-making;

- Good engineering;
- Professional responsibility;
- Multiculturalism and business customs in different cultures in light of morality and ethics; and
- Discussion of ethical dilemmas.

Students were introduced to ethical problems using current well publicized cases related to copyright infringement, whistleblowing, public safety, plagiarism, and cybercrime, as well as cases based on materials available from NSPE-BER (www.nspe.org, 2016) and NIEE (www.niee.org, 2016). The NSPE (www.nspe.org, 2016) and NIEE (www.niee.org, 2016) websites provide ample sources of useful information and serve as an excellent course resource.

Students worked on team-based assignments analyzing assigned ethical dilemmas and writing short reports. Final presentations included business and engineering ethical dilemmas, social customs, and business etiquette in different parts of the world.

The ethics class was offered in two formats: a traditional campus-based and a blended or hybrid method of delivery to accommodate non-traditional working students. In the hybrid format, half of the weekly sessions were delivered on campus and the other half online synchronously through Adobe's video-conferencing software. The class met twice a week for either a lecture, a discussion session, or team based assignments.

7.1 How to Help Students? Guidelines for Facilitating a Solution to Ethical Dilemmas

Instructors at PSU-Fayette and UPG use guidelines developed by Penn State University to assist students with facilitating solutions to ethical problems (http://www.engr.psu.edu/ethics/process1.asp, 2016). The guidelines (Rudnicka, 2005), (http://www.engr.psu.edu/ethics/process1.asp, 2016) consist of the following nine-step process:

Step 1: Determine the facts in the situation – obtain all of the unbiased facts possible.
Step 2: Define the Stakeholders – those with a vested interest in the outcome.
Step 3: Assess the motivations of the Stakeholders – using effective communication techniques and a personality assessment.
Step 4: Formulate alternative solutions – based on the most complete information available, using basic ethical core values as guide.
Step 5: Evaluate proposed alternatives – short-list ethical solutions only; may be a potential choice between/among two or more totally ethical solutions.
Step 6: Seek additional assistance, as appropriate – engineering codes of ethics, previous cases, peers, and reliance on personal experience, prayer.
Step 7: Select the best course of action – that which satisfies the highest core ethical values.
Step 8: Implement the selected solution – take action as warranted.
Step 9: Monitor and assess the outcome – note how to improve the next time.

Naturally, the guidelines serve an important educational function by providing a practical protocol to identify an ethical dilemma, analyze it, and devise a solution.

7.2 Learning Assessment: The Pittsburgh-Mines (P-M) Engineering Ethics Assessment Rubric

The Pittsburgh-Mines (P-M) Engineering Ethics Assessment Rubric (Rudnicka, 2005), (Shuman, Sindelar, Besterfield-Sacre, Wolfe, Pinkus, Mitcham, Miller and Olds, 2003) was used for student course assessment by instructors at PSU-Fayette and UPG. The rubric assesses five essential attributes of ethics understanding with five levels of achievement:

1. Recognition/Identification: ability to comprehend a problem,
2. Information: ability to gather pertinent information,

3. Analysis: ability to analyze the problem and to provide alternatives,
4. Perspective: ability to provide perspective of the problem from various points of view: employer, profession, and society, and
5. Resolution: ability to provide solutions.

The rubric provides a concise guide in a tabular format for assessment of vital knowledge and skills developed jointly by researchers from engineering, philosophy, and bioethics from the University of Pittsburgh and Colorado School of Mines (Shuman, Sindelar, Besterfield-Sacre, Wolfe, Pinkus, Mitcham, Miller and Olds, 2003). The rubric was used as one of the methods to evaluate a student's level of understanding and ability to devise solutions to the ethical problems discussed in class.

7.3 Learning Assessment Using DIT Test

The Defining Issues Test (DIT-1) Short Form (http://ethicaldevelopment.ua.edu/dit-and-dit-2/, 2015) was used in the ethics class for the 2014/15/16 academic years with fifty-four students for the purpose of internal review to assess the effectiveness of the ethics learning process. The DIT-1 tests were conducted twice for each group of students, the first time prior to instruction on ethics (as a pre-test) at the beginning of the course and the second time after the ethics instruction (as a post-test) at the end of the course.

The DIT test allows for assessment of moral development by "activation of moral schemas in the subject and assessing these schemas in terms of importance judgements"(http://ethicaldevelopment.us.edu/dit-and-dit-2/, 2015). The test checks moral reasoning and identifies the level of moral development based on the work of Kohlberg (Kohlberg and Lickona, 1976). Kohlberg identified six stages of moral development which can be grouped into three levels: pre-conventional morality (primary concern is of personal, individual nature), conventional morality (more concerned with society's wellbeing), and post-conventional morality (laws are scrutinized rather than just accepted, for society's good as a whole). The DIT test is a Likert type of test, which gives quantitative evaluation ratings. Validity of the implicit DIT test has been established in a variety of studies (http://ethicaldevelopment.ua.edu/dit-and-dit-2/, 2015).

The DIT-1 test was administered in the STS 233 course in spring of 2014/15/16 at PSU-Fayette campus to assess the effectiveness of ethics coverage. Mostly engineering and engineering technology freshman and sophomore students were enrolled in the course.

A DIT-1 Short Form (Heinz, Prisoner, and Newspaper Stories) was chosen due to the limited time available in the course. The collected results were checked for reliability through validity and consistency inspection. Namely, a score of M factor greater than four invalidated the questionnaire test. Also, a number of inconsistencies greater than eight rendered the test invalid. All together fifty-four students took the tests: two tests were not completed, and two had a score of M factor above four in either the pre-test or the post-test and were rejected and invalidated.

Descriptive data analysis was performed on collected DIT-1 Pre-Test and Post-Test data and results are given in Table 1:

Table 1. The Descriptive Statistics for P-Score of DIT pre-and post-tests.

Statistics	Pre-test	Post-test
Mean	15.11	25.33
Standard Error	2.76	4.20
Median	10.00	23.33
Mode	10.00	23.33
Standard Deviation	10.68	16.27
Range	43.34	70
Minimum	3.33	6.67
Maximum	46.67	76.67
Count	50	50
p-value	0.02661	

Hypothesis Testing:
To show the effectiveness of learning, hypothesis testing using the t-test for paired two sample means was used.
Null Hypothesis H_0:
There is no difference between sample means: $\mu_0 - \mu_a = 0$
Alternative Hypothesis H_a:
The sample mean of post-test, μ_a, is larger than the mean of the pre-test, μ_0:
$\mu_a - \mu_0 > 0$.
Using the t-Test for a Two-Sample for DIT-1 P-score data, assuming unequal variances, the p-value was 0.02661.

The significance level (α) was assumed to be 0.05, or 5%. Considering a p-value of 0.02661, the Null Hypothesis, H_0, is rejected. Consequently, the Alternative Hypothesis, H_a, is accepted.

This result validated the role of the ethics course in learning ethics principles and increasing students' awareness of ethical issues.

7.4 The Impact of the Ethics Component in STS 233

The impact survey was conducted at the end of the course. A survey similar to the one performed in [40] was adopted in the ethics course. The students responded very favorably to the coverage of ethics in the course. Some of the written comments were as follows:

- "As an engineer, it showed me the various ethical guidelines I should follow. It also explained how I should approach ethical dilemmas. Now when I am in a situation or conflict I feel as if I can think of the ethical codes learned in this class and they will help me make an ethical decision,"
- "Utility and the ethics used by engineers was thoroughly explained,"
- "It mostly made me more aware of the different situations that would come up in the business setting,"
- "It gave me a better understanding on how to handle business confrontations ethically and apply certain ways of thinking,"
- "The course helped me understand management point of view versus an engineering view point,"

- "Each aspect was taught thoroughly and at a good pace,"
- "The group discussions on ethical issues were very useful,"
- "I would have liked to see more ethical experiments such as the Stanford Prison Experiment. That was a very interesting & clear example of ethics & how they can change over time,"
- "I think there was just the right amount of all. The case summaries helped very much,"
- "The right amount of time on most aspects, the historical portion could be reduced, however this is biased as I do not like history very much,"
- "This course increased my ability to deal with ethical issues by showing me different ethical scenarios and how each scenario can be solved in a different way."

Many students wrote that the course increased their level of awareness and understanding of ethical issues both in general and in a professional setting. A few students identified their own professional experiences with the discussed moral and ethical issues. Furthermore, many felt that the course helped them to prepare for future ethical issues and dilemmas to be encountered in the workplace.

8. Conclusions

The article discusses the issues of interest to an ethics instructor such as ethics' historical background, ethics' educational frameworks, methods of covering ethics, and ethical reasoning models. The guidelines to assist students with the learning process and assessment tools for evaluating ethics learning effectiveness are provided. An example of an ethics course, which satisfies ABET's requirement, for freshmen and sophomore engineering and science major students is described. A hypothesis is formulated and tested to check the effectiveness of ethics learning using a DIT-1 test.

9. References

Baker, B.W. (2004). Engineering Ethics: An Overview. In J. H. Smith and P. M. Harper (editors). *Engineering Ethics: Concepts, Viewpoints, Cases and Codes*. National Institute for Engineering Ethics. Murdough Center for Engineering Professionalism. Texas Tech University. Lubbock, Texas.

Baker, R., Linda E. (July 2000). The Efficacy of Professional Ethics." The Hastings Center Report. Vol.30. Issue 4.

Broome, T.H., Jr. (Dec. 28 1986). Ethics: The Slippery Ethics of Engineering. *Washington Post.* Outlook Section. D2-4.

Broome, T.H. (2004). Some Thoughts About Good Engineering. In J. H. Smith and P. M. Harper (editors). *Engineering Ethics: Concepts, Viewpoints, Cases and Codes.* National Institute for Engineering Ethics. Murdough Center for Engineering Professionalism. Texas Tech University. Lubbock, Texas. 78-81.

Cantwell, M., Lam, P., Reyer, K., Rafferty, R.M. (2014). Improving Ethics Education in Engineering. Worcester Polytechnic Institute. Biomedical Eng. Dept.

Chandra, M. (2014). US Corporations Should Embrace International Corporate Social Responsibility Standards. In *Corporate Social Responsibility.* Haerens, M. and Zott, L. M. (editors). GREENHAVEN PRESS. Gale CENGAGE Learning.

Cook, K.L.B. (2008). Making Ethical Engineering Management Decisions in a Competitive Environment.

IEEE. IEEEAC Paper #1641. 1-4244-1488-1/08.

Davis, M. (1999). Ethics and the University. London: Routledge.

Davis, M. (1991). Thinking Like an Engineer: the Place of a Code of Ethics in the Practice of a Profession.

Philosophy and Public Affairs, 20, 150-167.

De George, R.T. (Nov.17, 2015). A History of Business Ethics. Available in https://www.scu.edu/ethics/focus-areas/business-ethics/resources/a-history-of-business-ethics/. (Retrieved Oct. 30, 2016).

Fan, L.C.N. and Fox P.W. (2009). Exploring Factors for Ethical Decision Making: Views from Construction

Professionals. *J. Prof. Issues Eng. Educ. Pract*. April. 135(2):60-69.

Gapinski, A. (2016). Licensure, Ethics, Welfare of the Public, and Uberization of Services. *Kwartalnik Nauk o Przedsiebiorstwie*. (*Enterprise Science Quarterly*). ISSN 1896-656X. No. 1(38). 49-56. GICID: 01.3001.0009.4068. Available at http://przedsiebiorstwo.waw.pl/resources/html/article/details?id=137923.

Herkert, J.R. (1999). ABET's Engineering Criteria 2000 and Engineering Ethics: Where Do We Go From Here? Online Ethics Center for Engineering and Research. Available at http:// onlineethics.org/text/essays/herkert2.

Herkert, J.R. (2000). Engineering ethics education in the USA: content, pedagogy and curriculum. *Eur. J. Eng. Ed*. Vol.25, No.4, 303-313.

Herkert, J.R. (2005). Ways of Thinking about and Teaching Ethical Problem Solving: Microethics and Macroethics in Engineering. *Science and Engineering Ethics*. 11, 373-385.

Herkert, J.R. (2006). Confession of a Shoveler: STS Subcultures and Engineering Ethics. Bulletin of Science, Technology & Society. Vol 26, No. 5. 410-418. DOI: 10.1177/0270467606293331.

Hursthouse, Rosalind. (2013). Virtue Ethics. *The Stanford Encyclopedia of Philosophy* (Fall 2013 Edition), Edward N. Zalta (ed.), from http://plato.stanford.edu/archives/fall2013/entries/ethics-virtue (Retrieved Oct. 25, 2016).

http://bulletins.psu.edu/undergrad/courses/S/S%20T%20S/233 (Retrieved April 20, 2016).

http://ethicaldevelopment.ua.edu/dit-and-dit-2/ (Retrieved Nov. 22, 2015).

http://www.engr.psu.edu/ethics/process1.asp (Retrieved March 2, 2016).

Jormsri, P., Kunaviktikul, W., Ketefian, S., and Chaowalit, A. (2005). & Chaowalit, A. (2005). Moral competence in nursing practice. *Nursing Ethics*, *12*(6), 582-594. DOI: 10.1191/0969733005ne828oa.

Kohlberg, L., Lickona, T., (ed.) (1976). *Moral stages and moralization: The cognitive-developmental approach. Moral Development and Behavior: Theory, Research and Social Issues.* Holt, NY: Rinehart and Winston.

Martin, M.W. and Schinzinger, R. (2005). *Ethics in Engineering*. McGraw Hill. New York.

McDonald, A.J., Hansen, J.R. (2012). *Truth, Lies, and O-Rings: Inside the Space Shuttle Challenger Disaster*. University Press of Florida.

Mele, D.(Oct-Dec 2013). Are Moral Competencies Important? IESE Business School. *Alumni Magazine IESE*. No. 131.

Michels, J. (August 2013).Professional Licensure – It's Important. *IE Industrial Engineer*. Member Forum.

Mitcham, C. (ed.). (2005). *Encyclopedia of Science, Technology and Ethics.* MacMillan Reference. Detroit, MI. USA.

National Academy of Engineering. (2016). *Infusing Ethics into the Development of Engineers: Exemplary Education Activities and Programs.* Washington: National Academies Press.

Newberry, B. P. (2005). Professional Engineering Organizations. Encyclopedia of Science, Technology, and Ethics.

Available in: www.encyclopedia.com/science/encyclopedias-almanacs-transcripts-and-maps/professional-engineering-organizations (Retrieved February 03, 2017).

Newhard, J. (2004). Three Moral Theories. In J. H. Smith and P. M. Harper (editors). *Engineering Ethics. Concepts, Viewpoints, Cases and Codes*. National Institute for Engineering Ethics. Murdough Center for Engineering Professionalism. Texas Tech University. Lubbock, Texas.

Pautz, M.C., Washington, C.P. (October 2009). Sarbanes-Oxley and the Relentless Pursuit of Government Accountability. The Perils of 21st-Century Reform. *A*dministration & Society. Vol. 41 No. 6 651-673. DOI: 10.1177/0095399709339011.

Pinkus, R., Shuman, L., Hummon, N. and Wolfe, H. (1997). *Engineering Ethics: Balancing Cost, Schedule, and Risk. Lessons Learned from the Space Shuttle*. Cambridge University Press.

Rogers, S.A. (2014). Ancient Engineering Fails: 12 Historic Structural Disasters. Available in http://weburbanist.com/2014/04/16/ancient-engineering-fail-12-historic-structural-disasters/ (Retrieved Oct. 22, 2016).

Rudnicka, E.A. (2005). Ethics in an Operations Management Course. *Science and Engineering Ethics*. Pp. 645-654.

Rudnicka, E.A., Besterfield-Sacre, M., Shuman, L.J. (2013). Development and Evaluation of a Model to Assess Engineering Ethical Reasoning and Decision Making. *International Journal of Engineering Education.* Vol 29, No. 4, pp. 948-966. TEMPUS Publications.

Qin Zhu, Feister, M.K., Zoltowski, C. B., Buzzanell, P.M., Oakes, W.C. (2014). Examining the Role of Culture in Assessing Individual Ethical Reasoning on Multidisciplinary Engineering Project teams. Frontiers in Education Conference. IEEE. DOI: 10.1109/FEI.20114.7044440.

Savulescu, J., Crisp, R., Fulford, K.W., Hope, T. (1999). Evaluating ethics competence in medical education. *J Med Ethics*. 25: 367/74.

Scanlon, C., Glover, J.A. (1995). A professional code of ethics: providing a moral compass for turbulent times. *Oncol Nurs Forum* 22: 1515/21.

Schreiber, R. (2014). Corporate Social Responsibility Is an Essential Strategy in Today's Marketplace. In *Corporate Social Responsibility.* Haerens, M. and Zott, L. M. (editors). GREENHAVEN PRESS. Gale CENGAGE Learning.

Shuman, L.J., Sindelar, M., Besterfield-Sacre, M., Wolfe, H., Pinkus, R., Mitcham, C., Miller, R. and Olds. B. (Nov. 5-8. 2003). Assessing Students' Abilities to resolve Ethical Dilemmas. *Frontiers in Education Conference*. Boulder. CO.

Singer, A.E. and Singer, M.S. (1997). Management Science and Business Ethics. *Journal of Business Ethics.* 16: 385-395

Smith, J.H., Harper, P. M., Burgess, R.A., (editors). (2008) *Engineering Ethics: Concepts, Viewpoints, Cases and Codes.* 2nd ed. National Institute for Engineering Ethics. Murdough Center for Engineering Professionalism. Texas Tech University. Lubbock, Texas.

Smith, J.H. and Harper, P. M. (editors). (2004) *Engineering Ethics: Concepts, Viewpoints, Cases and Codes.* Space Shuttle Challenger Case. National Institute for Engineering Ethics. Murdough Center for Engineering Professionalism. Texas Tech University. Lubbock, Texas. 147-158.

Unger, S.H. (1994). *Controlling Technology. Ethics and the Responsible Engineer*. 2nd ed. John Wiley & Sons. New York.

Weil, V. (1984). The Rise of Engineering Ethics. *Technology In Society*. Vol.6. 341-345.

Wright, R.A. (1987). *Human values in health care: the practice of ethics.* New York: McGraw-Hill.

www.abet.org (Retrieved April 21, 2016).

www.niee.org (Retrieved March 20, 2016).

www.nspe.org (Retrieved April 20, 2016).

The Effects of Laser Eye Protection on Color Recognition

Sherisse Pierre, M.S.[1]
Deborah Carstens, Ph.D.[1]
[1]*Florida Institute of Technology*
pierres2011@my.fit.edu; carstens@fit.edu

Abstract

The research explores color recognition when using Laser Eye Protection (LEP). A laser strike or cockpit illumination is a distraction and can temporarily blind pilots during one of the most critical phases of flight such as takeoff and landing, when the aircraft is low in altitude and there is little room for error. Aviation laser strikes are on the rise and so pilot controlled mitigation methods are necessary. LEP is one mitigation method currently available to pilots. When wearing LEP pilots should retain sufficient color recognition for several reasons. One reason is that many aviation instruments utilize color differences to indicate a different status, mode, position, or quantity. Another reason is that colored lights on an airfield identify different surface areas. Therefore, the study tested participants' ability to recognize color when using an LEP since this is vital to pilots in safely operating an aircraft.

Participants were exposed to several different colors while freely using the LEP as desired to acquaint themselves with how the LEP affects the appearance of color. Participants were then tested on color recognition when using the LEP compared to participants using non-tinted and nonprescription protection eyewear. The data was collected and analyzed with the results presented. The study results will be discussed along with future research ideas to expand upon the current literature with regards to LEP.

1. Introduction

A laser cockpit illumination is a distraction and can temporarily blind pilots during the most critical phases of flight. Aviation laser strikes are on the rise and so pilot controlled mitigation methods are necessary. Laser Eye Protection (LEP) is one mitigation method currently available to pilots. When wearing LEP, pilots should retain sufficient color recognition abilities. Many aviation instruments utilize color differences to indicate a different status, mode, position, or quantity. Colored lights on an airfield identify different surface areas and type of airport. ATC towers can display light gun signals for communication in the event of a radio failure (usually includes three colors; red, green, and white).

The aim of this study was to investigate the effects of LEP on color recognition using two different types of LEP and a pair of clear protection eyewear (with no special laser blocking capabilities). One rationale for the study is that the FAA recommends to "[p]erform human factors studies to investigate whether providing pilots with Laser Eye Protection (LEP) is a practical means to mitigate certain potential laser hazards. These studies should also address the effects of LEP on color vision, visual acuity, and operational performance" (Milburn, Neitz, Chidester, and Lemelin, 2013).

The research questions for the research are listed below:

RQ1: What is the effect of Laser Eye Protection on color recognition?
RQ2: For which color, from those investigated, is color recognition most greatly affected by Laser Eye Protection?

2. Literature Review

Aviation laser illumination incidents pose a threat to aviation safety and flight crew health. With cockpit laser illuminations, pilots can be distracted from their duties during one of the most critical phases of flight (Nakagawara, Wood, and Montgomery, 2006). The flight crew may also be susceptible to eye damage due to direct cockpit laser illuminations. Wyrsch, Baenninger, and Schmid (2010) covered a case study involving a teenage boy that "ordered a handheld laser pointer with green light on the Internet to use as a toy" (p. 1089). While playing with the device, his eyes were exposed to the green laser light several times, resulting in blurred vision and retinal damage. Wyrsch et al. (2010) stated that "his visual acuity was so poor in his left eye that he was only able to count fingers at a distance of 3 feet" (p. 1089). After four months of treatment, the boy's vision improved, but there was evidence of foveal scarring and he did not regain his previous vision capabilities. These authors also highlight the ease at which a Class III laser can be acquired and the similar outward appearances of harmless low powered laser pointers designed for presentations, and higher powered laser devices.

Nakagawara, Montgomery, and Wood (2011) conducted the study in which they examined laser illumination incident trends over the five-year period, January 2004 to December 2008. The research suggested that aviation laser strikes occurred more frequently in the months of November and December, and on weekends, especially Sundays. The times between 1900 (7:00 pm) and 2300 (11:00 pm) were the most popular times in which laser strikes occurred (Nakagawara et al., 2011). This study agreed with the FAA review in finding that laser strikes on commercial aircraft accounted for the majority (73%) of the incidents (Nakagawara et al., 2011).

To this date, there have been no major accidents resulting from an aviation laser illumination incident, but this threat should be mitigated to prevent such an accident (Nakagawara et al., 2006). One method that can be used in preventing these types of accidents is facilitating public awareness. Pilots, especially general aviation pilots, may not be aware of the growing threat and the possible associated hazards, and may not know what to do in the event that a laser illumination is experienced (Nakagawara et al., 2011). Members of the general public may not know that it is a federal violation, punishable by a fine or imprisonment, to point a laser at an aircraft, and they may also be unaware of the dangers it poses to pilots and everyone on board (FAA Modernization and Reform Act of 2012).

When using LEP pilots must be able to retain substantial color discriminating abilities because many aspects of aviation rely on different colors (Palakkamanil and Fielden, 2015). Milburn, Neitz, Chidester, and Lemelin (2013) highlight that over the years, the use of color coding in aviation has increased due to "changing technology inside the cockpit, on air traffic control displays, and in the airport environment" (p. 1). The use of color can sometimes aid in communicating an instruction or intention without the need for verbal or written communication; however, color can only be a successful communication tool if both the sender and receiver can recognize and discriminate between colors (Milburn et al., 2013).

With regards to airport lighting, lights of different colors may indicate a different surface or pavement area, for example, taxiway edge lights may be blue, while runway edge lights are generally white. A pilot must be able to differentiate between a runway and a taxiway for various safety reasons. At night, airport lighting plays an important part in surface recognition as it highlights the designated areas (Palakkamanil and Fielden, 2015).

Dykes, Schmeisser, Garcia, McLin, Harrington, and Apsey, (2000) suggest that utilizing computer modeling for color appearance testing can help LEP designers and manufacturers to produce devices that are effective and usable. Lucassen and Toet (2006) developed a computer software program, TNO

VisorSimulator, which can simulate the color perception changes that various LEP devices would effect. The software allows for testing of a multitude of spectral blocking filters in various regions of the visible spectrum, however, Lucassen and Toet (2006) warn that even though the simulator can display the effects of different filters on color appearance, producing filters with some spectral blocking combinations may not actually be possible. Kuyk, Brockmeier, Morin, LaFrance, and Foutch 2010) also conducted research into developing a computer-based tool that simulates color appearance when looking through LEP devices. The researchers developed a tool based on two software packages, SolidWorks™ and OptisWorks™, and concluded that, with this tool, color appearance through an LEP could be readily simulated with great precision, accuracy, and reliability.

LaFrance, Williamson, Svec, and Kuyk (2013) conducted a study to investigate the effects of different types of LEP on both "broad-band and narrow-band hue discrimination tasks" using "isoluminant caps" as the "broad-band illuminant" and an MFD as the "narrow-band illuminant". This study, however, contrary to Dykes et al. (2000), found that the color-balanced LEP affected color discrimination for broad-band light sources more so than for narrow-band light sources (LaFrance et al., 2013). The researchers explain that this may have been due to the color-balancing of the lenses resulting in an "alignment between LEP transmission bands" and the visual output of the MFD. This finding can be useful in manufacturing LEP if the device is to be tailored to suit increased PFD and MFD usage.

3. Methodology

The research explores color recognition when using LEP. The study tested participants' ability to recognize color when using an LEP. The research conducted was a quantitative exploratory research study with a post-test only modified quasi-experimental design. The study utilized three types of eyewear consisting of LEP1-RG, LEP2-RGB and EP3-Clear.

LEP1-RG had a visible light transmission of 18% and transmitted less than 10% of red light (630 – 670 nm wavelengths) and less than 4% of green light (532 nm wavelength). LEP1-RG complied with ANSI Z136.1 (American standard for safe use of lasers) and ANSI Z80.3 (American standard for sunglasses), and met the standards of ANSI Z87.1 (American standard for Occupational Personal Eye and Face Protection Devices). LEP2-RGB had a visible light transmission of 23.3% and transmitted approximately 6.3% of red light (633 – 640 nm wavelengths), approximately 3.2% of green light (532 nm wavelength), and approximately 3.2% of blue light (445 – 450 nm wavelengths). LEP2-RGB complied with ANSI Z136.1 and met the standards of ANSI Z87.1. The clear protection eyewear (EP3-Clear) had no laser blocking capabilities and exceeded the standards of ANSI Z87.1. This study includes the use of clear protection eyewear for comparison purposes.

The Color-block test was used to measure the LEPs' effects on color recognition. A Chi-squared test was used for statistical analysis. The target population was male and female adults with normal color vision. The accessible population was adult university students and employees with normal color vision based at FIT.

Before conducting the study, the study was approved by the university's Institutional Review Board (IRB). The participants were informed that the study would not exceed 25 minutes in length and that all identifying information will be kept confidential. A convenience sampling method was used to recruit 90 participants. This sampling method was used due the study's exploratory nature, time constraints, and the limited resources available to conduct the research. A power analysis was conducted a priori to determine the sample size for the study. This was done to ensure that a sufficient number of participants would be recruited to allow the study to have adequate statistical power. From the power analysis, the minimum sample size for this study was 86 participants. Therefore, it was ensured that over 86 participants were used in this study. Ninety (N = 90) participants were recruited for the study. There were 30 participants in each of the three groups assigned through rolling a dice. The three groups consisted of participants using one of the eyewear; LEP1-RG, LEP2-RGB, or EP3-Clear.

The procedure for each participant was to complete a questionnaire, perform a basic color vision test, and perform a five minute experience pre-test. Then each participant performed a Color-block test. This consisted of a controlled PowerPoint presentation showing instructions and blocks of different colors displayed on a black background. The black background was chosen based on previous similar color recognition and discrimination studies (Kuyk et al., 2010).

The laptop was set up at a distance of approximately 40 cm from the edge of the surface. Screen inclination angle of approximately 105° (Gangele and Mishra, 2015).

4. Results

This section addresses the study results with regards to LEPs. The chi-square goodness of fit test was used as the primary method to determine the statistical significance of the results. This statistical test was chosen due to the non-parametric nature of the data collected and is appropriate for statistical analysis when simultaneously comparing categorical variables. The independent variables were the type of LEP and color. The dependent variable was color recognition as measured by the Color-block test. Descriptive statistics were also calculated.

The participants consisted of 52% females and 48% males. The age distribution of the participants consisted of 91% between the ages of 18-29, 7% between the ages of 30-39, and 2% between the ages of 40-49. The participants' ethnicity consisted of 49% Caucasian/White, 16% Asian, 14% Black/African American, 12% Hispanic/Latino, 8% Mixed and 1% Other. The participant's eye color distribution consisted of 67% of the participants had brown eyes, 18% blue eyes, 9% green eyes, 4% hazel eyes, and 2% had an eye color not falling within the questionnaire categories. The participants recruited had different areas of study. Of the 90 participants, 39% were in the engineering area of study, 36% in the aeronautics area of study, 13% in the science area of study, 5% in the business area of study, 4% in the psychology area of study, and 3% in the education area of study.

The overall effect of LEP on color recognition in this study was found to be not statistically significant, $\chi2$ (6, N = 311) = 8.95, p = .17 which corresponds to the first research question:

RQ1: What is the effect of LEP on color recognition?

H01: Laser eye protection has no significant effect on color recognition.

It was found that at least one color was more affected by the LEP, and through post hoc analyses it was found that color recognition of amber was the most affected by LEP, $\chi2$ (3, N = 311) = 8.94, p = .03 which corresponds to the second research question:

RQ2: Which color from those investigated is color recognition most greatly affected by LEP?

HA2: The laser eye protection's effect on color recognition for at least one color is significantly different.

Table 1 identifies the number of participants that were able to correctly identify each of the four colors within each of the three groups.

Table 1: Participants' Color Recognition

Color	LEP1	LEP2	EP3
Blue	30	24	30
Green	30	25	30
Amber	10	15	30
Red	28	29	30

There were many limitations to the research. First, only two types of LEP were used which may not be representative of every LEP device available to pilots. The convenience method of sampling was used to recruit participants from a relatively small part of the population. This can limit the generalizability of the study. Also, a color's effects on other colors may have influenced how a color is perceived. Furthermore, each participant was provided with five minutes of LEP usage to become acquainted with the LEP and the study. Five minutes may not be long enough for a participant to truly gain experience with the LEP.

The overall effect of LEP on color recognition was not statistically significant. From the colors studied, color recognition of amber was the most affected by LEP. This study has the potential to educate and bring awareness to the aviation industry and general population about the hazards of laser strike incidents. From the results of this study, LEP may be an effective mitigation method for aviation laser strikes. However, the present study only investigated four colors and amber was the color that was not well recognized by participants.

No significant trends were observed with respect to color recognition and demographic data (ethnicity, eye color, subject area).

5. Conclusion

The potential significance of the research suggests that available LEP allows users to retain near accurate color recognition. This study highlights an area where LEP can be improved by performing more research into color recognition of amber and non-primary light colors. This study brings awareness to the growing problem of aviation laser strikes and cockpit illuminations. The research also encourages further investigation and research into developing a standard specifically for civil aviation LEP.

There are several future research areas to expand upon the present study. First, research should investigate the feasibility of a retractable windshield filter, which could be pulled down in front of the windshield when needed and removed when not needed. For example, pilots would use it when going into airports notorious for aviation laser strikes, or on approaches at night, but not during daytime cruise flight at altitude. The material would need to be transparent but would also need to not be easily fractured or become opaque. Research would also have to investigate how it could withstand constant altitude and pressure changes without degrading, while being able to house the laser protection dyes and filters. The aircraft itself would also have to be fitted with the filter and therefore tailored to different aircraft. The device, itself, would also have to be cost effective. The second research area to investigate is to design PFD and MFD technologies with the ability to change color characteristics such as hue, saturation, and warmth. This could be useful to enhance pilot color recognition when using LEP in the cockpit. There could be a setting that color-compensates for the use of different types of LEP. This type of setting should be easily selected and deselected.

It is difficult for law enforcement to apprehend individuals who shine lasers at aircraft due to the volatile nature of a laser strike incident. Future research could investigate improved methods of tracking and locating individuals who contribute to aviation laser strikes.

In conclusion, aviation laser strikes are on the rise and so pilot controlled mitigation methods are necessary. The findings suggest that there was no significant effect on color recognition. LEP is one potentially effective mitigation method currently available.

6. References

Dykes, J. R., Schmeisser, E. T., Garcia, P. V., McLin, L. N., Harrington, L. K., & Apsey, D. A. (2000, December). Changes in color appearance induced by a laser eye protection device: effects of stimulus spectrum width and context. Optometry and Vision Science, 77(SUPPLEMENT), 233. doi:10.1097/00006324-200012001-00370

FAA Modernization and Reform Act of 2012, Pub. L. No. 112-95, 126 Stat. 65 (2012).

Gangele, A., & Mishra, A. (2015). Optimal laptop VDU parameter setting using Taguchi method. Management Science Letters, 5, 961-968. doi:10.5267/j.msl.2015.8.001

Kuyk, T., Brockmeier, W., Morin, A., LaFrance, M., & Foutch, B. (2010, May). P-50: Simulating the effects of wearing laser eye protection on color appearance. SID Symposium Digest of Technical Papers, 41(1), 1430-1433. doi:10.1889/1.3499973

LaFrance, M. W., Williamson, C. A., Svec, L. A., & Kuyk, T. K. (2013, May). Laser Eye Protection and Visibility of Multi-Function Displays. Poster presented at the annual meeting of the Association for Research in Vision and Ophthalmology (ARVO), Seattle, WA, USA.

Lucassen, M. P., & Toet, A. (2006). TNO VisorSimulator: A tool supporting the spectral design of laser eye protection filters (pp. 1-22, Rep. No. TNO-DV3 2006 C012).

Milburn, N. J., Neitz, J., Chidester, T., & Lemelin, M. (2013, November). New genetic technology may help pilots, aviation employees, and color vision researchers. Aviation, Space, and Environmental Medicine, 84(11), 1218-1220. doi:10.3357/asem.3860.2013

Nakagawara, V. B., Wood, K. J., & Montgomery, R. W. (2006). A review of recent laser illumination events in the aviation environment (United States of America, Federal Aviation Administration, Office of Aerospace Medicine). Oklahoma City, OK: Federal Aviation Administration, Civil Aerospace Medical Institute. Retrieved from https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/200623.pdf.

Nakagawara, V. B., Montgomery, R. W., & Wood, K. J. (2011, November). Laser illumination of flight crewmembers by altitude and chronology of occurrence. Aviation, Space, and Environmental Medicine, 82(11), 1055-1060. doi:10.3357/asem.3124.2011

Palakkamanil, M. M., & Fielden, M. P. (2015, December). Effects of malicious ocular laser exposure in commercial airline pilots. Canadian Journal of Ophthalmology, 50(6), 429-432. doi:10.1016/j.jcjo.2015.09.002

Wyrsch, S., Baenninger, P. B., & Schmid, M. K. (2010, September 09). Retinal injuries from a handheld laser pointer. New England Journal of Medicine, 363(11), 1089-1091. doi:10.1056/nejmc1005818

Machine Learning: Magic Method vs. Massive Manpower

John Wang[1]

Jeffrey Hsu[2], Qiyang Chen[1], Sylvain Jaume[3]

[1]*Montclair State University*, [2]*Fairleigh Dickinson University,*[3]*Saint Peter's University*

wangj@montclair.edu; jeff@fdu.edu; chenq@montclair.edu; sjaume@saintpeters.edu

Abstract

When facing a big challenge from big data, Deep Learning (DL) has recharged the power of Machine Learning (ML) and enhanced its usefulness. This third artificial intelligence wave (DL and big data) is a harbinger of the fourth industrial revolution. We highlight the newest theoretical breakthroughs of ML and its applications in different areas. We also explore the future directions and potential long-term economic and social effects.

1. Introduction

Machine Learning (ML) operates much as human cognition does. However, ML learns things in a totally different way. ML involves computer algorithms that can "learn" or improve its performance over time on some task. ML techniques include three sub-themes: neural networks, fuzzy logic, and the naïve Bayes classifier. ML allows scholars to gather either new types of data, such as social media data, or vast quantities of traditional data with less expense. Children gradually accumulate their knowledge and readily build upon what they've learned in the past. For instance, they create words by threading vowel sounds together and compile sentences via strings of words. As the subset of ML, Neural Networks (NNs) are black-boxes and inspired by our understanding of the biology of the human brain.

As a current buzzword, Deep Learning (DL) represents a rebranding of NNs. These neurons are "trained" through exposure to often tens of thousands, sometimes hundreds of thousands of instances of human speech, objects within images, or different types of behavior until they learn to distinguish them. Over the past decade, DL has brought about state-of-the-art algorithms in speech recognition, computer vision, natural language processing and many other tasks. This was made possible by the advancement in Big Data and drastically increased chip processing abilities, especially general-purpose graphical processing units (GPGPUs). All this has created a growing interest in making the most of the potential offered by DL in almost every field (Pastur-Romay, Cedrón, Pazos, and Porto-Pazos, 2016). It is so fascinating to see recent events:

- In 2016, AlphaGo beat Korea's Lee Sedol (one of the world's best Go players) in a rout 4-1.
- It was reported in January 2017, that Google's AlphaGo secretively won 60 straight games against the world's top Go players. These top Go players have acknowledged that human beings are no match for robots in the complex board game and they should now start to learn from computers to explore new skills, which was sent by the 'Go God' to guide humans.
- AlphaGo defeated the world's best Go-player Ke Jie 3-0 on May 27, 2017 leaving no other competitors remaining.

2. Research Methodology

Over the years, Content Analysis (CA) has been applied to a variety of scopes. Quantitative Content Analysis (QCA) has experienced a renewed attractiveness in recent years because of technological advances and prolific applications in mass communication and personal communications research. New media, such as social media and mobile devices, has become all the rage. CA of textual big data faces new challenges.

After a first search based on keywords and phrases, we used the authors' names from the relevant studies identified in the initial searches and searched the databases again. The reference sections of the identified studies from the first run were then examined as well as existing reviews of the literature. Affinity Diagramming (AD) has been conducted. AD is a very simple but powerful technique for grouping and understanding information. In particular, AD provides a good way to identify and analyze issues. There are several variations of the technique.

3. Recent Applications

3.1. Government

Tax avoidance and tax evasion under the umbrella of abusive tax shelters resulted in a more than $450 billion U.S. tax gap in recent years (GAO, 2012; IRS, 2006). Tracking down fraud is a needle-in-a-haystack quest because the 74,608-page federal tax laws are full of legal gray areas and fuzzy logic. Data mining had been used to root out fraud in corporate tax returns since 2000. The IRS collects pre-existing data from filed tax returns and analyzes them for patterns. By contrast, ML does not require pre-existing evidence. Instead, it focuses on rule mining, in which individual tax code regulations are lined up against one another to ascertain if they can be used collectively to create a sophisticated tax dodge.

Warner, Wijesinghe, Marques, Badar, and Rosen. (2015) built a functioning end-to-end codebase capable of executing all the steps of an authorized genetic algorithm. In particular, they developed a genetic representation with the capacity to generate complex tax evasion schemes like IBOB (installment-sale bogus optional basis). The schemes produced by the algorithm consist of sequences of transactions within an ownership network of tax entities. Schemes are ranked according to a "fitness function." The authors believe their algorithm can provide valuable insight to auditors seeking to reduce the national tax gap. Enforcement efforts have traditionally been focused on single financial entities and missed complex transaction flows within large partnership networks. These schemes have caused big losses and are extremely difficult to target without detailed foreknowledge of the associated pattern of activity. Their algorithm provides detailed exemplars of network-based evasion and helps to mitigate this problem.

3.2. IT and Software

Having applied the OSEL_RBF (Online Sequential Extreme Learning Machine with Gaussian Radial Basis Function) algorithm, Demertzis and Iliadis (2016) introduced a novel bio-inspired intelligence cyber-threat management system namely Ladon. According to the Greek mythology, Ladon was the huge dragon with the 100 heads, which had the ability to stay continuously up, to guard the golden "Esperides" apples in the tree of life. They experimentally explored the classification performance accuracy of the advanced information systems' security mechanism through scenario analysis with very promising results. The lower layers of the system (Transport, Network, and Data) have been enriched and the upper layers (Session, Presentation, and Application) have been amplified in an intelligent manner. As an effective cross-layer system of network supervision, Ladon has capabilities of automated control and adds more integrity to the rest of the security infrastructure of Network Operating Systems. Ladon can properly classify network traffic, label malware traffic and identify fast-flux botnets to protect, control and offer early warning in cases of detour or misleading of the digital security measures with high learning speed and accuracy, ease of implementation, minimal human intervention and minimum computational power and resources.

3.3. Bioinformatics

The Deep Artificial Neuron-Astrocyte Networks (DANAN) could overcome difficulties in architecture design, learning processes, and scalability of current ML methods. Pastur-Romay, Cedrón, Pazos, and Porto-Pazos. (2016) reviewed the main architectures of Deep Artificial Neural Networks (DNNs) and their usefulness in Pharmacology and Bioinformatics. The featured applications are: drug design, virtual screening (VS), Quantitative Structure-Activity Relationship (QSAR) research, protein structure prediction and genomics (and other omics) data mining. The future need of neuromorphic hardware for DNNs is also discussed, and the two most advanced chips are reviewed: IBM TrueNorth and SpiNNaker.

GoogLeNet projects were originally targeted at the company's autonomous car project, teaching self-driving cars to recognize everything from road layouts to stop signs. The company has now applied GoogLeNet tech to cancer diagnosis and delivered stunning performance. There are numerous slides per patient, each of which is 10+ gigapixels when digitized at 40X magnification. Imagine having to go through a thousand 10-megapixel (MP) photos, and having to be responsible for every pixel. GoogLeNet did a better job overall compared with an experienced pathologist who had unlimited time to examine the slides, with an astonishing score of 89%. vs. 73%.

By means of kinematic analysis of a simple reach-to-drop task, Crippa, Salvatore, Perego, Forti, and Nobile. (2015) developed a supervised ML method to correctly discriminate 15 preschool children with ASD from 15 typically developing children. Their proof-of-concept study reached a maximum classification accuracy of 96.7 % with seven features related to the goal-oriented part of the movement. These preliminary findings offer insight into a possible motor signature of ASD that may be potentially useful in identifying a well-defined subset of patients, reducing the clinical heterogeneity within the broad behavioral phenotype.

3.4. Transportation

Current driverless cars use expensive sensors or radar to sense their environment. As Thilmany (2016) reported, engineers at the University of Cambridge have developed SegNet, an object recognition application. The system uses DL mapping of street scenes, including barriers, into a camera or smartphone in real time. Instead of controlling the car directly, the system enables it to "see" by recognizing the road ahead of it and the neighborhood helping the car maneuver along the road and avoid collisions. SegNet views a street scene and immediately identifies its contents, placing them into 12 categories, including roads, street signs, pedestrians, buildings, and cyclists. Rather than attempting to classify objects by size or shape, SegNet recognizes them by their color, intensity, texture, and spectral information, the type of data easily extracted from the pixels of digital photographs. This enables the system to identify objects, like trees or shrubs, with shapes the system has never seen before. Beyond driverless cars, the system could be used in other applications, such as robotics, augmented reality, and surveillance or security camera.

In order to prevent drowsiness related crashes, Wang, Jeong, Kim, Choi, and Yang. (2016) developed individuals' drowsy behavior detection technology. A driving experiment was performed for obtaining driving information through a driving simulator. Moreover, the authors investigate effects of using different input parameter combinations (lateral acceleration, longitudinal acceleration, and steering angles with different time window sizes), on drowsy driving detection using a random forest algorithm. Comparing to using an ANN algorithm, the random forests algorithm performs better on processing complex input data for drowsy behavior detection. The results, which reveal high accuracy (84.8 %) on drowsy driving behavior detection, can be applied towards the study of operating real vehicles.

Flight delays are a major issue faced by airline companies. Delay in aircraft take off s can lead to penalties and additional costs, leading to revenue loss. The causes for delays can be weather, traffic queues, or component issues. Dattaram and Madhusudanan (2016) focused on the problem of delays due to component issues in the aircraft. By applying exploratory analytics, stochastic approaches, and ML techniques, the authors analyze and establish the relationship between monitoring data and aircraft delays. They use Hidden Markov Models (HMM) for delay prediction, and conclude that more appropriate training sequences can improve the HMM accuracy of predicting delay states.

Planning and policy analysis at the national, state and inter-regional corridor levels depend on reliable information and forecasts about long-distance travel. Emerging passive data collection technologies such as GPS, smartphones, and social media provide the opportunity to supplement or replace traditional long-distance travel surveys. However, certain important trip information, such as trip purpose, travel mode, and travelers' socio-demographic characteristics, are missing from passively collected travel data. One promising solution to this data issue is to impute the missing information based on supplementary data (e.g., land use) and advanced statistical or data mining algorithms. Lu and Zhang (2015) estimated trip purposes for long-distance passenger travel via decision tree and meta-learning. They simulated a passively collected long-distance trip dataset from the 1995 American Travel Survey for the development and validation of the ML methods. Scenario analysis has been conducted. Their research design provided not only a practically useful approach for long-distance trip purpose imputation, but also generated valuable insights for future long-distance travel surveys.

3.5. Industry Sectors

According to Anifowose, Labadin, and Abdulraheem (2016), computational intelligence (CI) techniques have positively impacted the petroleum reservoir characterization and modeling landscape. The ML concepts of hybrid intelligent system (HIS) satisfy the need for robust techniques. The authors study the impact of HIS on the petroleum reservoir characterization process and find huge potentials of HIS in the improvement of petroleum reservoir property predictions. HIS can lead to improved exploration, more efficient exploitation, increased production, and more effective management of energy resources.

As per Kalkat (2015), all motor-driven machinery used in the modern world can develop faults. The maintenance plans include analyzing the external relevant information of critical components to evaluate its internal state. By using two types of artificial neural networks (ANNs) and stress analyzed with computer-based software ANNs, the author deals with the effectiveness of wavelet-based features for fault diagnosis of a gearbox. The proposed model has superior performance to adapt experimental results. His approaches are novel to predict real-time vibration and acceleration parameters of unloaded gearbox with five types of oils.

3.6. Healthcare

The rapid expansion in the volume, variety, timeliness, and availability of healthcare data is creating new opportunities for improving the specification of health econometric models. Crown (2016) examined the implications of the utility maximization principles of consumer demand theory for the specification and econometric modelling of healthcare expenditure models. It considers the inherent endogeneity problems introduced by the underlying patient and physician behaviors influencing the data and suggests an IVs (Instrumental Variables) approach for addressing these problems.

Having learned normative peer-group behavior from data, Weiss, Kulikowski, Galen, Olsen, and Natarajan. (2015) present techniques for detecting outliers and managing and reducing healthcare costs. The described peer-group techniques are well-matched with accepted medical practice where decisions must be validated by a standard of performance. Starting with millions of patient insurance records, they analyzed physician billing records and their related prescriptions. The goal was to pinpoint physicians who exceeded normative oxycodone prescription levels relative to their peers with similar specialties and patient populations. The authors sorted the data by actual cost and applied a prediction-method transformation that supports strong empirical validation. The empirical results were tested on independent data with high prediction rate and significant cost reduction in a representative healthcare population. Their approach is suitable for many types of peer groups and different types of cost measures and sample designs.

Nowadays, eating more healthily, and avoiding obesity is a big concern, especially in developed countries. With the intention of measuring calories and nutrition in everyday meals, Pouladzadeh, Shirmohammadi, Bakirov, Bulut, and Yassine. (2015) proposed distributed support vector machine implementation in cloud computing systems using the MapReduce technique that improves scalability and parallelism of split data set training for food recognition and classification. The performance and generalization property of their algorithm are evaluated in Hadoop with the improved results.

3.7. Environment

In order to help policy makers in developing efficient scarce water utilization strategies, Patel and Ramachandran (2015) analyzed flow data over a period of 30 years from three different observation points established in upper Cauvery river sub-basin. ANN model uses a multi-layer feed forward network trained with a backpropagation algorithm and support vector regression with epsilon intensive–loss function is used. Auto-regressive moving average models are also applied to the same data. The performance of different techniques is compared using performance metrics.

With the purpose of improving regional water quality, Fatehi, Amiri, Alizadeh, and Adamowski. (2015) explored eighty-eight catchments in the southern basins of the Caspian Sea because the physical attributes of catchments have a significant influence on the chemistry and physical features of in-stream water quality. The authors used Artificial Neural Networks (ANNs) to model the relationship between land use/cover, associated with other physical attributes of the catchment such as geological permeability and hydrologic soil groups, and in-stream water quality parameters. To enhance the architecture of ANNs, the study applied backward elimination-based multiple linear regression, through which the optimum input nodes of ANNs can be determined amongst the most relevant variables. The authors apply a transformation approach to qualify the performance of ANNs in four quality classes, ranging from unsatisfactory to very good.

3.8. Automatic recognition

Researchers at the Massachusetts Institute of Technology have developed a computer program that learns simple, visual concepts the way humans do. After seeing only one example, the program can recognize and recreate a handwritten character, outperforming human experts. The system uses a Bayesian program learning framework, which generates a unique program for each handwritten alphabet character. A probabilistic programming technique then matches a program to a character or generates a new program for an unfamiliar one (Thilmany, 2016).

Noda, Yamaguchi, Nakadai, Okuno, Ogata. (2015) introduced a connectionist-hidden Markov model (HMM) system for noise-robust Audio-visual speech recognition (AVSR). As one of the most promising solutions for reliable speech recognition, AVSR system performs very well even in a noisy environment. However, precautious selection of sensory features is decisive for attaining high recognition performance. A convolutional neural network (CNN) is utilized to extract visual features from raw mouth area images. A multi-stream HMM (MSHMM) is applied for integrating the acquired audio and visual HMMs independently trained with the respective features. A high word recognition rate gain is attained.

In line with Ransbotham (2015), The Echo Nest merged two perspectives – ML and cultural analytics - to describe music in a way that made it analytics-friendly, with the goal of using analytics to help users find new music they'd enjoy. A self-described music intelligence company connects people with music they love. The company's product describes itself as a "friend "that you rely on musically, to better understand who you are as a fan, to understand all the music that's out there, and to make connections.

3.9. Education

Vardarlier and Silahtaroglu (2016) proposed a Big Data Warehouse and a model for universities to be used for gossip management. The author tested it with 300 volunteer students for 65 days. In the model, unsupervised ML algorithms have been employed. User generated data has been collected from students to learn "gossip" in relation to students' problems associated with school, classes, staff, and instructors. The findings and results of the pilot study suggest that social media messages among students may give important clues for the happenings at school and this information may be used for management purposes. The model may be developed and implemented by not only universities but also other relevant organizations.

Somyürek (2015) examined fifty-six studies conducted between 2002 and 2012 to identify prominent themes and approaches on adaptive educational hypermedia systems. According to the content analysis, the new technological trends and approaches were grouped into seven categories: standardization, semantic web, modular frameworks, data mining, ML techniques, social web, and device adaptation. Furthermore, four challenges are suggested as explanation why adaptive systems are still not used on a large scale: inter-operability, open corpus knowledge, usage across a variety of delivery devices, and the design of meta-adaptive systems.

Plagiarism in free text has become a common occurrence due to the wide availability of voluminous information resources. Automatic plagiarism detection systems aim to identify plagiarized content present in large repositories. This task is rendered difficult using sophisticated plagiarism techniques such as paraphrasing and summarization, which mask the occurrence of plagiarism. Chitra and Rajkumar (2016) developed a monolingual plagiarism detection technique to tackle cases of paraphrased plagiarism. A support vector machine based paraphrase recognition system, which works by extracting lexical, syntactic, and semantic features from input text has been used. Both sentence-level and passage-level approaches have been investigated. The performance of the system has been evaluated on various corpora, and the passage level approach has registered promising results.

3.10. The Internet of Things

Having combined supervised ML algorithms and unsupervised learning techniques, Alfaro, Cano-montero, Gómez, Moguerza, and Ortega. (2016) present a multi-stage sentiment analysis and opinion mining scheme. This successfully tested new methods to detect opinion trends in weblog comments. Its design is quite flexible for updating any changes in opinion trends in newly arrived messages. Policy makers can interpret prototype vectors of words. The scheme presented in this work may be customized for specific weblogs. The authors believe that the proposed tool may be directly used for the detection of population opinion trends within electoral campaigns or during the design process of new laws and public policies. Equally, it can also be adopted in several other applications such as automated categorization and detection of feedback messages linked to marketing and promotional campaigns, commercial products, and services, as well as reviewing and opinion websites.

For customer segmentation, online customer reviews (OCRs) had been used by increasingly e-commerce web sites recently. Jiang, Cai, Olle, and Qin. (2015) proposed a two-stage approach that employs latent class analysis (LCA): the feature-mention matrix construction stage and the LCA-based customer segmentation stage, to durable product review mining for effective customer segmentation analysis. Also, empirical results based on real-world data sustain its feasibility, and comparative experiments results show that there are significant advantages when using LCA over other methods. In the meantime, the authors found that human involvement in feature reduction process in key-feature determination step would raise the analysis accuracy.

4. Problems

As Silver and Hassabis. (2016) pointed out, a learning program such as AlphaGo cannot learn to play chess or checkers without extensive human labor. The design and implementation of the AlphaGo system required more than 30 million training examples culled from the Internet, and years of effort by a large team of researchers and engineers. In fact, merely improving AlphaGo's performance from defeating the European Go champion, Fan Hui, to defeating Lee Sedol required several months of intensive work.

To train SegNet, a group of Cambridge undergraduates manually labeled every pixel within 5,000 images. The researchers then trained the system by exposing it to those images. SegNet then generated its own algorithms to identify new objects. In operation, it classifies images in a speedy 65 milliseconds. Although the system has been successfully tested on both city roads and motorways, it is not ready for prime time and can only be used as a warning system when a collision is possible. As one of the participants admitted, "However, there are a million knobs that we can turn to fine-tune the system so that it keeps getting better." The researchers hope to train it to recognize objects in more rural settings, under an extended range of weather conditions, and in varied climates (Thilmany, 2016).

5. Future Directions

5.1. Human-level artificial intelligence

According to Davenport and Kirby (2016), two scholars at MIT, on the low end, ML systems simply respond to human queries and instructions; while at the (still theoretical) high end, they then formulate their own objectives. The most capable ML systems can learn their decisions get better with more data, and they remember previously ingested information. Mapping cognitive technologies by how autonomously they work and the tasks they perform shows the current state of smart machines and anticipates how future technologies might unfold.

It has been noticed by Zhang (2016), a big development in Korea is the transition from machine-oriented AI to human-oriented AI and humanlike machine intelligence. Scientists talk, more often than before, to each other to find common interests between AI and cognitive science.

Knight (2015) made it clear, "Bringing machine-learning algorithms closer to the capacities of human learning should lead to more powerful artificial intelligence systems as well as more powerful theoretical paradigms for understanding human cognition," Tenenbaum said. "We want to understand everyday human inductive leaps in computational terms."

5.2. Deep Learning could go even deeper

World media has called 2017 "the year of artificial intelligence". Groundbreaking advances are happening across a variety of AI applications, specifically deep learning, including image classification, video analytics, speech recognition, and natural language processing. DL is the fastest growing segment of AI. In the ML community, DL approaches have recently attracted increasing attention because deep NNs can use multiple processing layers with multiple linear and non-linear transformations and effectively extract robust latent features that enable various recognition algorithms to demonstrate revolutionary generalization capabilities under diverse application conditions.

5.3. The integration of other disciplines and technology with ML

Crown (2016) considers the potential role of data science methods such as ML for the analysis of healthcare data, particularly the potential for r using ML methods to estimate causal-effects models by combining ML with traditional econometric methods.

Bone, Goodwin, Black, Lee, and Audhkhasi. (2015) found out that use of ML in the absence of clinical domain expertise can be tenuous and lead to misinformed conclusions. They also highlight some especially promising areas for collaborative work at the intersection of computational and behavioral science.

How to make the online learning, genetic algorithm, SVM (Support Vector Machines) and ELM (Extreme Learning Machines) together will be a very worthwhile to explore direction (Ding, Zhao, Zhang, Xu, and Nie , 2015). Also, the combined analysis of spatial, spectral data dimensions and temporal data could help certain applications.

6. Economic and Social Effects

6.1. Job killer or job creator?

In agreement with Braun, Zweck, & Holtmannspötter (2016), like the industrial revolution, developments in intelligent algorithms are progressing at ever-increasing speed, which will also have far-reaching social consequences for vocational fields outside of the artificial intelligence and information technologies. Impacts of the knowledge and information society include changes that work towards an increasingly important service sector and a significant increase in knowledge work.

ML can create certain jobs, such as validating the results of AI, preparing the data for ML, and creating and designing systems. AI could double annual economic growth rates in 2035 for 12 developed economies by changing the nature of work and creating a new relationship between man and machine. The impact of AI technologies on business is projected to increase labor productivity by up to 40 percent and enable people to make more efficient use of their time (Accenture, 2017).

6.2. Successful few vs. mediocre many

Our information economy is creating a growing divide between the successful few and mediocre many. We are in the midst of a "winner-takes-all" economy: one or very few companies tend to dominate a category or an industry whereas those at the bottom suffer shrinking returns. According to Editeur (2015), the Finnish Social Insurance Institution (KELA) has given some preliminary elements concerning Finland's plan to experiment and then generalize the implementation of a basic income in the country. All Finnish citizens would be paid an untaxed benefit sum free of charge at the level of 800 euros, a universal basic income.

6.3. To tax or not to tax

Sooner than later, ML will replace many jobs that are currently performed by humans, creating a social cost in the process. It could cause a much higher unemployment rate if we cannot move displaced workers to new jobs after training. Should ML be taxed? Let's have a look at both sides of the argument.

Bill Gates recently started the debate on automation technology (AT). Gates emphasized

that AT is arriving concurrently with business needs to automate and cut costs, and the combination of those two forces could result in a wave of displaced workers. He argues that we need funds to manage this displacement. By taxing AT that is pilfering human jobs, we can use the funds to train workers for either more skilled labor or different jobs. Many understaffed service sectors are hiring, such as caring for the elderly, children, and people with special needs.

The opposite side argues that taxing AT could asphyxiate innovation, penalize good companies, and restrain productivity. How can the government justify a tax on the very thing that could improve productivity when complaining it is low? The other argument is that any effort to stifle productivity is essentially a tax on the entire American consumer. The biggest part of our economy is consumer spending, which could be beneficial from lower labor/input costs and productivity gains.

7. Conclusion

We investigate current applications of ML in different service providers and industries sectors: including science (physics, astronomy, and biology), manufacturing, aerospace, engineering, medicine, finance and banking, telecommunications, IT & software, marketing and sales, optimization, control, and troubleshooting, etc. Deep Learning (DL) has renewed interest in ML, an interdisciplinary field. From the autonomous car to *facial* and gesture *recognition* to personalized medicine; from recommender systems to targeted advertising to cyber-threat detecting systems; from self-learning robots to natural language processing to bioinformatics, applications are everywhere.

We also explore the future directions and potential long-term economic and social effects. DL and big data are key drivers for the future growth of the global economy. The third artificial intelligence wave leads the fourth industrial revolution. Are you ready for the newest revolution?

8. References

Accenture. (2017). Future of Artificial Intelligence Economic Growth. https://www.accenture.com/us-en/insight-artificial-intelligence-future-growth

Alfaro, C., Cano-montero, J., Gómez, J., Moguerza, J., Ortega, F. (2016). A multi-stage method for content classification and opinion mining on weblog comments. Annals of Operations Research, 236(1), 197-213.

Anifowose, F. A., Labadin, J., Abdulraheem, A. (2016). Hybrid intelligent systems in petroleum reservoir characterization and modeling: the journey so far and the challenges ahead. Journal of Petroleum Exploration and Production Technology, 7(1), 251-263.

Bone, D., Goodwin, M. S., Black, M. P., Lee, C., Audhkhasi, K. (2015). Applying machine learning to facilitate autism diagnostics: Pitfalls and Promises. Journal of Autism and Developmental .Disorders, 45(5), 1121-1136.

Braun, A., Zweck, A., Holtmannspötter, D. (2016). The ambiguity of intelligent algorithms: job killer or supporting assistant. European Journal of Futures Research. 4(1), 1-8.

Chitra, A., & Rajkumar, A. (2016) Plagiarism detection using machine learning-based paraphrase recognizer. Journal of Intelligent Systems, 25(3), 351-359.

Crippa, A., Salvatore, C., Perego, P., Forti, S., Nobile, M. (2015). Use of machine learning to identify children with autism and their motor abnormalities. Journal of Autism and Developmental Disorders, 45(7), 2146-2156.

Crown, W. H. (2016). Specification issues in a big data context: Controlling for the endogeneity of consumer and provider behaviours in healthcare treatment effects models. PharmacoEconomics, 34(2) , 95-100.

Dattaram, B. A., & Madhusudanan, N. (2016). Delay prediction of aircrafts based on health monitoring data. International Journal of Business Analytics and Intelligence, 4(1), 29-37.

Davenport, T. H., & Kirby, J. (2016). Just how smart are smart machines? MIT Sloan Management Review, 57(3), 21-25.

Demertzis, K., & Iliadis, L. (2016). Journal of Applied Mathematics and Bioinformatics. 6(3), 45-64.

Ding, S., Zhao, H., Zhang, Y., Xu, X., Nie, R. (2015). Extreme learning machine: Algorithm, theory and applications. The Artificial Intelligence Review, 44(1), 103-115.

Fatehi, I., Amiri, B. J., Alizadeh, A., Adamowski, J. (2015). Modeling the relationship between catchment attributes and in-stream water quality. Water Resources Management, 29(14) , 5055-5072.

Jiang, S., Cai, S., Olle, G., Qin, Z. (2015). Durable product review mining for customer segmentation. Kybernetes, 44(1), 138-124.

Kalkat, M. (2015). Investigations on the effect of oil quality on gearboxes using neural network predictors. Industrial Lubrication and Tribology, 67(2) , 99-109.

Lu, Y., & Zhang, L. (2015). Imputing trip purposes for long-distance travel. Transportation, 42(4), 581- 595.

Noda, K., Yamaguchi, Y., Nakadai, K., Okuno, H.G., Ogata, T. (2015). Audio-visual speech recognition using Deep Learning. Applied Intelligence, 42(4), 722-737.

Pastur-Romay, L. A., Cedrón, F., Pazos, A., Porto-Pazos, A. B. (2016). Deep artificial neural networks and neuromorphic chips for big data analysis: Pharmaceutical and bioinformatics applications. International Journal of Molecular Sciences, 17(8), 1313.

Patel, S. and Ramachandran, P. (2015). A comparison of machine learning techniques for modeling river flow time series: The case of upper Cauvery river basin. Water Resources Management, 29(2), 589-602.

Pouladzadeh, P., Shirmohammadi, S., Bakirov, A., Bulut, A., Yassine, A. (2015). Cloud-based SVM for food categorization. Multimedia Tools and Applications, 74(14), 5243-5260.

Ransbotham, S. (2015). Analytics in e major. MIT Sloan Management Review, 56(3), 0-0.

Silver, D. and Hassabis, D. (2016). AlphaGo: Mastering the ancient game of Go with Machine Learning. Posted by Google DeepMind.

Somyürek, S. (2015). The new trends in adaptive educational hypermedia systems. International Review of Research in Open and Distance Learning, 16.1.

Surden, H. (2014). Machine learning and law. Washington Law Review, 89(1), 87-115.

Tao, Y., & Zhang, W. (2016). Establishment of cross-border e-commerce credit evaluation system based on big data. Management & Engineering, 24, 3-15.

Thilmany, J. (2016). More ways machines see. Mechanical Engineering, 138(4), 22-23.

Vardarlier, P., & Silahtaroglu, G. (2016). Gossip management at universities using big data warehouse model integrated with a decision support system. International Journal of Research in Business and Social Science, 5(1), 1-14.

Wang, M.S., Jeong, N.T., Kim, K.S., Choi, S.B., Yang, S.M. (2016). Drowsy behavior detection based on driving information. International Journal of Automotive Technology, 17(1), 165-173.

Warner, G., Wijesinghe, S., Marques, U., Badar, O., Rosen, J. (2015). Modeling tax evasion with Genetic Algorithms. Economics of Governance, 16(2), 165-178.

Weiss, S. M., Kulikowski, C. A., Galen, R. S., Olsen, P. A., Natarajan, R. (2015). Managing healthcare costs by peer-group modeling. Applied Intelligence, 43(4), 752-759.

Zhang, B.T. (2016). Humans and machines in the evolution of AI in Korea. AI Magazine, 37(2), 108-112.

Presence Level of Low Cost Controllers for Mobile Based Virtual Reality Headsets

Summer Lindsey[1]
Deborah Carstens[1], Meredith Carroll[1]
[1]*Florida Institute of Technology, College of Aeronautics*
Slindsey2013@my.fit.edu; carstens@fit.edu; mcarroll@fit.edu

Abstract

Mobile based virtual reality (VR) is a recent technology resulting in a gap in the literature with regards to research of its limited controller options and their effectiveness. Past research has been performed on high-end controllers and high performance headsets. Therefore, the aim of this study was to identify how involved and how much in control participants feel they have when operating different controllers in a VR environment. The methodology for the study consisted of participants utilizing different controllers in performing the same task to detect the level of presence. The types of controllers tested in this study consisted of the Steel Series XL Stratus Gaming Controller, the touchpad on the Samsung Gear VR headset, and the Leap Motion. The results discuss recommendations for VR companies to incorporate in future VR headsets to have their users achieve a greater level of presence when utilizing controllers. Future research areas are also discussed.

1. Introduction

Virtual reality (VR) has been a viable technology in research, military, and medical fields for training and evaluation. The cost of implementing a VR set-up used to be expensive. However, with the development of mobile-based headsets, smartphones can be used as the rotational position tracker, display and audio device. One can build a mobile-based VR headset out of cardboard. The development of this newly accessible VR has led it to develop into a consumer-based market. In 2016, Samsung sold over $2.3 million dollars of the Samsung Gear VR headset and the consumer VR industry is expected to continue to grow (SuperData Research, 2016)

One of the driving reasons for a top selling technology brand is its user experience (Kraft, 2012). As new VR headset versions are being released every year, it is important that companies make intuitive interfaces and easy to use controls. In spite of this need, most VR headsets do not come with controllers and a universal way to interact in VR has yet to be established (Perry, 2015). One way that we can increase the user experience in VR is by ensuring an immersive environment. By doing so, this can improve the feeling of authenticity of a VR experience. This paper evaluated controllers that were readily available to consumers on the market today that were compatible with the Samsung Gear VR to determine factors of controllers that affect or increase presence feelings in VR.

2. Literature Review

2.1. Virtual Reality Experience

VR aims to mimic the real world as closely as possible. Sutcliffe and Gault (2004) developed a set of heuristics that can be applied to virtual environments (VEs) which was based on the issues that tend to arise with VR. VEs simulate real-world environments in the same way that the user interacts with it. When users are interacting within the VE, it should match their expectation of what an object should do and how it should respond. Therefore, responses in a VE should closely match the user's inputs – and those inputs should be as instantaneous as possible without lag. These heuristics can be used to measure how well the VE results in the user interaction feeling seamless and a part of the environment. Sutcliffe and Gault (2004) also suggests that controls will mirror as closely as real-life interaction. This will result in users' feeling of presence in the VE, which is an important construct since it has been shown to improve the user experience and level of realism in the environment (Shafer, Carbonara, and Popova, 2011). The presence level is contingent on the task such as virtual hands being ideal for any environment in which the user is manipulating objects (Sutcliffe, and Gault, 2004). These heuristics discussed set the framework for the interaction aspect of VR which is discussed in the next section.

2.2. Presence and Interaction

Presence can be defined as the feeling of being within an environment contrary to where your physical body lies (Biocca, 1997). Traditionally, research focuses on the influence of graphics and refresh rate in VR on the feelings of presence. However, the level of involvement in a VE can also greatly influence a user's feeling a presence. If a user is actively engaging within an environment, they may feel a higher sense of presence compared to a VR viewing experience (Welch, Blackmon, Liu, Mellers, and Stark, 1996). The main way users interact with a VE is by utilizing a controller. Controllers in general should be intuitive and easy to use, while requiring little to no training or reference manuals (Sanchez, 2011). Many studies show the benefit of using a controller that is naturally mapped (or using interaction methods that match the real-life task). For example, using a steering wheel for a racing game is more enjoyable and results in higher senses of presence compared to using a standard gaming controller (Williams, 2014). Yet, if a user is accustomed to an existing controller such as a gamepad, they will choose to use the gamepad (Gerling, Klauser, and Niesenhaus, 2011). This means that users may not choose a controller that elicits a higher sense of presence and is more enjoyable if they find another controller easier to use. As users, may not prefer using a controller that they find difficult or demanding to use – which can also cause decrements to presence (Johnson, and Wiles, 2010). Due to the varying factors that can influence presence levels, this warrants a formal evaluation of the available controllers for mobile based VR headsets. This study aims to isolate presence for controllers in order to draw recommendations for mobile-based VR headset controllers.

3. Methods

This study aimed to evaluate the presence level of consumer controllers for mobile VR. Due to this fact, controllers which were currently available to consumers at the time of this study were utilized. The SteelSeries Stratus XL Bluetooth gaming controller, the Leap Motion, and the Samsung Gear VR touchpad were evaluated. Both the Leap Motion and SteelSeries conditions utilized *Vridge* – a program that allows PC-based VR games to be streamed to a phone over Wi-Fi. This was used as the Leap Motion was not supported directly with a mobile-based VR headset. However, a compatible faceplate developed by Leap Motion was currently under development at the time of this study – warranting its evaluation to develop recommendations before its release to consumers. A total of 23 participants from a southeastern university ranging from 18 to 34 years old were recruited and consisted of 17 males and six females. Each participant was exposed to all three controllers in varying orders. Participants were given a matching task where an object would spawn with a shape, color, and pattern (e.g. a red sphere with dots) and utilized a set of menus in order to match what was seen on the screen.

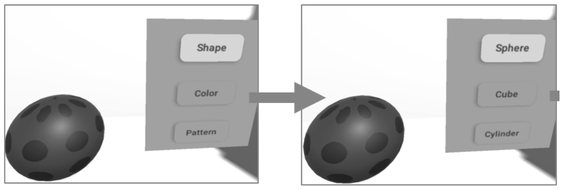

Figure 1. Menu Task

For the SteelSeries controller, participants used the left joystick to navigate and the "A" button to make selections. The Leap Motion tracked the participant's hands and rendered wireframe hands in the VE, so participants would simply reach in front of them to select button options. For the touchpad condition, participants used a pink circle locked at the center of the screen and would position their head to highlight an option and tap anywhere in the touchpad on the side of the headset to select an option.

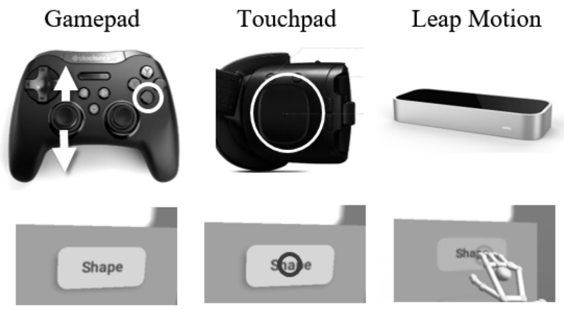

Figure 2. Controller Selections

Once all three features (shape, color, and pattern) were selected, a continue button would appear. Once pressed, this was counted as one trial. Participants were given 10 trials. After each condition, participants were given a subset of Witmer, Jerome, and Singer's (2005) involvement/control questions from their presence questionnaire (Witmer, Jerome, and Singer, 2005). as well as a comment box to note anything about their experience. The scores from this questionnaire aim to answer the research question: Does controller type have an influence on presence level? We hypothesized that there would be a significant difference between controllers for presence level.

4. Results

Participants were given five presence questions on a Likert based 7-point scale. The highest presence score a controller could receive was a total of 35 points.

Table 1. Presence Scores

	M	*SD*
Leap Motion	26.57	5.45
Gamepad	30.13	3.74
Touchpad	31.96	2.61

A univariate analysis in SPSS (Version 20.0.0) showed a significant effect for presence ($F(1.593, 35.045) = 16.184$, $p < .001$). A post hoc analysis with Tukey's HSD found significant differences. Leap Motion was found to have significantly lower presence scores than gamepad ($p = .004$ and touchpad ($p < .001$). Additionally, gamepad was found to have a significantly lower score than touchpad ($p = .013$). Based on these findings we rejected the null hypotheses.

5. Discussion

The findings in this study show the effects of a difficult controller. Many users found it difficult to make selections within the VE with the Leap Motion controller due to reach issues. In order to reach the buttons, participants often needed a full arm extension. Once users reached fully forward, the hand became level with the Leap Motion tracker. This made it difficult for the Leap Motion to determine the position of the fingertips and it would often render them as curved. Considering that the fingertips were the trigger for a button press to register, this required users to attempt to press multiple times to select. Additionally, because the task had to be streamed over Wi-Fi, many users experience virtual "drift" which caused them to have to rotate their chair up to 90 degrees over the course of the task. In the comments, eight participants listed they had selection issues, and seven participants found it difficult to use. Past research shows that controllers that can be cognitively demanding often result in a decrease in presence (Johnson, and Wiles, 2010). We believe because of these issues, the Leap Motion received the lowest presence scores even though it was a naturally mapped controller. Participants noted that the touchpad "feels immersive without feeling slow". This controller actively engages the user in the VE compared to the gamepad which was noted as "a lot less immersive than the touchpad", but did not exhibit selection issues like the Leap Motion. This is reflected with the touchpad receiving the highest presence scores of all three controllers. Regardless of the touchpad's presence level, a lot of users noted that the gamepad felt more familiar and that they preferred it over the other two selection methods.

6. Conclusions and Future Research

This study evaluated the presence level of controllers for mobile-based VR. Participants completed a matching task using three different controllers and answered a questionnaire about the level of presence in regard to involvement and control felt during the task. A large decrement in the presence levels for the Leap Motion was seen due to performance issues. As Leap Motion was in development of its mobile-based integrated faceplate at the time of this study, it is suggested that Leap Motion consider these findings and ensure the following improvements: a more intuitive occluded hand rendering from the Leap Motion and an ability to adjust Leap Motion button depth. This leads into a possible future research area for the Leap Motion. Different menu styles (such as a self-positioned menu instead of a world-positioned menu) should be evaluated with the Leap Motion to determine the optimum style for performance, involvement, and user experience. For the touchpad, it is suggested that a hands-free gaze cursor be evaluated as some users noted it made them overly aware of wearing the headset by tapping on the side. For the gamepad, it is suggested that VR headset companies continue to add support functionally for the traditional gamepad as many users noted a preference for this controller as they had a pre-existing history with the controller.

This study experienced limitations in participants as well as performance issues. If participants did not have reach issues within the VE, the Leap Motion may have received higher presence scores. However, virtual drift and the finger curling of the Leap Motion are limitations of the current technology and should be improved in future iterations. This study should also be administered with other demographics to ensure the generalizability of these findings. This study sets a framework for the influences and user desires of controllers for VR experiences. Researchers should continue to evaluate controllers in other tasks, and in comparison to other technology to refine and improve the consumers' experiences with entertainment VR.

7. References

Biocca, F. (1997). The cyborg's dilemma: Embodiment in virtual environments. *IEEE.*

Gerling, K., Klauser, M. & Niesenhaus, J. (2011). Measuring the impact of game controllers on player experience in FPS games. *MindTrek'11 Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments*. 83-86. DOI: 10.1145/2181037.2181052

Johnson, D. & Wiles, J. (2010). Effective affective user interface design in games. *Ergonomics*, 46(13-14). 1332-1345. DOI: 10.1080/00140130310001610865

Kraft, C. (2012). User experience innovation. New York: Springer-Verlag.

N.a. (2016). 2016 year in review. SuperData Research.

Perry, T. (2015). Virtual reality goes social. *IEEE Spectrum, 53*(1). 56-57. DOI: 10.1109/MSPEC.2016.7367470

Sanchez, J. (2011). Playability: analyzing user experience in video games. *Behaviour & Information Technology, 31*. 1033-1054.

Shafer, D., Carbonara, C., & Popova, L. (2011). Spatial Presence and perceived reality as predictors of motion-based video game enjoyment. *Presence* 20(6). 591-619.

Sutcliffe, A. & Gault, B. (2004). Heuristic evaluation of virtual reality applications. *Interacting with Computers*, 16(4). 831-849. DOI: 10.1016/j.intcom.2004.05.001

Welch, R., Blackmon, T., Liu, A., Mellers, B. & Stark, L. (1996). The effects of pictorial realism, delay of visual feedback, and observer interactivity on the subjective sense of presence. *Presence, 5*(3). 263-273.

Williams, K. (2014). The effects of dissociation, game controllers, and 3D versus 2D presence and enjoyment. *Computers in Human Behavior, 38.* 142-150.

Witmer, B., Jerome, C., & Singer, M. (2005). The factor structure of the presence questionnaire. *Presence*, 14(3). 298-312. DOI: 10.1162/105474605323384654

Non-economic Dimensions of Innovation Adoption in Interactive Communication Networks: International Comparisons

Karol I. Pelc[1]

[1]*Michigan Technological University, School of Business and Economics*

kipelc@mtu.edu

Abstract

A multi-dimensional model of innovation adoption process in interactive communication networks is proposed. In addition to the economic dimension, analyzed in earlier publications (Pelc, 2014, and 2015), the author presents social, technological and cultural dimensions of the innovation adoption process. Three hypotheses are formulated concerning the influence of non-economic factors on the adoption process. Those hypotheses are used as a framework for the literature review and comparative analysis of data on the innovation adoption in interactive communication networks in different countries. For illustrative purposes, the Facebook adoption is used as representative of such networks with specific statistical data on the adoption process in selected countries of Europe and in the U. S., the social dimension is represented by percentage of the millennials' population as the most active in interactive networking. The technological dimension is represented by two measures: (1) Access to broadband transmission and (2) Number of smartphone users. A set of measures representing the cultural dimension is based on the Hofstede's model of national culture. The following quantitative measures of culture have been selected for comparative analysis: power distance, individualism index, uncertainty avoidance index and indulgence index. Correlation between the Facebook penetration in different countries and selected measures is discussed. The cultural dimension and the individualism index appear to have a stronger influence on innovation adoption than any other non-economic factor.

1. Introduction

Adoption of innovation constitutes the final phase of the diffusion process, in which innovation transforms resources in a new way and generates economic outcomes (Schumpeter, 1975). It has been the subject of many publications due to its importance for the overall effectiveness of innovation (Rogers, 1962; Skiadas, 1985; Girifalco, 1991; Wildemuth, 1992). The majority of authors emphasized economic importance of innovation diffusion and analyzed economic conditions that determine rate of diffusion measured by number of adopters in proportion to total population. That proportion is frequently referred to as the penetration rate. In recent decades, penetration rate of the Internet, as a major innovation, has become a common reference point for studies of technological and economic development of societies. Commonly accepted opinion suggests that the rate of penetration of the Internet is correlated with economic status and wealth of society. In general, the rate of penetration is much higher in rich countries, that are economically developed, than in poor countries with limited investment capacity, inadequate infrastructure, poor education systems and delays in industrialization. Innovation adoption is not advancing with the same speed in all countries. Due to this disharmony, a digital divide emerged that creates additional barriers to economic and social progress. It has been presented by Rainie (2016). For example, it seems almost impossible to compare living conditions and chances for economic development in countries of extremely low Internet penetration rate e.g. Eritrea

(1%) or Central Africa Republic (4.1%) with those of the highest Internet penetration rate e.g. Iceland (98.2%) or Liechtenstein (95.2%), as presented by the Internet World Stats (2016). Similar disparities can be observed in penetration rates of interactive communication networks such as Facebook, WhatsApp, etc. Correlation exists between the level of GDP per capita and the innovation penetration rate in countries of extreme levels of both factors i.e. the highest GDP and highest innovation adoption rates as well as the lowest GDP and lowest innovation adoption rate.

A very different pattern has been identified in a study on interactive communication networks in Central Europe (Pelc, 2015) where the Facebook penetration level is at the level of approximately 41% in most of the countries (see Table 1). Exceptions are Germany (35.7%), Hungary (51.5%) and Poland (36.8%). At the same time, the level of GDP per capita differs quite clearly among countries in this group ranging from $26,000 (Hungary) to $59,300 (Switzerland). Results of that case study of Central Europe showed that there is no correlation between GDP per capita and levels of penetration of interactive networking (represented by Facebook) in countries of medium innovation penetration rate. The most puzzling is comparison between Germany and Hungary. It suggests that the highest penetration of Facebook (in Hungary) coincides with the lowest GDP per capita of the group, when the lowest penetration of Facebook (in Germany) coincides with an almost highest GDP per capita. That irregularity stimulated interest of this author in exploring non-economic factors influencing the innovation adoption. Potentially, those factors might be the source of irregularity. Preliminary results of that exploration combined with a multidimensional model of adoption process are presented in this paper.

2. Multidimensional model and hypotheses on non-economic dimensions

As the economic dimension of the innovation adoption process appeared to be insufficient to explain that process adequately, four additional dimensions had to be considered: social, technological, cultural, and historical. They are presented in Fig. 1. Each dimension may be characterized by certain measurable parameters that shape the adoption process and influence its dynamics. As mentioned earlier, the economic dimension is most frequently reflected by the GDP per capita but it may also involve comparative analysis of household income, productivity, investment rates etc. The social dimension can be based on such parameters as population age distribution (age groups), gender, race etc. The technological dimension should be focused on parameters directly influencing or being potentially influenced by a given type of innovation. In the case of interactive communication networks, those parameters will certainly include properties, quality and status of computing and communication hardware and software, as well as availability of telecommunication infrastructure. The cultural dimension may reflect national culture and tradition as motivators of adoption decisions, innovativeness of social groups and individuals. Culture may also affect the level of expectations and extent of tolerance related to privacy protection. The historical dimension may be based on assessment of technology evolution and dynamics of innovation in the past (experiences of innovation adoption: successes and failures). From among these five dimensions we selected only three non-economic dimensions for the current case study on innovation adoption in Central Europe (and comparative data for the U.S.) i.e. social, technological and cultural.

In order to explore the impact of different non-economic dimensions on the adoption process in countries selected for the case study the following three working hypotheses have been formulated:

1) Social dimension hypothesis: Age distribution of potential users' population is correlated with penetration of innovation (adoption rate) i.e. the younger is the population, the higher penetration rate of interactive communication networking;
2) Technological dimension hypothesis: Accessibility of advanced technological infrastructure and hardware such as broadband Internet and smartphones is correlated with penetration of interactive communication networking;

3) Cultural dimension hypothesis: National culture has an impact on the innovation adoption and penetration rate of interactive communication networking. Preliminary assessment of support for the first two hypotheses is possible based on the data presented in Table 1.

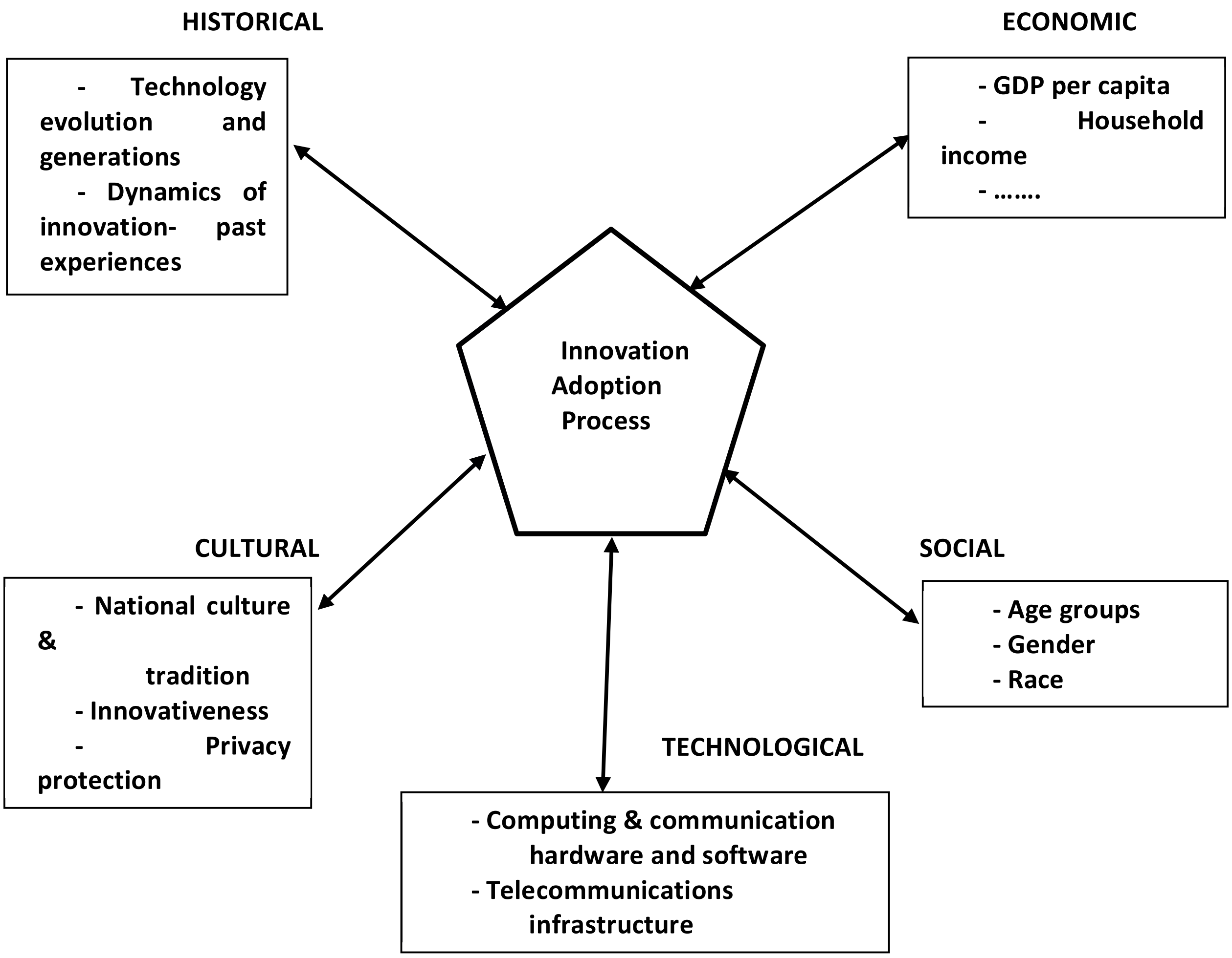

Figure 1. Dimensions of innovation adoption process

The social dimension has been analyzed by comparing demographic data on the population of millennials in the age group between 15 and 24 as a percentage of total population in respective countries of Central Europe. The outcome suggests that those populations do not differ substantially among countries of the region (majority is in the range between 10.2% and 11.3% except for Czech Republic and Slovenia being below 10%). At the same time, the Facebook penetration rates are clearly different in respective countries. Hence, they are not caused by (or correlated with) the social dimension. It is an indication that the hypothesis (1) concerning the impact of social dimension on penetration of innovation in the selected group of countries cannot be supported.

Table 1. Facebook adoption in Central Europe and the U. S.: Economic, social and technological dimensions.

Data sources: CIA (2015), Facebook (2015), Pewinternet (2017) and International Telecommunications Union 2000-2014 website*, Google Mobile Planet project 2013** (via Wikipedia)

Country	Facebook penetration rate % (2015)	Economic dimension GDP/capita PPP $ (2015)	Social dimension Millennials population age group 15 – 24 % of total population (2015)	Technological dimension A Broadband mobile Internet access % of total population (2014) *	Technological dimension B Smartphone population penetration % of total population (2013) **
Austria	40.8	47,500	11.33	55.5	48.0
Czech Republic	42.7	31,500	9.89	44.0	41.6
Germany	35.7	47,400	10.22	41.0	39.8
Hungary	51.5	26,000	11.19	23.1	34.4
Poland	36.8	26,400	11.11	49.3	35.0
Slovakia	42.4	29,500	11.32	34.9	45.9
Slovenia	41.2	30,900	9.58	37.1	n.a.
Switzerland	42.5	59,300	11.11	41.4	54.0
REFERENCE DATA					
United States	59.7	56,300	13.46	74.7	56.4

The technological dimension has been analyzed by comparing data on two technological systems i.e. broadband mobile Internet access (see column of technological dimension marked A in Table 1) and smartphone penetration (see column marked B). These data are not consistent across the countries of interest but a more detailed insight in comparison between Hungary and Germany (regarding Facebook penetration and both technological systems availability) suggests that in both technologies Germany presents higher levels of access than Hungary. Hence, it might be expected that Facebook penetration should be higher in Germany than in Hungary. However, data on this penetration indicate to the contrary. It means the technological dimension, represented by selected two parameters, does not support hypothesis (2).

3. Cultural dimension of innovation adoption process

The cultural dimension appears to be more difficult to define and represent by measurable parameters due to the complexity of national culture. Some authors tried to apply sociological research tools and techniques such as surveys and questionnaires to overcome this difficulty. Herbig and Palumbo (1994) explored the impact of national culture on innovation adoption in Japan and the U. S. They emphasized differences between traditional norms of behavior in those two countries. Desmarchelier and Fang (2016) analyzed cultural aspects of the innovation diffusion process through simulation of selected dimensions of national culture. The most comprehensive analysis and quantification of parameters of national culture has been developed by Hofstede (2001) and his coauthors (2010). In the most recent book of those authors (Hofstede et al.,2010) a collection of data is presented for 76 countries with reference to basic dimensions of national culture. For purposes of this paper, we selected four essential parameters/indices with potential impact on adoption rate of interactive communication networking. Those are following: power distance, individualism, uncertainty avoidance, and indulgence vs restraint index. Corresponding data have been extracted from that book for the group of countries in Central Europe and the U. S. Those data are presented in Table 2.

Table 2. Hofstede's dimensions of national culture for Central Europe and the U.S.

Data extracted from: Hofstede, G. et al. (2010). Information derived from the IBM Data Base of international surveys in 76 countries.

Country	**Power Distance Index PDI**	**Individualism Index IND**	**Uncertainty Avoidance Index UAI**	**Indulgence vs Restraint Index IVR**
Austria	11	55	70	63
Czech Republic	57	58	74	29
Germany	35	67	65	40
Hungary	46	80	82	31
Poland	68	60	93	29
Slovakia	100	52	51	28
Slovenia	71	57	88	48
Switzerland	26 G 70 F	69 G 64 F	56 G 70 F	66
Reference Data				
United States	40	91	46	68

From among the Hofstede's dimensions of national culture shown in Table 2, the individualism index seems to be the most interesting and essential for analysis of the impact of cultural dimension on the innovation adoption process. It can be illustrated by the case of irregularity in penetration rates of Germany and Hungary discovered earlier (see section 2 of this paper). The individualism index is much higher for Hungary (value of 80 points on scale of 100) than for any other country of the group under consideration. It is also closest to the value for the U.S. (91 points). Even though it is not fully documented, the individualism index seems to correlate positively with the penetration rates of Facebook in those countries. It also indicates unique strength of individualism of adopters in Hungary, much higher than that of Germany (67 points). This observation suggests that the hypothesis (3) concerning the cultural dimension can be supported by data on individualism index. It should be emphasized here that the small sample size and the limited range of accessible data do not qualify for statistical analysis and full verification of the hypothesis (e.g. by Chi-square analysis). It is just a preliminary indication of support for the hypothesis. It should be the subject of further research involving a broader set of data. This result is more clearly shown in Table 3. It is also in accordance with arguments of Herbig and Palumbo (1994) who suggested that attitudes related to adoption of innovation in Japan and the U. S. are driven largely by cultural components of collectivism (Japan) and individualism (U. S.).

Table 3. Facebook penetration vs individualism index: Case of Germany, Hungary, and the U. S. (2015)
Data sources: CIA (2016), Facebook (2015)

Country	GDP/capita PPP $	Internet penetration rate %	Facebook penetration rate %	Individualism index
Germany	47,400	88.4	35.7	67
Hungary	26,000	76.1	51.5	80
United States	56,300	87.9	59.7	91

4. Final remarks and conclusions

The multidimensional model of the innovation adoption process proposed in this paper facilitates the review of different aspects of innovation. It extends beyond economic effects or constraints affecting that process. An illustrative case of such review has been presented in the form of three hypotheses concerning the impact of three different non-economic dimensions on the innovation adoption process. Partial assessment of those hypotheses (as an illustration for the model) is based on data representing respective dimensions of innovation adoption in the selected group of countries (Central Europe and the U. S.). Hypothesis (1) concerning age distribution of population as a factor influencing adoption has not been supported. Hypothesis (2) concerning importance of access to technologies as a factor influencing adoption of innovation has not been consistently supported. Finally, hypothesis (3) suggesting strong impact of national culture on adoption of innovation has been partly supported by Hofstede's dimensions' data for selected countries. Those data indicate that the level of individualism of each nation may decide about its capacity for adoption of innovation. Hence, that hypothesis (3) has been partly supported, and deserves further analysis. It is important to mention that presented case data do not allow for general and definite verification of hypotheses. However, the collected data provide a pattern of possible impacts of all dimensions included in the model. Further research is needed to fully verify the proposed model and to fully verify respective hypotheses. Selection of model dimensions should be combined with a systematic assessment of validity for different parameters as representatives of respective dimensions of the model. For illustration purposes, the current paper is based on selection of only one or two parameters for each dimension. The scope of the data should also be broadened to constitute a methodologically appropriate basis of analysis. In particular, number and diversity of countries included in the review should be larger than just one geographic region of Europe.

A general conclusion of this review and case study indicate that the proposed model can be useful for exploration of forces shaping the innovation adoption process in a much broader context than just one economic dimension. Even though this paper is focused on interactive communication networks, it may be viewed as a contribution to the methodology of research on larger classes of technological innovations.

5. Acknowledgement

An earlier version of this paper was presented at the 23rd Annual International Conference on Industry, Engineering, and Management Systems (IEMS), March 20 -22, 2017 in Cocoa Beach, FL. The author addresses thanks to participants of session "Management of Technology" for their remarks.

6. References

CIA (2015). *The World Factbook: Country Comparison: GDP per capita*, https://www.cia.gov/library/publications/resources/the-world-factbook/rankorder/2004rank.htm Retrieved 04/04/2016

CIA (2016). *The World Factbook*, https://www.cia.gov/library/publications/resources/the-world-factbook/geos/rp.html . Retrieved 03/03/2017

Desmarchelier, B., Fang, E.S. (2016). National culture and innovation diffusion. Exploratory insights from agent-based modeling. *Technological Forecasting and Social Change*, 105, 121-128.

Facebook (2015). Potential reach estimates. https://www.facebook.com/ads/create/. Retrieved 02/28/2016

Girifalco, L. A. (1991). *Dynamics of Technological Change*. Van Nostrand Reinhold, New York

Herbig, P.A., Palumbo, F. (1994). The effect of culture on the adoption process: A comparison of Japanese and American behavior. *Technological Forecasting and Social Change*, 46,71-101

Hofstede, G. (2001). *Culture's Consequences: Comparing Values, Behaviors, Institutions, and Organizations Across Nations*, (2nd edition), Sage Publications, Thousand Oaks, CA

Hofstede, G., Hofstede, G. J., Minkov, M. (2010). *Cultures and Organizations: Software of the Mind*, 3rd edition, McGraw Hill, New York

Internet World Stats (2016). Usage and Population Statistics. http://www.internetworldstats.com/stats4.htm#europe . Retrieved 02/23/2017

Pelc, K. I. (2014). Adoption process and complexity of innovation in social networking. *The Journal of Management and Engineering Integration,* 7, 1, 92-99

Pelc, K. I. (2015). Adoption of innovation in interactive communication networks of Central Europe. T*ransformations,* 3-4 (86-87) ,78 – 90

Pewinternet (2017). Who owns cellphones and smartphones, http://www.pewinternet.org/chart/who-owns-cellphones-and-smartphones/. Retrieved 02/23/2017

Rainie, L. (2016). Digital divides 2016, Pew Research Center. http://www.pewinternet.org/2016/07/14/digital-divides-2016/ . Retrieved 01/28/2017

Rogers, E. M. (1962). *Diffusion of Innovations*, Fifth edition, Free Press, New York (1962, 1983, 2003).

Schumpeter, J. A. (1975). *Capitalism, Socialism and Democracy*, Harper & Row Publishers, New York (First 1942).

Skiadas, C. (1985). Two generalized rational models for forecasting innovation diffusion. *Technological Forecasting and Social Change*, 27, 1, 39-61

Wildemuth, B. M. (1992). An empirically grounded model of the adoption of intellectual technologies, *Journal of the American Society for Information Science* (1986 -1998), 43, 3, 210 – 224

Optimum Tour Route Formulation Incorporating Satisfaction with Attractions at a Theme Park

Yutaka Shirai[1]
Hiroyuki Ono[1]
[1]*Chiba Institute of Technology, Japan*
yutaka.shirai@it-chiba.ac.jp

Abstract

Theme park guests usually visit attractions, giving due consideration to their satisfaction with and waiting time at those attractions. A tour route of highest satisfaction can be realized if all the attractions are visited. However, it is usually impossible to visit all of them during operation hours practically. In addition, as the number of attractions increases, the number of candidate tour routes increases rapidly, making it more difficult to find the optimal tour route using a simple procedure. This study proposes an approach to determine an efficient tour route using the following procedures. First, satisfaction with each attraction in a theme park is investigated using a questionnaire survey. Next, a combination of attractions of high satisfaction that can be visited during operation hours is determined considering the time necessary for each attraction (duration + average queuing time + expected average travel time) by application of the Knapsack Problem based on the satisfaction investigated. Then an efficient tour route is determined by treatment as a Traveling Salesman Problem using the selected attractions with the Knapsack Problem. Furthermore, the effectiveness of this proposed method is verified by numerical experimentation according to gender, operation hours, and weather.

1. Introduction

A person visiting a theme park often determines which attractions to ride in advance. High satisfaction is obtainable by selecting popular attractions at which many people gather, whereas attractions should be chosen so that a tour is completed within the theme park operation hours. The waiting time at attractions should also be regarded along with traveling time between and duration of attractions. Accordingly, a tour might not be able to include many popular attractions requiring long waiting time (with high guest satisfaction). In addition, an unplanned tour might require more time than anticipated and prevent its completion.

Planning a tour route for visiting attractions requires not only optimization of the tour distance simply but to optimize the tour route with "satisfaction with attractions" and "time required (duration + average queuing time + expected average travel time) of each attraction" examined.

Satisfaction with attractions might vary for male and female guests in the cases of a tour in large-scale facilities such as theme parks, so that a tour route might be different for male and female guests. A tour route might also be changed according to holidays, weekdays, or weather.

This study was conducted to ascertain a combination of attractions at a theme park with high satisfaction that can be visited during operation hours, and to propose a method of ascertaining an efficient tour route for the combination. We adopt the proposed method in view of the Knapsack

Problem (Kellerer, Pferschy, & Pisinger, 2010; Kolesar, 1967; Martello, Pisinger, & Toth, 1999; Martello & Toth, 1990) to narrow down attractions that can be visited during operating hours. Additionally, to seek a route that includes the narrowed-down attractions that can be visited efficiently is a Traveling Salesman Problem (Fischer & Merz, 2005; Lawler, Lenstra, Rinnooy Kan, & Shmoys, 1985; Lin & Kernighan, 1973), one solution to which is the Ant System (Dorigo & Stutzle, 2004; Wang, Zhou, Zhao, & Xia, 2012).

Finally, we verify the effectiveness of the proposed method by comparing tour routes according to gender (male, female, and overall), operation hours, and weather by numerical experiment. The method proposed herein, applying Knapsack Problem and Traveling Salesman Problem, has significance because previous studies particularly addressing Knapsack Problem and Traveling Salesman Problem (Fischer & Merz, 2005; Kolesar, 1967; Lin & Kernighan, 1973; Martello, Pisinger, & Toth, 1999) do not address determination of a tour route considering satisfaction with attractions.

2. Problem Setting

2.1. Outline of Theme Parks

This study examines a theme park in Japan that has 39 attractions in all and which is operated according to the following four patterns of operating hours:

- Weekday: 8:00 a.m. – 10:00 p.m. (840 min)
- Holiday: 8:00 a.m. – 10:00 p.m. (840 min)
- After 6 hours: 6:00 p.m. – 10:00 p.m. (240 min) [Weekdays only]
- Starlight hours: 3:00 p.m. – 10:00 p.m. (420 min) [Holidays only]

2.2. Satisfaction with Attraction

Satisfaction means customer satisfaction, a concept indicating whether the performance of a product or service satisfies the level of customer expectation, and represents the degree of popularity of an attraction in this study. An attraction with higher satisfaction is more popular, whereas lower satisfaction is inferred for less popular attractions. A questionnaire survey on satisfaction was administered to 105 participants (65 male, 40 female) with check boxes for attractions they wish to visit. The total number of boxes checked for an attraction (totaled result) was defined as satisfaction with the attraction. Table 1 presents survey results of satisfaction for male, female, and all respondents.

2.3. Distance between Attractions

The distance between attractions was estimated by measuring the distance between the entrances of the particular attractions on brochures distributed by the theme park and Google Maps (Google Maps, 2016) using a curvimeter.

2.4. Time Required for Attraction

The time required was estimated by "duration + average-queuing-time + expected average travel time" for each attraction to select attractions with high satisfaction that can be visited during operating hours using the Knapsack Problem. Duration in minutes disclosed on the web site of the theme park (TDR, 2016) was used as the "duration of each attraction." Data of average queuing times for one year from November, 2015 through October, 2016 published on the web site (TDR, 2016) were used as the "average queuing time of each attraction." Data of average queuing times according to the weather of "clear" and "cloudy or rainy" were employed in addition to the average queuing times on weekdays and holidays. The "expected average travel time between attractions" was set to 3.99 min. Because the travel time on a tour route is unknown when selecting attractions, the expected average travel time between attractions was computed from the total distance between attractions (see Section 2.3) with walking speed set to 80 m/min according to the "Regulation for Enforcement of Fair Competition Code on Description of Real Property" of Japan (Real Property Regulation, 2016).

Table 2 presents the time required for each attraction (duration + average queuing time + expected average travel time) used for this study.

Table 1. Satisfaction with each attraction

Attraction Number	Satisfaction (Totaled Result)		
	All Respondents	Male Respondents	Female Respondents
1	12	2	10
2	32	19	13
3	2	1	1
4	22	18	4
5	1	1	0
6	55	36	19
7	3	1	2
8	5	3	2
9	1	1	0
10	7	5	2
11	2	2	0
12	10	2	8
13	3	0	3
14	39	21	18
15	16	8	8
16	0	0	0
17	11	10	1
18	34	22	12
19	8	4	4
20	68	45	23
21	67	46	21
22	9	3	6
23	4	2	2
24	5	3	2
25	8	4	4
26	2	2	0
27	35	23	12
28	65	49	16
29	9	6	3
30	11	5	6
31	21	12	9
32	48	20	28
33	3	3	0
34	37	24	13
35	9	4	5
36	11	0	11
37	4	2	2
38	27	18	9
39	6	3	3

Table 2. Time required for each attraction (min)
(duration + average queuing time + expected average travel time)

Attraction Number	Time Required on Weekdays (Clear)	Time Required on Weekdays (Cloudy or Rainy)	Time Required on Holidays (Clear)	Time Required on Holidays (Cloudy or Rainy)
1	15	13	19	17
2	23	22	25	24
3	16	15	25	23
4	30	28	34	31
5	13	10	17	14
6	29	26	33	32
7	25	25	25	25
8	20	14	26	20
9	14	12	17	15
10	27	20	33	25
11	20	17	25	22
12	26	24	30	30
13	26	26	31	33
14	37	29	48	42
15	21	20	21	21
16	12	12	12	12
17	19	25	42	33
18	33	27	49	44
19	49	45	65	63
20	95	78	115	104
21	71	62	88	86
22	36	24	42	34
23	14	14	14	14
24	14	14	14	14
25	12	12	12	12
26	14	14	14	14
27	60	50	80	68
28	68	50	91	74
29	25	20	32	24
30	20	18	24	23
31	43	39	50	48
32	66	54	85	77
33	9	9	9	9
34	53	46	70	66
35	33	32	37	37
36	23	20	27	25
37	19	19	19	24
38	72	63	97	96
39	28	25	36	33

3. Procedure Adopted in this Study

3.1. Procedure of Attraction Selection

The Knapsack Problem (Kellerer, Pferschy, & Pisinger, 2010; Kolesar, 1967; Martello, Pisinger, & Toth, 1999; Martello & Toth, 1990) fills a fixed-volume knapsack with items, in which, given the volume and value of each item and the capacity of a knapsack, some items are chosen from the set of given items so that the total value is maximized under the condition that the total volume of the selected items does not exceed the knapsack capacity. The Knapsack Problem is applicable to project selection, the purchase of commodities within a budget, personnel management based on employee's ability, and packing problems of loads to trucks and cargo vessels, etc.

Attractions are selected in this study by substituting the "time required (duration + average queuing time + expected average travel time) for each attraction" to the volume of each item, the "satisfaction with each attraction" to the value of each item, and the "operation hours of the theme park" to the knapsack capacity in the Knapsack Problem. The following equations used for this study as shown below.

$$\max.\ T = \sum_{i=1}^{m} c_i x_i \tag{1}$$

$$\text{Subject to } \sum_{i=1}^{m} a_i x_i \le b \tag{2}$$

$$x_i \in \{0,\ 1\} \tag{3}$$

Therein, T stands for total satisfaction, m signifies the total number of attractions, c_i represents satisfaction with Attraction i, x_i = 1; in cases where Attraction i is selected, = 0; in cases where Attraction i is not selected, a_i represents the time required for Attraction i; b denotes operating hours.

Equation (1) represents the maximizing total satisfaction T and Eq. (2) shows that the total time necessary for selected attractions does not exceed operation hours.

3.2. Search Procedure for Tour Routes

The Traveling Salesman Problem (Fischer & Merz, 2005; Lawler, Lenstra, Rinnooy Kan, & Shmoys, 1985; Lin & Kernighan, 1973) is to find a route with the shortest traveling distance when a salesman starts in a city, visits each city only once, and returns to the origin city. The TSP has been studied broadly as a fundamental index to compare different optimization techniques. Cities are replaced by attractions selected by the Knapsack Problem to ascertain a tour route. The following equations are used for this study.

$$\min.\ Z = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} y_{ij} \tag{4}$$

$$\text{Subject to } \sum_{j=1}^{n} y_{ij} = 1 \qquad \forall i \in N \tag{5}$$

$$\sum_{i=1}^{n} y_{ij} = 1 \qquad \forall j \in N \tag{6}$$

$$\sum_{i \in S} \sum_{j \in N \setminus S} y_{ij} \ge 1 \quad \forall S \subset N (S \ne \phi, \quad S \ne N) \tag{7}$$

$$y_{ij} \in \{0,\ 1\} \quad \forall i, \quad j \in N \tag{8}$$

In those equations, Z represents the total tour distance, n is the number of attractions selected by the Knapsack Problem, d_{ij} signifies the distance from Attraction i to j, y_{ij} = 1; when a route from Attraction i to j is taken, y_{ij} = 0; otherwise, N denotes the set of attraction numbers selected by the Knapsack Problem, and S stands for a subset of N (not an empty set, not equal to N).

Equation (4) represents minimization of the total tour distance, Eq. (5) suggests that only one route exists from Attraction i to other attractions, Eq. (6) shows that there is only one route to reach Attraction j, and Eq. (7) represents that a route is a tour route that visits all attractions selected by the Knapsack Problem only once, in which "＼" denotes subtraction of the set.

3.3. Ant System

The Ant Colony Optimization (Dorigo & Stutzle, 2004; Wang, Zhou, Zhao, & Xia, 2012) procedure simulates ant behavior, including the Ant System (Dorigo & Stutzle, 2004; Wang, Zhou, Zhao, & Xia, 2012), an Ant Colony Optimization with improved pheromone intensity developed for the Traveling

Salesman Problem. The pheromone is secreted from ants and is a substance that promotes certain actions to other ants.

Search is conducted by artificial ants in the Ant System by generating tour routes while making stops during wandering on a prey field. Paths connecting the respective stops are provided with respective pheromone intensity. Each artificial ant chooses a route with high pheromone intensity stochastically from the current stop to move to the following stop. A tour route is generated when all stops are visited. The pheromone intensity on each path is enhanced according to the total tour distance of the generated tour route, where the pheromone intensity that engenders a shorter tour route is enhanced; otherwise it is not so enhanced.

Because the generated tour routes are influenced by probability, and because many tour routes might serve as candidates, it is difficult to estimate the performance of the generated tour routes. For that reason, it is considered that pheromone intensity provided by a single artificial ant has great uncertainty. Nevertheless, pheromone intensity compiled in search for a plurality of tour routes by multiple artificial ants is likely to be used as a good information source in problem search. The algorithm of the ant system is constructed so that collective search is conducted through interaction between artificial ants while pheromone intensity built up by many artificial ants is used effectively. Figure 1 presents a conceptual diagram of search by artificial ants in the ant system. Because artificial ants switch to a shorter route as search progresses when artificial ants go to a prey field from a nest, the pheromone intensity of a shorter route is enhanced. Shorter routes tend to be selected easily, as shown in this figure. The Ant System algorithm is described below.

[Step 1] Let search number t = 1. Set the maximum search number, the upper limit and lower limit of pheromone intensity, and τ_{ij}, initial pheromone intensity between stops i and j.

[Step 2] Position each artificial ant at an initial stop.

[Step 3] Repeat the selection of a stop for each artificial ant using the following equation until a tour route is completed as

$$P_{ij}^{k}(t) = \begin{cases} \left([\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}\right) \Big/ \left(\sum_{i \in J_i^k} [\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta} \right) & \text{if} \quad j \in J_i^k \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

where P_{ij}^{k} signifies the probability that artificial ant k selects the route between stops i and j, J_i^k denotes the set of unvisited stops when artificial ant k is on stop i, η_{ij} represents the reciprocal of distance between stops i and j, and α and β respectively denote parameters to control the impact of pheromone intensity and distance.

[Step 4] Renew pheromone intensity between each stop based on the tour route and total tour distance of each artificial ant, and adjust the pheromone intensity based on the upper and lower limits of pheromone intensity as

$$\tau_{ij}(t+1) \leftarrow (1-\rho) \cdot \tau_{ij}(t) + \Delta\tau_{ij}(t) \tag{10}$$

$$\Delta\tau_{ij}(t) = \sum_{k=1}^{h} \begin{cases} 1 / L^{k}(t) & \text{if } (i,j) \in T^{k}(t) \\ 0 & \text{otherwise} \end{cases} \tag{11}$$

where ρ is the evaporation coefficient of pheromone decreasing with time, $\Delta\tau_{ij}$ stands for the increase in pheromone intensity from stop i to j, h is the number of artificial ants, and

T_k and L_k respectively represent the tour route and the total tour distance of artificial ant k.

[Step 5] If search number t has not reached the maximum search number, then let $t = t+1$ and return to [Step 2].

[Step 6] Output the best tour route out of the tour routes obtained, and quit.

In this study, a stop is replaced by an attraction selected in the Knapsack Problem, and a tour route is determined by using the Ant System.

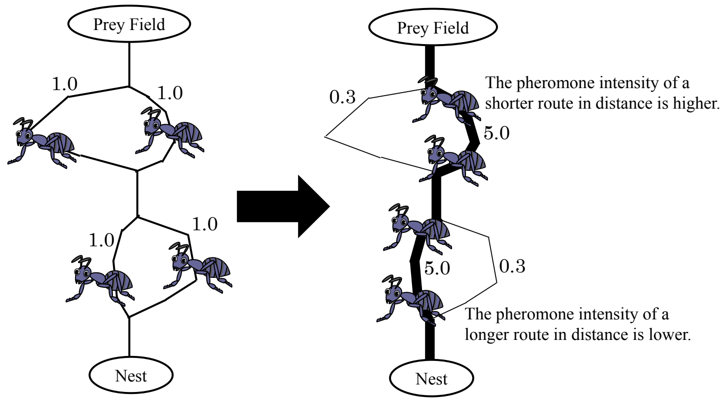

Figure 1. Conceptual diagram of search by artificial ants in the Ant System.

3.4. Proposed Method

Time required (duration + average queuing time + expected average travel time) for each attraction is determined first, based on satisfaction obtained using a questionnaire survey and the average queuing time of attractions available on the internet (TDR, 2016) in this study. Because the travel time on a tour route is unknown when selecting attractions, the expected average travel time between attractions is employed. Then attractions with high satisfaction that can be visited within operation hours are selected with a Knapsack Problem applied using dynamic programming (Bellman, 2003; Lew & Mauch, 2010; Martello, Pisinger, & Toth, 1999; Smith, 2007).

Next, an efficient tour route is determined from the selected attractions using the Ant System. The algorithm of the proposed method is presented below.

[Step 1] Obtain satisfaction with each attraction using a questionnaire survey.

[Step 2] Select attractions with high satisfaction that can be visited during operation hours from all the attractions except the theme park entrance with a Knapsack Problem applied using dynamic programming.

[Step 3] A tour route accommodating attractions selected by [Step 2] is determined using the Ant System; a tour route with the highest satisfaction is finally presented as a solution.

4. Numerical Experiment

4.1. Outline of Numerical Experiment

Satisfaction with each attraction is determined using a questionnaire survey, as described in the preceding section, as the first step of this study. Next, a combination of attractions with high satisfaction is determined with a Knapsack Problem applied to the satisfaction of male, female, and all respondents obtained using the questionnaire survey considering four patterns of operation hours. Then an efficient tour route is sought with the Ant System using this result.

A numerical experiment was conducted for 39 attractions using the time required for attractions on "weekdays," "holidays," "clear days," and "cloudy or rainy days" and four patterns of operation hours, and for male, female, and all respondents. A PC with an Intel® Core™ i7-2670QM processor at 2.20 GHz and a memory of 8.00 GB was used for calculations related to the numerical experiment.

[Operation hours]

- Weekdays: 840 min
- Holidays: 840 min
- After 6 hours: 240 min (on weekdays only)
- Starlight hours: 420 min (on holidays only)

4.2. Numerical Experiment on Attraction Selection

A numerical experiment on attraction selection was conducted with a Knapsack Problem applied in which attractions with highest satisfaction possible that could be visited in the operation hours were selected for male, female, and all guests on "weekdays," "holidays," "clear days," and "cloudy or rainy days." Table 3 presents the results of attraction selection.

This result revealed that about half of the attractions in the park could be visited on weekdays. Sixteen attractions were selected irrespective of gender and weather including Attractions 2, 6, 20, and 21 which were especially popular according to the totaled result of the questionnaire.

Fewer attractions were selected on holidays than on weekdays, probably because the average queuing time of attractions is longer on holidays than on weekdays. Eleven attractions including Attractions 2, 6, 20, and 21 were selected irrespective of gender and weather.

The attractions that can be visited were considerably fewer for After 6 operation hours because After 6 was the shortest of the four types of operation hours. Although Attractions 2 and 6 were selected irrespective of gender and weather, Attraction 21 was selected for only male guests; Attraction 20 was not selected by either male or female guests.

Five attractions including Attractions 2, 6, and 21 were selected irrespective of gender and weather on Starlight operation hours, although Attraction 20 was not selected by either male or female guests.

Generally, many attractions could be visited on days with bad weather irrespective of gender and operation hours, presumably because the waiting time for attractions was short on bad weather conditions. Consequently, Attractions 2 and 6 were selected for all operation hours irrespective of gender and weather.

Table 3. Results of attraction selection

	Operation Hours	Weather	Number of Attractions (pieces)	Total Satisfaction	Expected Total Time Required (min)
All Guests	Weekdays (840 min)	Clear	22	637	839
		Cloudy or Rainy	27	676	839
	Holidays (840 min)	Clear	17	565	837
		Cloudy or Rainy	19	596	837
	After 6 (240 min)	Clear	6	266	240
		Cloudy or Rainy	7	308	236
	Starlight (420 min)	Sunny	10	350	420
		Cloudy or Rainy	8	368	416
Male Guests	Weekdays (840 min)	Clear	22	398	840
		Cloudy or Rainy	28	412	818
	Holidays (840 min)	Clear	17	356	840
		Cloudy or Rainy	19	374	838
	After 6 (240 min)	Clear	6	178	240
		Cloudy or Rainy	7	201	236
	Starlight (420 min)	Clear	10	226	416
		Cloudy or Rainy	8	243	414
Female Guests	Weekdays (840 min)	Clear	23	251	840
		Cloudy or Rainy	27	268	840
	Holidays (840 min)	Clear	18	226	839
		Cloudy or Rainy	18	237	826
	After 6 (240 min)	Clear	8	115	240
		Cloudy or Rainy	9	127	235
	Starlight (420 min)	Clear	10	146	419
		Cloudy or Rainy	11	152	409

4.3. Numerical Experiment on Tour Route Search

Tour routes were compared for attractions selected in Section 4.2 according to gender, weather, and operation hours using the ant system. Table 4 presents the best result obtained using this numerical experiment. We employed the following Ant System parameters: number of artificial ants = 39 (total of attractions), α = 1.0, β = 5.0, p = 0.1, and the number of searches = 1,000 from results of preliminary experiments.

This result proposed efficient tour routes that went round along the perimeter of the theme park irrespective of gender, operation hours, and weather. The attraction selection for male and overall guests became similar as operation hours shortened, finally yielding the almost identical tour route. However, the tour route presented for female guests was quite different because of the difference in attraction selection. The tour routes for male and overall guests became almost identical, probably because the male–female ratio in respondents tended to be high for the questionnaire survey of satisfaction with attractions. Furthermore, the use of expected average travel time for attraction selection yielded the total required time of tour routes on weekdays and holidays considerably shorter than the upper limit of operation hours. This point must be improved in the future.

Figures 2–4 portrays the best tour routes computed for each category of operation hours on weekdays, where numbers in the figure denote respective attraction numbers, and where "0" represents the park entrance.

Table 4. Best result obtained using this numerical experiment

	Operation Hours	Weather	Number of Attractions (pieces)	Total Satisfaction	Total Time Required (min)	Total Tour Distance (m)
All Guests	Weekdays (840 min)	Clear	22	637	783	2603
		Cloudy or Rainy	27	676	770	3150
	Holidays (840 min)	Clear	17	565	797	2457
		Cloudy or Rainy	19	596	794	2571
	After 6 (240 min)	Clear	6	266	238	1817
		Cloudy or Rainy	7	308	229	1756
	Starlight (420 min)	Sunny	10	350	403	1867
		Cloudy or Rainy	8	368	412	2093
Male Guests	Weekdays (840 min)	Clear	22	398	789	3023
		Cloudy or Rainy	28	412	766	3097
	Holidays (840 min)	Clear	17	356	800	2300
		Cloudy or Rainy	19	374	801	3020
	After 6 (240 min)	Clear	6	178	237	1710
		Cloudy or Rainy	7	201	229	1756
	Starlight (420 min)	Clear	10	226	398	1917
		Cloudy or Rainy	8	243	408	1991
Female Guests	Weekdays (840 min)	Clear	23	251	788	3245
		Cloudy or Rainy	27	268	773	3303
	Holidays (840 min)	Clear	18	226	797	2481
		Cloudy or Rainy	18	237	787	2564
	After 6 (240 min)	Clear	8	115	229	1743
		Cloudy or Rainy	9	127	222	1881
	Starlight (420 min)	Clear	10	146	402	1895
		Cloudy or Rainy	11	152	392	2095

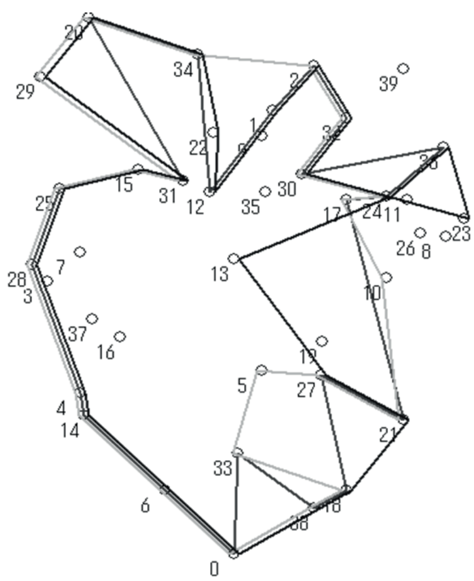

Figure 2. Optimal tour routes for clear weekdays.

Route for all guests:

0-6-14-4-28-25-15-31-20-34-12-1-2-32-30-36-24-17-21-27-18-38-33-0

Route for male guests:

0-38-18-33-5-27-21-10-17-24-30-32-2-34-20-29-31-15-25-28-4-14-6-0

Route for female guests:

0-6-14-4-28-25-15-31-29-20-34-22-12-1-2-32-30-23-36-24-13-27-21-18-0

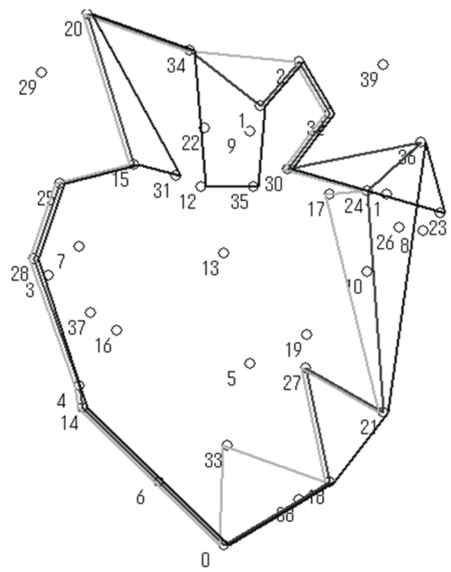

Figure 3. Optimal tour routes for clear holidays.

Route for all guests: 0-6-14-4-28-25-15-20-34-1-2-32-30-36-24-21-27-18-0

Route for male guests: 0-33-18-27-21-17-24-30-32-2-34-20-15-25-28-4-14-6-0

Route for female guests: 0-18-21-36-23-30-32-2-1-35-12-34-20-31-15-25-28-14-6-0

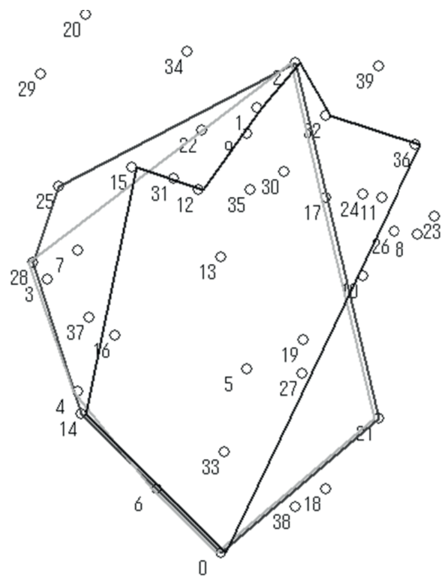

Figure 4. Optimal tour routes for clear After 6 hours.

Route for all guests: 0-21-2-25-28-14-6-0

Route for male guests: 0-21-17-2-28-4-6-0

Route for female guests: 0-6-14-15-12-1-2-32-36-0

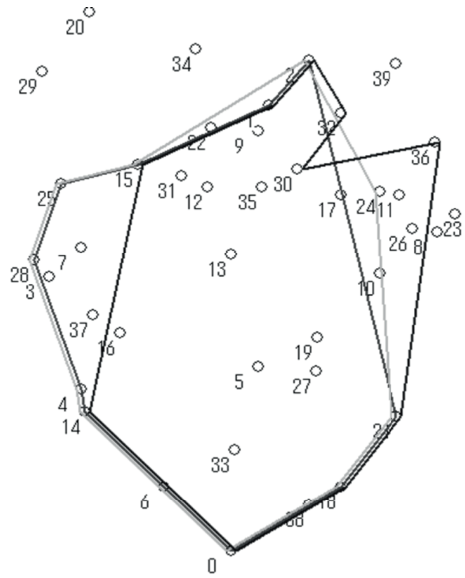

Figure 5. Optimal tour routes for clear Starlight hours.
Route for all guests: 0-18-21-2-1-15-25-28-4-14-6-0
Route for male guests: 0-18-21-24-2-15-25-28-4-14-6-0
Route for female guests: 0-18-21-36-30-32-2-1-15-14-6-0

5. Conclusion

This study has proposed an efficient tour route in a theme park considering guest satisfaction with attractions. Satisfaction with each attraction is investigated using a questionnaire survey at first in the proposed method. Then, attractions to be visited are selected based on satisfaction with a Knapsack Problem applied with consideration of operation hours and time necessary (duration + average queuing time + expected average travel time) for each attraction. Then an efficient tour route is determined with the Ant System applied to the selected attractions. This study has verified the effectiveness of the proposed method, which determines a tour route including attractions with high satisfaction by numerical experimentation considering gender, operation hours, and weather. This proposed method is applicable to other fields. Our future subjects include the following issues.

(1) The use of expected average travel time for attraction selection yielded total required time of tour routes on weekdays and holidays that is considerably shorter than the upper limit of operating hours. This point must be improved.

(2) A tour route should include the schedules of shows and parades in addition to attractions to be more realistic.

6. References

Bellman, R. (2003). Dynamic Programming. Dover Publications.

Dorigo, M., & Stutzle, T. (2004). Ant Colony Optimization. The MIT Press.

Fischer, T., & Merz, P. (2005). A Distributed Chained Lin-Kernighan Algorithm for TSP Problems, Proceedings of the 19th International Parallel and Distributed Processing Symposium (IPDPS 2005). IEEE Computer Society Press. 72–81.

Google Maps. (2016, March). https://www.google.com/maps/

Kellerer, H., Pferschy, U., & Pisinger, D. (2010). Knapsack Problems. Springer.

Kolesar, P. J. (1967). A branch and bound algorithm for the knapsack problem. Manage, Management Science, 13(9), 723–.735.

Lawler, E. L., Lenstra, J. K., Rinnooy Kan, A. H. G., & Shmoys, D. B. (1985). The Traveling Salesman Problem: A Guided Tour of Combinatorial Optimization. John Wiley & Sons.

Lew, A., & Mauch, H. (2010). Dynamic Programming: A Computational Tool. Springer.

Lin, S., & Kernighan, B. W. (1973). An Effective Heuristic Algorithm for the Traveling Saleseman Problem. Operations Research, 21(2), 498–516.

Pisinger, D., & Toth, P. (1999). Dynamic Programming and Strong Bounds for the 0-1 Knapsack Problem. Management Science, 45(3), 414–424.

Martello, S., & Toth, P. (1990). Knapsack Problems: Algorithms and Computer Implementations. Wiley.

Real Property Regulation. (2016, March). http://www.rftc.jp/kiyak/hyouji_sekou.html (in Japanese)

Smith, D. K. (2007). Dynamic programming and board games: A survey, European Journal of Operational Research. 176(3), 1299–1318.

TDR Web Site. (2016, December). http://tokyodisneyresort.info/index.php (in Japanese)

Wang, R., Zhou, X., Zhao, L., & Xia, Z. (2012). An Ant System with Two Colonies and Its Application to Traveling Salesman Problem. IEEJ Transactions on Electronics, Information and Systems. 132(12), 2043–2050.

Taguchi Analysis for Maximizing Metal Recovery from Ore

J. S. Sutterfield[1]
Amani S. Floyd[1], Ulysses D. Foreman, III[1]
[1]*Florida A&M University*
pisces4914@earthlink.net

Abstract

A matter of concern for those in the ore processing industry is the processing conditions that are the most effective in removing metal from the ore. If the processing conditions are not properly adjusted, then some of the metal will be lost, which might otherwise have been recovered. In this paper the set of conditions is examined for processing ore to extract the maximum yield of metal content. This examination is performed using Taguchi's method of experimental analysis with an L_8 (2^3) orthogonal array.

1. Introduction and literature review

Factorial Analysis as employed in experimental methods is a very powerful and frequently used method for performing experimental analysis and arriving at valuable conclusions. Factorial Analysis relies upon a mathematical device known as orthogonal arrays. These were first studied by the great Swiss mathematician and physicist, Leonhard Euler (1707-1783), and were originally viewed as a type of mathematical recreation (Taguchi, 1988). Since Euler's time, they have been studied extensively by Joseph Leonard Walsh (1895-1973) and others as a part of the general investigation of orthogonal functions (Taguchi, 1988).

Factorial Analysis has been in use for upward of 70 years and was extended considerably through the efforts of Frank Yates (1937, 1970). Excellent discussions of the topic may be found in such works as Box, *et al* (1978), Cochran and Cox (1957), Fisher (1966) and Montgomery (2008). On the application and adaptation of Factorial Analysis to specific problems, one should see such works as John (1971, 1972), Margolin (1967, 1969), Plackett and Burman (1946). Taguchi (1988) has extensive discussions and examples of the various approaches to Factorial Analysis.

Factorial analysis is extremely versatile, and has been used in such widely varied applications as pilot plant designs, development of storm water overflow systems, sewage treatment facilities, and petrochemical plant design (Box, et al, 1978). Further, applications of factorial analysis have been in passenger car tire life analysis, x-ray inspection to determine tensile strength, analysis of cast aluminum machine parts, and in the production process for laminate boards (Taguchi, 1988). One very useful application of factorial analysis is that of using a two-level analysis to eliminate insignificant control factors, and combining it with a two or three-way layout to determine optimal values for the significant control factors (Sutterfield, et al, 2012).

In factorial analysis, several experimental conditions, known as control factors, are systematically varied to determine how some factor of interest, known as the response factor, is affected by changes in the control factors. It must be emphasized that the control factors are changed systematically: This is why orthogonal arrays are vitally important in Factorial Analysis. An orthogonal array actually provides a template for systematically conducting a factorial analysis. In orthogonal arrays, each column is, mathematically speaking, orthogonal to each of the other columns in the array. The experimental runs are randomized, which means assigning a random number to each row in the orthogonal array. An example of an orthogonal array is shown in **Table 1**.

Table 1: Example Orthogonal Array

No.	Run Number	1 A	2 B	3 AxB	4 C	5 AxC	6 BxC	7 e	Response Variable
1	4	1	1	1	1	1	1	1	RV_1
2	8	1	1	1	2	2	2	2	RV_2
3	3	1	2	2	1	1	2	2	RV_3
4	6	1	2	2	2	2	1	1	RV_4
5	1	2	1	2	1	2	1	2	RV_5
6	7	2	1	2	2	1	2	1	RV_6
7	5	2	2	1	1	2	2	1	RV_7
8	2	2	2	1	2	1	1	2	RV_8

In the above orthogonal array, three control factors, “A,” “B,” and “C” are examined along with their interactions. These interactions are identified as “AxB,” “AxC” and “BxC.” The “AxBxC” is not shown in the above array, but it could be adapted to include this interaction. The next to last column, labeled “e,” is where the random experimental error is to be found. The last column, labeled “Response Variable,” contains the measured values for the response variable. Further, the level of each control factor for a given experimental run is set by the corresponding entry in the orthogonal array. Using Figure 1 above, for example, in run number “6,” factor “A” is set at its lower level, factor “B” at its upper level and factor “C” at its upper level. Moreover, the upper levels of two of three interactions are to be found in this row.

In general, orthogonal arrays such as that in **Table 1** are identified by the number of the rows in the array, the number of factors and levels to be examined, or both. Thus, the orthogonal array in **Table 1** can be described as an L_8, referring to the number of rows; a 2^3 indicating that three control factors, along with their interactions, are to be examined at two levels each; or as $L_8 (2^3)$ indicating both. Again, if four factors, along with their interactions, were to be examined, each at two levels, an orthogonal array of sixteen rows and fifteen columns would be required: Such an orthogonal array would be designated as an $L_{16} (2^4)$.

In the Taguchi adaptation of orthogonal arrays, they have the curious property that if the numbers of the columns for any two of the principal control factors are added together, the number of the column is obtained in which the interaction results for those two factors. For example, if factors “A” and “B” were of interest, their corresponding columns are “1” and “2.” If “1” and “2” are added together the result is “3,” meaning that “3” is the number of the column in which the interaction of “A” and “B,” “AxB,” will be found. The reader may verify from Figure 1 that similar results will be found for the factor combinations of “A” and “C,” as well as for “B” and “C.” The application of orthogonal arrays does not limit Factorial Analysis to two factor levels: Orthogonal arrays have been developed for three or more levels and for very large numbers of factors. For example the designation $L_{27} (3^{13})$ would indicate an array with thirteen factors to be tested at three levels. Such an array would require 27 rows.

2. Methodology

To perform a Factorial Analysis, it is necessary first to decide upon those quantities (control factors) thought to affect the phenomenon (response factor) to be investigated. One then decides upon the number of levels of each factor to be investigated, along with the range in which each control factor is believed to exert the greatest effect.

Since experiments frequently involve a large number of factors, they are expensive to perform. Consequently, it is fairly commonplace to reduce experimental cost by performing initial experiments at two levels to identify those factors having the greatest effect, as well as those having little to no effect. Also, it is desirable to attempt to obtain the range in which those factors produce the greatest effect. Once this is done, subsequent experiments can be performed with fewer control factors using levels within the range found previously to have the greatest effect.

It is worth pointing out that if it were desirable to investigate factors at differing levels, that it is possible to do so. For example, if it were desired to investigate thirteen (13) different factors, say factor A at four (4) levels, factor B at three (3) levels, and the remaining six (6) factors at two (2) levels each, it would be possible to adapt a standard orthogonal array to accommodate such an investigation. It would be identified as an L_{16} (4^1 x 3^1 x 2^6) array. There are a vast number of arrays and adaptations: There are upward of 800 variations and adaptations of L_{16} alone (Taguchi, 1988).

Once the factors and their levels have been determined, and a satisfactory orthogonal array selected, the array itself becomes a template for conducting the experiment. The rows are *randomized*, to conform to one of the canons of experimental method (Montgomery, *et al*, 2008), and the experiment executed according to this randomization. The experiment analyzed in the following section using Taguchi methods was conducted in this way.

3. Application of methodology

The experiment analyzed in this paper was originally performed for the Strike It Rich ore refinement company. The purpose of the original experiment was to analyze an ore refining process to determine which of three control variables, or combinations of control variables, most affected the ore yield obtained from the refining process. The factors which were thought most to affect the process are shown below in **Table 2**:

Table 2: Factors involved in ore recovery process

Legend:	Factor Level	
Control factor	Low	High
A: Time (hrs.)	1	3
B: Concentration (%)	30	50
C: Temperature (^oC)	1600	1900

This experiment was aimed at determining those values of the control factors, along with possible factor interactions, which would maximize yield from the refining process. Ore yield was the response variable, and was measured in grams per hour of pure metal. It was desired to check all possible interactions up to and including a single three-factor interaction. For three control factors, the total number of two-factor interactions is three, and the total number of three factor interactions is one. Thus, an L_8 (2^3) orthogonal array was selected for the experiment, viz., an array having 8 rows and 7 columns. The assignment of the control factors, along with the randomization of the runs is shown in **Table 3**.

In **Table 3**, the first column indicates the number of the row in the orthogonal array. The numbers in the second column indicate the randomized order in which the experiments were run. Columns 1, 2, and 4 are the columns to which control factors "A," "B," and "C," respectively, are assigned. The remaining columns are those to which the interactions of these control factors are assigned.

One of the unique facets of Taguchi's method is that the columns are arranged so that adding the column numbers of the control factors gives the number of the column to which the interaction for those control factors is assigned. For example, Column 3 is where the AxB interaction is assigned. Column 5 is where the AxC interaction found, and column 6 the BxC interaction.

Column 7 of our array demands a bit of special attention. Ordinarily, the last column of an array would be used to capture experimental error. However, in our application the three-factor interaction must occupy the last column. Since an $L_8\,(2^3)$ array can have at most 7 columns, there was no column to which the experimental error might be assigned. Because it was desired to examine the three-factor interaction, it was not desirable to employ confounding. This introduced a slight complication into the analysis which will be discussed in the following section.

Another unique facet of Taguchi's method is the use of coded data for the response variable. This is done to increase the precision of the analysis. Columns 8 and 9 contain the response variable data for each of the two runs. Column 10 is obtained by averaging columns 8 and 9 and deducting a value called the *working mean* from each of the averages obtained for the response variable. The working mean is simply a quick estimate of the true mean, and is used to expedite analysis. For the present application, a working mean of 78 was selected.

An experimental run is conducted by setting each control factor to the particular level indicated by the number in the row for that control factor. The values for the interactions are obtained as a fortuitous result of executing the experiment. Referring to **Table 3**, to execute Run #6, Control Factor A would be set to 2, Control Factor B to 1, and Control Factor C to 2. The levels of the interactions would be as shown in **Table 3**.

Table 3: Experimental results for ore refining experiment

		A	B	AxB	C	AxC	BxC	AxBxC	Response (gms./hr.)		Mean response	Coded response
Run no.	Rand. No.	1	2	3	4	5	6	7	Trial 1	Trial 2		
1	4	1	1	1	1	1	1	1	80	62	71	-7
2	8	1	1	1	2	2	2	2	65	63	64	-14
3	3	1	2	2	1	1	2	2	69	73	71	-7
4	6	1	2	2	2	2	1	1	74	80	77	-1
5	1	2	1	2	1	2	1	2	81	79	80	2
6	7	2	1	2	2	1	2	1	84	86	85	7
7	5	2	2	1	1	2	2	1	91	93	92	14
8	2	2	2	1	2	1	1	2	93	93	93	15

The total variation is obtained by summing the squares of the coded values, and deducting the square of the sum of these divided by 8, the number of coded values. This is illustrated in the following calculation:

$$S_T = X_1^2 + X_2^2 + X_3^2 + \ldots + X_8^2 - \frac{(CF)^2}{8}$$

Then, substituting the coded data for the response variable from **Table 3** …

$$S_T = (-7)^2 + (-14)^2 + ... + (14)^2 + (15)^2 - \frac{[-7 - 14 + ... + 14 + (15)]^2}{8}$$

$$S_T = 758.88\ gm./hr.$$

The effect for a given control factor is obtained by summing the values of the response factor for the “1s” in a given column, summing the values of the response factor for the “2s” in the column, taking the difference between the two sums, and squaring it. The result of the calculation is is known as the variation for the effect. For a 2^n orthogonal array, the variation for any factor may be written as …

$$S = \frac{[(\Sigma RV_2) - (\Sigma RV_1)]^2}{n}$$

where …

RV_2 – the value of the response variable at the high level of the control factor in question
RV_1 – the value of the response variable at the low level of the control factor in question
n – the number of rows, viz., the number of experiments performed

This computation is illustrated for control factor “A” as follows:
Coded values corresponding with “1s” in column for A) = -38, and the sum for the “2s” in column A is 38.
Coded values corresponding with “2s” in column for A) = -1,016

$$S_A = \frac{[(38 - (-38))]^2}{8}$$

$$S_A = 722\ gm./hr.$$

The variations for the remaining control factors and their interactions are calculated similarly. The tentative results for these calculations are shown in **Table 4**, the analysis of variance.

Table 4: Analysis of variance for ore refining experiment

Factor	*dof*	*Variation*
A	1	551
B	1	126
AxB	1	-4
C	1	-7
AxC	1	-10.13
BxC	1	0
AxBxC	1	26
e	0	0.5
Totals	7	682.37

We say tentative because The ANOVA in **Table 4** indicates a problem: The variations for control factor C, the AxB interaction and the AxC interaction are all negative. Now, inasmuch as it is impossible to have negative values for variation, it is evident that a problem exists somewhere with the data. Thus, it was necessary to re-examine the original data to determine the problem. This examination disclosed a possible problem with the first value of the Run #1, the value of 80. This value stands out against those of other trials for Control Factor A at level 1. It was decided, therefore, to use the Fisher-Yates method to estimate the true value for this particular response. This method yielded an estimate for the true value of 60.57. This value, however still led to one of interactions having a negative variation. Eventually, a trial and error process led to the selection of a value of 62 as the best estimate for the questionable value. The value of 62 was selected because a value slightly more than 62, and a value slightly less than 62 both led to negative variations. The value of 62, therefore, was supposed to be the best approximation of the true value. This value resulted in the revised ANOVA shown in **Table 5**.

Table 5: Revised experimental results

		A	B	AxB	C	AxC	BxC	AxBxC	Response (gms.)		Mean response	Coded response
Run no.	Rand. No.	1	2	3	4	5	6	7	Trial 1	Trial 2		
1	4	1	1	1	1	1	1	1	62	62	62	-16
2	8	1	1	1	2	2	2	2	65	63	64	-14
3	3	1	2	2	1	1	2	2	69	73	71	-7
4	6	1	2	2	2	2	1	1	74	80	77	-1
5	1	2	1	2	1	2	1	2	81	79	80	2
6	7	2	1	2	2	1	2	1	84	86	85	7
7	5	2	2	1	1	2	2	1	91	93	92	14
8	2	2	2	1	2	1	1	2	93	93	93	15

4. Analysis of results

The **ANOVA** obtained with the revised data is shown in **Table 6**.

Table 6: Analysis of variance with revised data

Source	*f*	*S*	*V*	*F_0 (99%)*	*S'*	*ρ (%)*
A	1	722.00	722	320.89	719.75	73.74
B	1	220.50	220.5	98.00	218.25	22.36
AxB	1	0.50	0.5	------	------	------
C	1	24.50	24.5	10.89	22.25	2.28
AxC	1	0.00	0	------	------	------
BxC	1	0.00	0	------	------	------
AxBxC	1	8.00	8	------	------	------
e	0	0.50	------	------	------	------
(e)	4	9.00	2.25	------	15.75	1.61
Total	7	976.00			976.00	100.00

Now it is evident from **Table 6** that only control factors "A," and "B," are significant at the 99% level, while "C" is significant at about the 97% level. However, none of the two-factor interactions proved to be significant, either at the 99%, nor even the 95% level. The three-factor interaction, however, is unusual and demands a bit of explanation. On the face of it, the three-factor interaction, AxBxC, would appear to be significant at the 99% level. However, it is highly improbable that a three-factor interaction would be significant when all of the two-factor interactions are 0, or approximately so. Thus, we combine all of the values of the interactions, along with their degrees of freedom to obtain an error term of 9 with four degrees of freedom. This term is known as the pooled error, and becomes the basis for calculating the variance of the control variables in the experiment. The results shown in **Table 6** are based upon this operation.

Now, the $F_{1,4}$ statistic at a 95% level of significance is a value of 7.71, and it may be seen from **Table 6** that the least of the F_0 values, that for control factor **C,** is more than five times greater than the $F_{1,4}$ statistic. Further, the $F_{1,4}$ statistic for a 99% significance level is 21.2. Thus, it is evident from **Table 6** that the significance for the **A** and **B** control factors is well beyond the 99% significance level, while that for the control factor **C** is beyond the 95% level.

One further step was necessary to complete **Table 6**. The values of each of the three significant control factors are the *gross variation* for each. This means that each of these three factors contains the amount of one experimental error variation per degree of freedom, viz., 2.25. Since each of the significant control factors has only one degree of freedom, each also contains the amount of one experimental error variation. Thus, in order to obtain the desired net variation for each of the control variables, we deduct 2.25, the amount of one experimental error variation. This adjustment results in the values for *net variation* shown in the column labeled ***S'***. Now, having combined the insignificant control factors and their interactions with the experimental error term, and having adjusted the gross variation values to obtain net variation, the revised analysis of variation was obtained as shown in **Table 7**.

Table 7: Revised analysis of variance

Source	*f*	*S*	*V*	F_0 *(99%)*	*S'*	*ρ (%)*
A	**1**	**722.00**	**722**	**320.89**	**719.75**	**73.74**
B	**1**	**220.50**	**220.5**	**98.00**	**218.25**	**22.36**
C	**1**	**24.50**	**24.5**	**10.89**	**22.25**	**2.28**
(e)	**4**	**9.00**	**2.25**	**------**	**15.75**	**1.61**
Total	**7**	**976.00**			**976.00**	**100.00**

Here it will be seen that ***Control Factor A*** accounts for 73.74% of the total variation; ***Control Factor B*** for 22.36%; and **Control Factor C** for 2.28%; and the ***experimental error*** for 1.61%.

We turn next to an estimation of the confidence levels for each of the mean of the response variables. In order to do this, it is necessary to estimate the average effects of levels of the above control variables. Then …

$$\bar{\mathbf{A}}_1 = 78 + \left(\frac{-38}{4}\right) = 68.5\text{gm / hr}$$

$$\bar{\mathbf{A}}_2 = 78 + \left(\frac{38}{4}\right) = 87.5\text{gm / hr}$$

$$\bar{\mathbf{B}}_1 = 78 + \left(\frac{4}{4}\right) = 79\text{gm / hr}$$

$$\bar{\mathbf{B}}_2 = 78 + \left(\frac{8}{4}\right) = 80\text{gm / hr}$$

$$\bar{\mathbf{C}}_1 = 78 + \left(\frac{4}{4}\right) = 79\text{gm / hr}$$

$$\bar{\mathbf{C}}_2 = 78 + \left(\frac{8}{4}\right) = 80\text{gm / hr}$$

Thus, the desired yield is maximized when the control variables take on the values $\bar{\mathbf{A}}_2$, $\bar{\mathbf{B}}_2$ and $\bar{\mathbf{C}}_2$. Next, we wish to estimate the mean effect, $\hat{\mu}$, at optimal conditions. This mean is estimated as …

$$\hat{\mu} = \bar{\mathbf{A}}_2 + \bar{\mathbf{B}}_2 + \bar{\mathbf{C}}_2 - 2 * \bar{\mathbf{M}}$$

$$\hat{\mu} = 87.5 + 79.0 + 80.0 - 2 * 78$$

$$\hat{\mu} = 90.5 \text{ gm / hr}$$

The general expression for the confidence limits of a statistical quantity is …

$$\mu = \hat{\mu} \pm \sqrt{F_n^m x V_e x \frac{1}{n_e}}$$

where …
$\hat{\mu}$ – the estimate of the true mean at optimal conditions obtained from the data
F_n^m – the ***F*** statistic at the significance level corresponding to the desired confidence limit with "m" degrees of freedom in the numerator and "n" degrees of freedom in the denominator
V_e – the experimental error variation
n_e – the effective number of experimental repetitions

Now, it will be recalled that the **A** and **B** control factors, were found to be significant at well above the 99% level; control factor **C** was found to be significant at about the 97% level. Since the **A** and **B** control factors are well above 99%, and the control factor **C** is near 99%, the ***F*** statistic for 99% is taken as a good but conservative estimate of the true value. Then, using the value of μ calculated above as

90.5, an ***F*** (99%) statistic of 11.26, a V_e equal to 9.0, as in **Table 4** above, and an n_e equal to 8, we have for the calculation …

$$\mu = 90.5 \pm \sqrt{11.26 * 9.0 * \frac{1}{8}}$$

μ **= 90.5 ± 3.56 gm/hr**

Thus, the mean effect of the response variables, the average rate at which the pure is processed from the ore, lies between 86.94 and 94.06 gm/hr. with a significance level of 0.01.

5. Conclusions

The foregoing experimental analysis was performed upon a set of data taken from an experiment which was aimed at determining the set of control factor values to maximize the yield for a metal. In the instant analysis it was desired to investigate interactions among all control factors, and consequently it was necessary to recast the original data in an orthogonal array, an L_8 (2^3). Using this array made it possible to study all possible control factor interactions up to and including the three-factor (AxBxC). However, using this array resulted in a slight complication due to the fact that analyzing all interactions consumed all available columns, leaving no column for the error variation. The results disclosed that only factors **A** (time), **B** (concentration) and **C** (temperature) were significant. For this experiment, the values for these factors to maximize yield were found to be …

$$\mathbf{A = 3\,hr.}$$

$$\mathbf{B = 50\%}$$

$$\mathbf{C = 1,900\,^{o}C}$$

Further, the mean effect was found to be …

μ **= 90.5 ± 3.56 gm/hr**

No two-factor interactions were found to be significant, nor was the three-factor determined to be significant.

In performing this analysis the foundation has been laid for further experimentation on those control factors which were found significant. This experimentation would be aimed at determining the optimal values of these factors to maximize the yield from the process. The starting point for this investigation would be the sub-optimal values obtained in the present investigation. Such further investigation would employ response surface methods.

Finally, it is important to make mention of the fact that as the number of factors in an experiment becomes large, the number of repetitions (rows) necessary to test all of the combinations of factors increases exponentially. Thus, it becomes expensive and unwieldy to execute such as experiment. In this case, an experimental design known as the partial or fractional factorial may be employed to decrease the number of replications necessary for the experiment. For a discussion of the fractional factorial design, see Box, *et al* (1978), Cochran and Cox (1957), or Montgomery (2008).

6. References

Box, G. E., Hunter, J. S., & Hunter, W. G. (1978). *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building* (1 ed.). New York: Wiley-Interscience, pg. 15.

Cochran, W. and Cox, G. (1957). *Experimental Design. Second edition.*(Wiley Series in Probability and Mathematical Statistics)*. New York, NY: Wiley.

Fisher, R. A. (1966). *The Design of Experiments, Eighth Edition*. New York: Hafner Publishing Company.

John, P. (1971). *Statistical Design & Analysis Experiment*. New York: The MacMillan Company.

Margolin, B. H. (1967). "Systematic Methods of Analyzing 2^n3^m Factorial Experiments with Applications," *Technometrics*, vol. 9, pgs. 245-260.

Montgomery, D. C. (2008). *Design and Analysis of Experiments, 7th Ed.*. Main: John Wiley & Sons Inc, Somerset, New Jersey, U.S.A., pgs. 414-415.

Plackett, R. L. and J. P. Burman (1946). "The design of Multi-factorial Experiments," *Biometrika*, vol, 33, pgs. 305-325.

Sutterfield, J. S., Paul Nkansah, Asia N. McFarland, Kristin S. Leek, Tajadin I. Muhammad (2014). "Optimization of Turbine Engine Design Parameters Using Combined Taguchi Methods," *The Journal of Management and Engineering Integration,* Vol. 5, No. 1, Summer 2012, pgs. 80-91

Taguchi, G. (1987). *The System of Experimental Design: Engineering Methods to Optimize Quality and Minimize Cost.* Tokyo: Quality Resources, Kraus International Publication, White Plains, NY, vol. 1.

Yates, F. (1937). "The design and analysis of factorial experiments," *Imperial Bureau of Soil Science. Technical Communication*. London: Imperial Bureau of Soil Science, technical comment No. 35.

Yates, F. (1970). "Selected Papers," Hafner (Macmillan), New York.

Yin, G.Z., and Jillie, D.W. (1987). "Orthogonal Design for Process Optimization and its Application in Plasma Etching," *Solid State Technology*, pgs. 127-132.

Analysis of an Assembly Line in the Food Processing Industry: A Case Study

Mehmet Savsar[1]

Angie K. Elsaadany[1], Rana Hassneiah[1], Altaf Alajmi[1]

[1]*Kuwait University, College of Engineering & Petroleum*

msavsar@gmail.com; angiie.94@hotmail.com; rana_hassneiah@hotmail.com; al6afn@gmail.com

Abstract

Several factors affect productivity and efficiency of Manual Mixed-Model Assembly Lines (MMMAL), which are common in the Food Processing Industry (FPI). In this paper, analysis is carried out for the Americana Company's MMMAL, which is a purely manual assembly line set up for the production of various types of freshly prepared salads to be distributed to various markets in the State of Kuwait. Several problems causing delays and inefficiencies on the line are identified and appropriate approaches are used to determine the best solutions, which increase line efficiency and minimize balance delays. In particular, line balancing tools are utilized to distribute the workload evenly and remove the bottleneck from the current assembly line in order to increase line efficiency and productivity. Furthermore, various types of salads are scheduled for production on the same line in such a way as to reduce the average work flow time. The procedure and the approach utilized in this paper can be useful for the operation managers and industrial engineers dealing with similar assembly lines in the food processing industry.

Keywords: Mixed-Model Assembly Line, Line Balancing, Food Processing Line, Manual Assembly Line, Line Efficiency, Productivity.

1. Introduction

Henry Ford first introduced manufacturing assembly lines in the 1900s for assembling automobiles. It was considered innovative and saved a lot of time since it took into consideration the effects of the learning curve of the worker on assembly line. Ever since, assembly lines have been applied to all types of manufacturing systems and have made mass production possible. In today's consuming society and ever-increasing demand for a variety of products, only mass production can cope with high demand in a competitive environment.

The Food Processing Industry (FPI) is very broad and ever-changing due to the immense increase in demand and also a variety of products. Food manufacturing companies must be able to reach maximum production in order to meet the continuously increasing customer demand. Also, because of the huge variety in food products, companies must make advanced plans in order to be able to produce a variety of products on the same line, to keep up with the demand, and to be competitive within the market. It is extremely expensive to use a dedicated assembly production line for each food product. Therefore, companies usually produce more than one product on the same line, which is called mixed-model assembly line. A very common mixed-model assembly line in the FPI is the manual mixed-model assembly line. Manual assemblies are preferred since the quality of different ingredients must be inspected visually while assembling the final product. It is difficult to automate the quality control procedures in many cases. However, one of the first drawbacks in using workers for manual assembly is that the workers get fatigued easily; therefore, their assembly capacity is limited and cannot be pushed harder. Another drawback or disadvantage of using manual assembly is the high percentage of waste and a lot of nonvalue-added activities performed by the workers. Furthermore, in manual assembly lines, bottlenecks and congestions can occur within stations, which reduce line productivity and decrease its efficiency. There are multiple workers on the line and each worker usually represents an individual workstation. The speed or the throughput of each workstation on the line is the numbers of products produced in a set time. The speed may differ between workstations which results in a bottleneck and congestion.

A very effective approach to solving bottlenecks and minimizing the wasted time is by using line balancing. Line balancing redistributes work element tasks to ensure a continuous smooth work flow on the assembly line. After applying line balancing, the processing time, which is the total time needed to finish a product, will be minimized and will increase line productivity since the workers will be able to produce the same demand in less time. In this paper, we have considered line balancing and productivity improvement for a specific assembly line in FPI. While extensive literature exists in the area of assembly line operations, there are very few research and literature article dedicated to food assembly lines. In the following section, we present the review of some available literature related to our study.

2. Literature Review

Every researcher has a different approach to solve a given problem. The objectives to achieve may also be different. Depending on the way a researcher views a problem, a specific set of goals, or *objectives* are defined. Production efficiency is one of the main objectives for a manufacturing company. Bolat et al. (1994) have considered mixed model assembly lines and developed algorithms to determine a job sequence which minimizes total setup and utility work costs simultaneously. Zupan and Herakovic (2015) considered production efficiency and tried to improve it through production leveling or smoothing and by improving the throughput of assembly lines. Ismail (2016) and Zhang and Kucukkoc (2013) considered cycle times and studied the issue of how to reduce either the cycle times or the number of work elements. Zhang and Kucukkoc (2013) also considered such constraints as work orders while reducing the workstations and work-elements. Peng (2014) consented with the previous two authors, he then proceeded by making an excellent point that a two-sided assembly line should be taken into consideration more because work is added on both sides of the conveyor.

On the topic of capacity, Peng (2014) stated that in order for the production capacity to increase, the number of workstations must be minimized since they have an inversely related relationship. Depending on the objective considered, the factors taken into consideration will change. Something that most authors agreed on is grouping work families together and taking into consideration their sequences. Another issue to keep in mind is the "*perishability*" of a product in multi-product assembly lines. Buyukozkan et al. (2016) considered "***quality defects caused by stations on the product***" and stated that one must take the "reliability of the line" into consideration.

Time is also a very important factor that most authors mentioned in one way or another. Time, like cost, has many aspects to take into consideration. Cycle time is a time component that we have to take into consideration. Different authors define the cycle time differently. Zupan and Herakovic (2015) and Grzechca (2015) both defined the cycle time as the time between end products, that is pre-determined by the production rate. On the other hand, Ismail (2016) defined the cycle time as "*the time it takes to do a process. It includes the time from when an operator starts a process until the work is ready to be passed on. The cycle time for each workstation was measured from the start of picking the part until it has been located at the next workstation*". Whilst Buyukozkan et al. (2016) defined it as the "*summation of processing times of all tasks assigned to that workstation*". Buyukozkan et al. (2016) also stated that if the workload is different between the workstations, the cycle time will become more critical. Grzechca (2015) similarly indicated that if the processing time of a workstation is more than that of the cycle time, then the preceding workstation would become idle and have to wait. A useful time measurement tool is "takt time". Ismail (2016) defined it as the maximum time that is allowed in a workstation in order for the demand to be met. The takt time along with conveyor speeds are used in order to improve and determine the best course of action for the production plan and sequencing.

Performance of the system is also measured differently depending on the objective being considered. Zupan and Herakovic (2015) and Adnan et al. (2016) all agreed that the *'throughput'* is a very efficient way of measuring the performance of the system. Ismail (2016) defined throughput as "*the average number of jobs produced per hour*". Another important measure is Line Efficiency that Grzechca (2015) and Adnan et al. (2016) agreed on. Here Ismail (2016) defined efficiency as "*ratio of the current productivity level to the best practice productivity level. Best practice is defined as the largest productivity achievable*". Grzechca (2015) said that a good performance measure, especially for systems with conveyors, is to find the smoothness index and line time.

As with any system, some issues may suddenly appear that were not planned in advance. Different authors identified different issues one must take into consideration. Zupan and Herakovic (2015) and Grzechca (2015) both conceded that a big issue is due to the arrangement of tasks that must be performed and the order in which they must be arranged. They both stated that if it is subjective than it could be an issue when trying to solve the problem. With respect to methodologies utilized, we cannot compare one method to another. This is because each researcher had different objectives and different problems. Thus, they chose different methods to reach their goals and to optimize their objectives. Nevertheless, we can see the types of methods each researcher used and check if there are any recurring methods. Buyukozkan et al. (2016) and Adnan et al. (2016) both decided to use Assembly Line Balancing methods. Buyukozkan et al. (2016) used C# for the coding and then used Minitab-17 to formulate the problem and solve it. Adnan et al. (2016) used Lean Lab Tools such as "Yamazumi Charts". This then leads to Lean Production Techniques and the Toyota Production System (TPS). As indicated by Zupan and Herakovic (2015) "a*n effective technique of the TPS to reduce waste and to raise the production efficiency is also the production leveling or smoothing*." Adnan et al. (2016) indicated that "*lean manufacturing also focuses on cost reduction through eliminating unnecessary activity by applying management philosophy which focuses on identifying and eliminating waste from each steps in the production chain*".

Recently some other approaches can be seen in the literature analyzing assembly lines. Make, et al. (2017) presented a review of a two-sided assembly line balancing problem. Unuigbe, et al. (2016) applied a fuzzy logic concept to solve assembly line balancing problems and presented a case application of a tricycle assembly line. Yilmaz and Yilmaz (2016) developed a procedure and a new approach for balancing a multi-manned assembly line with classified teams. Within team-oriented approaches, tasks are assigned to teams before being assigned to workstations, which is a realistic approach in industry. By doing so, it becomes clear which workers assemble which tasks.

In this paper, several problems causing delays and inefficiencies on a food processing assembly line are identified and appropriate approaches are used to determine the best solutions, which increase line efficiency and minimize balance delays. In particular, line balancing tools are utilized to distribute the workload evenly and remove the bottleneck from the current assembly line in order to increase line efficiency and productivity. Furthermore, various types of products are scheduled for production on the same line in such a way as to reduce the average work flow time. While a typical assembly line balancing procedure has been utilized in this paper, the example selected and the detailed procedures to increase efficiency in the food processing industry are new and can be utilized by assembly operators and engineers to improve the performance of their lines. The FPI assembly line considered in this paper is different from other lines, because a variety of products with variable work elements are assembled on the same line. The line has to be balanced for all of the products based on the work elements performed.

3. Mixed Model Assembly Line

The company selected for this case study was one of the biggest companies in the food processing industry in the Middle East. It had several assembly lines. However, one of the most intriguing production lines was the salad manual production line. Numerous products are produced on the same assembly line, with a total of 10 different salad variants with 9 workers on the line. The products on the line are all perishable and cannot be made-to-stock. Therefore, they are made-to-order. The main processes on the salad assembly line are all in series. These main processes usually start with the plastic bowl, manually handled and filled with the core ingredient; then a plastic separator is manually added along with the specified dressing according to the salad variant; and then finally the rest of the ingredients are consecutively added. After the main assembly of the variant, a salad sleeve is placed around the closed salad bowl. Every 12 finished salad bowls are manually placed in a carton box, where it is then stored in a chilled storage area waiting to be distributed during the night shift to different local customers. Figure 1 shows the layout of the salad line. As it will be discussed in the next section, one of the main problems in this line was the inefficiency and waste of time due to several reasons. Thus, one of the objectives in this study was to increase efficiency and to reduce the wasted time.

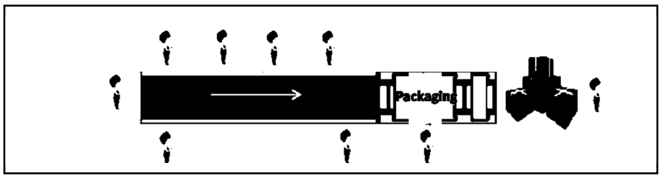

Figure 1: Salad assembly line layout

3.1. Determining the Bottleneck

A bottleneck is defined as the specific point within the production system that gets congested, as it cannot keep up with the incoming flow of products. The occurrence of bottlenecks on the production line is due to the unbalanced workload amongst the workstations. A shift analysis was conducted in the company to identify the bottleneck. As seen from Table 1, minor stoppages had the highest percentages within the shift, with an approximate value of 23%, and were mainly due to the "salad sleeve" worker as seen in Figure 2. Thirteen percent of minor stoppages were due to the labor who packages the finished products within the carton box.

Table 1. Shift Analysis for salad line

Line Status	State	Activity Duration (Hours)	Total Duration (Hours)	Percentage of Total (Hours)
Run	Processing	3.36	3.36	43.47%
Down	Minor Stoppages	1.81	2.1	23.42%
	Wasted Time	0.29		3.75%
Set up	Preparation	0.35	1.27	4.53%
	Changeovers	0.5		6.47%
	Cleaning	0.42		5.43%
Break	Lunch break	1	1	12.94%
Total			7.73	100%

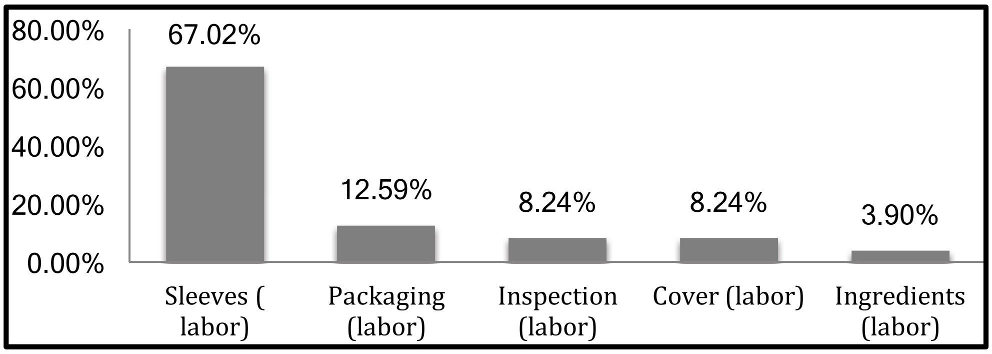

Figure 2: Pareto analysis of line stoppage reasons

3.2. Determining the Cycle Time

The salad line consisted of nine workstations since each worker was considered as a different workstation. Each workstation may consist of a maximum of two work elements, which is defined as the smallest division of a task. The defined cycle time [T_c] is the time it takes to produce one product. Allowances are very important when deciding standard cycle times, which are to be used to rebalance the line. To get the workstation cycle time, each work element must be observed for several times to collect enough data. For our purpose, we have collected 35 data values for each time element. The minimum time value represents the best processing time observed for each work element, and then combined with an allowance to give the workstation cycle time. The following equations have been utilized in calculating the cycle time. Table 2 shows the notations utilized in the formulation below. Table 3 shows the data used in calculating cycle times, which are summarized in the same table.

Table 2. Definition of notations used in allowance calculation equations

Symbol	Definition
i	Set of task numbers = { 1, 2, ..., l }, l = (8,9)
j	Set of work elements = { 1, 2, ..., m}, m = (1,2,3)
k	Set of data points = { 1, 2, ..., n}, n = 35
W_{ea}	Work element allowance
t_{ijk}	j^{th} work element of task i and data k
t_{ai}	Total actual time of task i
min_k	Minimum data point k for work element i
max_k	Maximum data point k for work element i
min_{ci}	Minimum cycle time of task i
R_{ijk}	Range for each work element j
R_{Ti}	Total range of task i

$$W_{ea} = \frac{\min t_{ai} - \min_{ci}}{R_{Ti}} * R_{ijk}$$

$$\min t_{ai} = \min_k [\ \sum_{j=1}^{m} t_{ijk}\ ]$$

$$\min_{ci} = \sum_{j=1}^{m} \min_k(t_{ijk})$$

$$R_{ijk} = \max_k(t_{ijk}) - \min_k(t_{ijk})$$

$$R_{Ti} = \sum_{j=1}^{m} R_{ijk} = \max_k(t_{ijk}) - \min_k(t_{ijk})$$

Table 3. Work element times and cycle times summarized and calculated from collected data

Worker No →		1	2	3	4	5	6	7	8	9
Caesar Salad	**Min Value**	1.46	2.38	1.28	1.27	1.2	1.33	1.06	6.53	-
	Allowances	0	0.28	0	0	0	0	0	1.33	-
	Cycle Time	1.46	2.66	1.28	1.27	1.2	1.33	1.06	7.86	-
Chicken Caesar Salad	**Min Value**	1.46	2.38	1.73	1.32	1.2	1.33	1.06	6.53	-
	Allowances	0	0.28	0.62	0	0	0	0	1.33	-
	Cycle Time	1.46	2.66	2.35	1.32	1.2	1.33	1.06	7.86	-
Greek Salad	**Min Value**	1.46	2.38	2.25	0.93	1.2	1.33	1.06	6.53	-
	Allowances	0	0.28	0.24	0	0	0	0	1.33	-
	Cycle Time	1.46	2.66	2.49	0.93	1.2	1.33	1.06	7.86	-
Pasta Salad	**Min Value**	1.43	2.38	1.16	0.97	0.86	1.2	1.33	1.06	6.53
	Allowances	0	0.28	0	0	0	0	0	0	1.33
	Cycle Time	1.43	2.66	1.16	0.97	0.86	1.2	1.33	1.06	7.86
Four Season Salad	**Min Value**	1.46	1.73	2.38	3.63	2.73	1.2	1.33	1.06	6.53
	Allowances	0	0.26	0.28	0.33	1.08	0	0	0	1.33
	Cycle Time	1.46	1.99	2.66	3.96	3.81	1.2	1.33	1.06	7.86
Tabbouleh Salad	**Min Value**	1.61	2.38	1.84	1.24	1.2	1.33	1.06	6.53	-
	Allowances	0	0.28	0	0	0	0	0	1.33	-
	Cycle Time	1.61	2.66	1.84	1.24	1.2	1.33	1.06	7.86	-
Corn Salad	**Min Value**	1.45	1.59	2.38	2.66	1.56	1.2	1.33	1.06	6.53
	Allowances	0	0.38	0.29	0	0	0	0	0	1.33
	Cycle Time	1.45	1.97	2.66	2.66	1.56	1.2	1.33	1.06	7.86
Mexican Salad	**Min Value**	1.49	2.38	2.99	2.66	1.24	1.2	1.33	1.06	6.53
	Allowances	0	0.28	0.03	0	0	0	0	0	1.33
	Cycle Time	1.49	2.66	3.02	2.66	1.24	1.2	1.33	1.03	7.86
Seafood Salad	**Min Value**	2.78	3.99	2.38	1	2	2.36	1.2	2.39	6.53
	Allowances	0.29	0	0.28	0	0.37	0.25	0	0.4	1.33
	Cycle Time	3.07	3.99	2.66	1	2.37	2.61	1.2	2.79	7.86
Fattoush Salad	**Min Value**	2.66	1.71	1.6	3.02	0.46	1.81	1.2	2.39	6.53
	Allowances	0.24	0.12	0.22	0.06	2.02	0.44	0	0.4	1.33
	Cycle Time	2.9	1.82	1.83	2.43	2.48	2.25	1.2	2.79	7.86

4. Assembly Line Balancing

One of the problems that caused the line to stop was due to the packaging labor; as he had to assemble the box, fill it with the salad products, seal it and then sign it off. As seen from Table 4, before applying the line balancing, most salad variants needed 9 workers. After applying the Computer Method of Sequencing Operations for Assembly Lines (COMSOAL), we saw that the number of workers for some salad variants decreased**.** The best solution is then to use two workers at the beginning of the shift to start opening the boxes (after that, one will continue assembling the boxes while the other goes on the production line). Since opening the box is not done on the line, its work element will be removed from the adjusted system. Another problem for the minor stoppages was due to the sleeves worker. As seen from Figure 3, the workload is distributed between the original worker and the inspection worker (as the inspection worker, in some cases, puts on the sleeves for some of the products). By fractioning the workload, the sleeve worker will be able to keep up with the worker and reduce the minor stoppages.

Table 4. Number of workers allocated to each station before and after redesigning assembly line.

Salad Variant	Current LB	Adjusted LB
Greek Salad	9 workers	9 workers
Fattish Salad	9 workers	9 workers
Chicken Caesar Salad	8 workers	8 workers
Four Season Salad	9 workers	8 workers
Caesar Salad	8 workers	8 workers
Seafood Salad	9 workers	9 workers
Corn Salad	8 workers	8 workers
Mexican Salad	9 workers	8 workers
Tabbouleh Salad	8 workers	8 workers
Pasta Salad	9 workers	7 workers

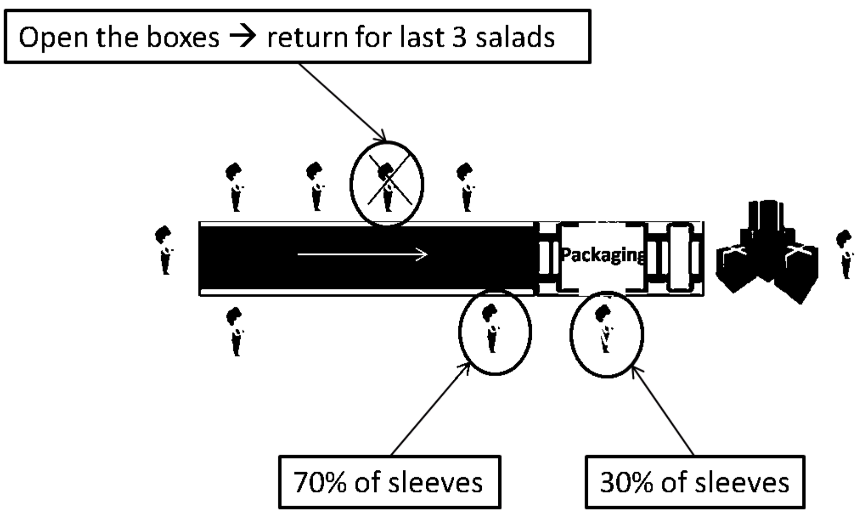

Figure 3. Distribution of work

As seen from Figure 4, the calculated cycle time for each workstation was entered into the COMSOAL Method (Grover, 2007) in order to find the current line efficiency, which was found to be 31.9%. A very important parameter is the Takt time (maximum allowable processing time for each work station), which was used to calculate various line performance measures. After modifying the workstations and using line balancing to balance the workload, the efficiency increased by 15.8%. Figure 5 shows this result. Some of the modifications include mixing some ingredients together to make it one work element, which reduces time. Another modification was a consequence of line balancing, which was reducing the number of workers for some variants. One of the work elements within the packaging workstation was removed and made an external work element, not to be included on the assembly line.

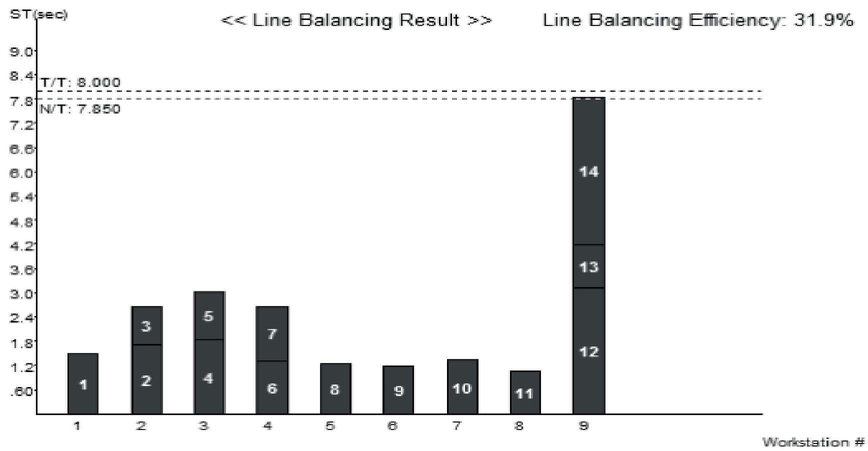

Figure 4. Current system workstations

5. Discussion of Results

As each salad variant was studied differently, line balancing was applied on each salad product. Table 5 summarizes the efficiency improvements after balancing the workload. Figure 6 shows that after applying line balancing, the cycle time was reduced from 3.8 seconds to 2.3 seconds per product. Figure 7 shows that after applying line balancing and removing the minor stoppages, the shift time was reduced from 7.73 hours to 4.29 hour, resulting in a huge reduction of 3.44 hours.

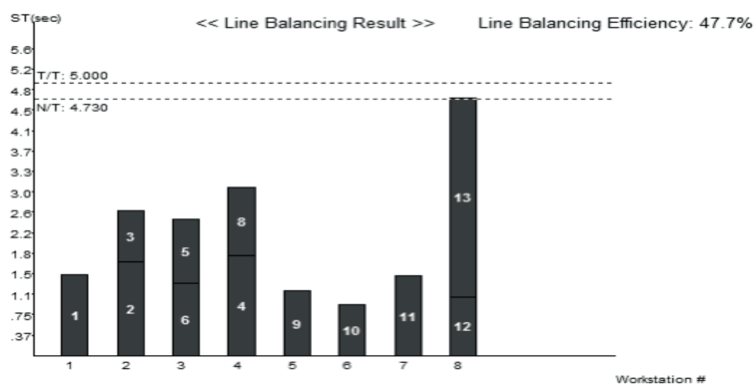

Figure 5. System's adjusted workstations

Table 5. Salad Line variant and average efficiency

Salad Variant	Current LB	Adjusted LB	% Efficiency Increase
Greek Salad	30.9%	44.0%	42.4%
Fattoush Salad	38.6%	54.5%	41.2%
Chicken Caesar Salad	30.6%	42.6%	39.2%
Four Season Salad	35.8%	53.4%	49.2%
Caesar Salad	28.8%	39.6%	37.5%
Seafood Salad	38.5%	53.7%	39.5%
Corn Salad	34.9%	46.4%	33.0%
Mexican Salad	31.9%	47.7%	49.5%
Tabbouleh Salad	29.9%	41.4%	38.5%
Pasta Salad	26.2%	46.5%	77.5%
Average	32.61%	46.98%	44.7%

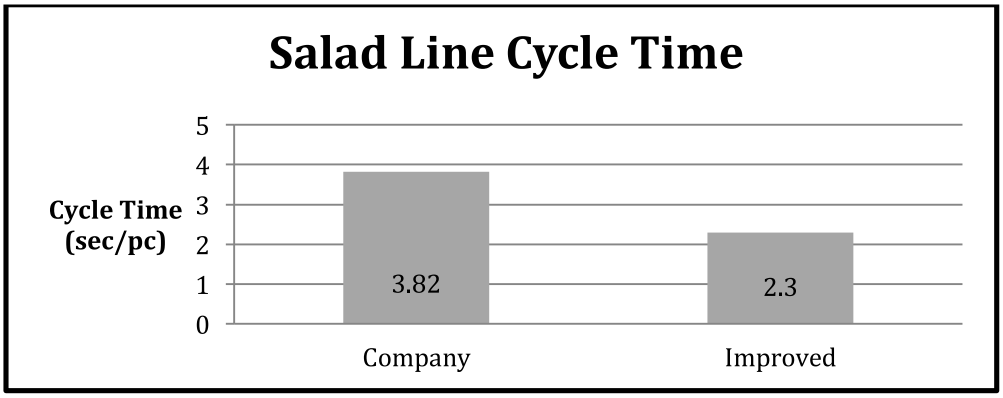

Figure 6. Salad Line cycle time improvement

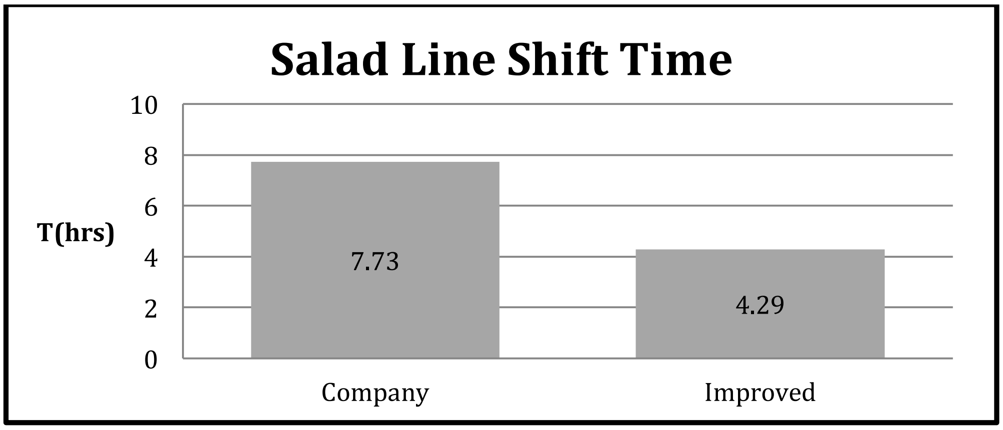

Figure 7. Salad Line Shift hour comparison

Current vs. Improved Efficiency: *Figure 8 shows that after the reduction of the shift time by removing minor stoppages, the efficiency increased from the varying range of 27% to 55% (average of 40%) to approximately 61%.*

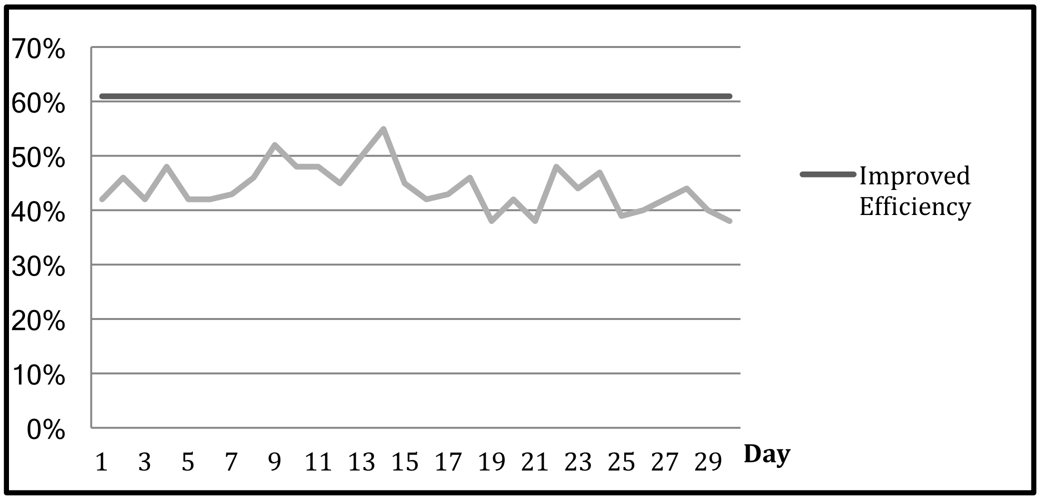

Figure 8. Salad Line current vs. improved efficiency

Current vs. Increased Productivity: *Figure 9 shows that after the removal of all minor stoppages (wasted time and minor stoppages), the productivity of the workers increased from 52 pieces to 93 pieces per person-hour, which was an increase of about 80% or 1.8 times.*

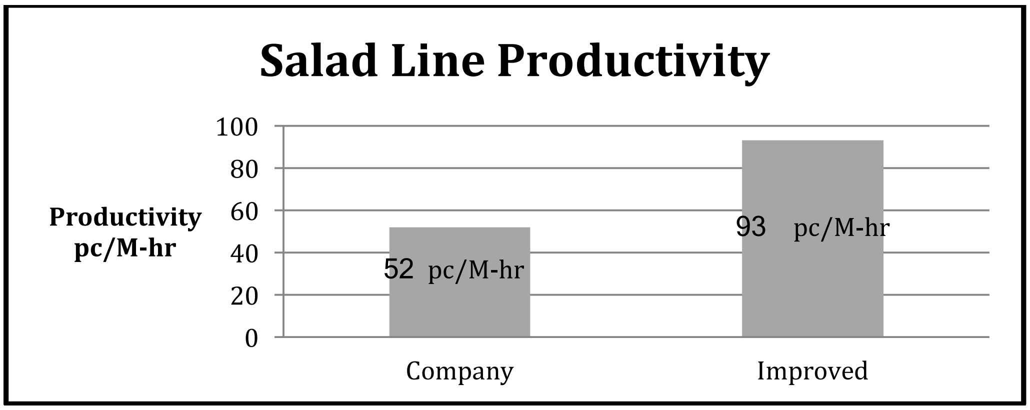

Figure 9. Salad Line productivity comparison

Sequencing Varients of Salads: *Table 6 shows the sequencing variants of salads based on the number of workers while taking into consideration the shared ingredients between each variant.*

Table 6. Salad Line sequencing based on number of workers and ingredients.

Sequence #	Salad Type	# of workers
1	Pasta Salad	7 workers
2	**Tabbouleh** Salad	8 workers
3	Mexican Salad	
4	Corn Salad	
5	Four Season Salad	
6	Caesar Salad	
7	Chicken Caesar Salad	
8	Greek Salad	9 workers
9	Fattoush Salad	
10	Seafood Salad	

Cost Reduction: *In addition to the above improvements in efficiency and other performance measures, overtime was eliminated as a result of the reduction in the shift time to achieve the required daily production. Reduction of overtime resulted in a cost savings of about $5,000 peryear for the salad line only.*

6. Conclusions

Mixed-model assembly lines must be very carefully analyzed and various available tools, including line balancing tools, must be utilized in order to increase line efficiency and its production rate. Manual mixed-model assembly lines are straightforward, where the workload and worker processing time defines many attributes for the assembly line. Line-balancing techniques are the best approach to solve most problems related to time and bottleneck analysis. However, detailed procedures and step by step approaches must be followed to balance a given line, increase its efficiency, and reduce the waste. As it has been shown in the analysis of a basic assembly line in food processing industry in this paper, line efficiency was increased by as much as 44%. Furthermore, using the procedures outlined, cycle time and the required shift time was reduced by as much as 40% and 45% respectively. The procedures and concepts presented in this paper can be utilized by operations managers and production engineers to improve their assembly lines, to achieve higher efficiency and production output.

7. References

Adnan, A. N., Arbaai, N. A., Ismail, A. (2016), "Improvement of overall efficiency of production line by using line balancing", *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 12.

Bolat, A., Savsar, M., and Al-Fawzan, M.A. (1994), "Algorithms for Real-Time Scheduling of Jobs on Mixed Model Assembly Lines", *Computers and Operations Research,* Vol. 21, No. 5, 487-498.

Buyukozkan, K., Kucukkoc, I., Satoglu, S., Zhang, D.Z (2016), "Lexicographic bottleneckmixed model assembly line balancing problem: Artificial bee colony and tabu-search approaches with optimized parameters", *Elsevier,* vol.50, pp. 151–166.

Groover, M. P., Automation, Production Systems, and Computer-Integrated Manufacturing, 3rd Edition, Prentice Hall Press, NJ, USA, 2007

Grzechca, W. (2015), "Assembly Line Balancing Problem with Quality Inspection Stations", *Cybernetics and Intelligent Systems (CIS) and IEEE Conference on Robotics, Automation and Mechatronics (RAM), IEEE 7th International Conference.*

Make, M. R. A., Rashid, M. F. F., and Razali, M. M. (2017) "A review of two-sided assembly line balancing problem," International Journal of Advanced Manufacturing Technology, 89:1743–1763.

Peng, T. (2014) , "A Firing Sequence based Algorithm for Two-Sides Assembly Line Balancing", IEEE 18th International Conference on Computer Supported Cooperative Work in Design.

Unuigbe, A.I., Unuigbe, H.A., Aigboje, E.O. and Ehizibue, P.A. (2016). "Assembly Line Balancing Using Fuzzy Logic: A Case Study of a Tricycle Assembly Line," Open Journal of Optimization, 5, 59-70

Yilmaz, H. and Yilmaz, M. (2016) "A multi-manned assembly line balancing problem with classified teams: a new approach," Assembly Automation, 36 (1), 51-59,

Zhang, D. Z., Kucukkoc, I. (2013), "Balancing Mixed-Model Parallel Two-Sided Assembly Lines", 5th IESM Conference, Rabat, Morocco.

Zupan, H. , Herakovic, N. (2015), "Production line balancing with discrete event simulation: A case study", Elsevier, vol. 48, Issue 3, pp. 2305-2311.

Failure Modes and Effects Analysis (FMEA): Factors Affecting Execution and Implementation of the FMEA and an Alternate Method for Process Risk Assessment

Christopher Kluse[1]

[1]*Bowling Green State University*

ckluse@bgsu.edu

Abstract

The FMEA has long been considered the preferred approach to assess and mitigate risk during design and manufacturing processes. However in practice, FMEA's are often a static document, are frequently the basis for registrar audit findings, and simply are not executed to meet the intent of the FMEA process. FMEA's are created to satisfy customer deliverables, third party registrar audits, and PPAP (Production Part Approval Process) requirements, however FMEA's often fail to deliver risk mitigation and defect prevention benefits claimed in most FMEA training and FMEA instruction documents. After observing this phenomenon in the automotive industry, this researcher used a qualitative design to determine the factors that hinder the FMEA process and lead to static FMEA's that fails to deliver the intended dynamic risk assessment.

This study used a phenomenological based research design to investigate the factors and underlying conditions that lead to poor execution of the FMEA process and to poor development of the FMEA document. Participants were also asked to offer suggestions or alternate methods to assess risk in lieu of the FMEA process. In this study, 13 participants were interviewed; each of these participants are engineers from Tier 1 automotive manufacturing facilities and are responsible to lead and develop FMEA's for current automotive components. The study was limited to the automotive industry and those engineers that have experience in FMEA development and have received formal training in the FMEA process.

1. Introduction

Failure mode and effects analysis has been an accepted risk assessment tool since introduction of MIL-P-1629 by the military in 1949. This document was a comprehensive method and established the "requirements and procedures for performing a failure mode, effects, and criticality analysis (FMECA) to systematically evaluate and document, by item failure mode analysis, the potential impact of each functional or hardware failure on mission success, personnel and system safety, system performance, maintainability, and maintenance requirements." (MIL-STD-1629A). The standard has since been cancelled (MIL-STD-1629A Note 3, 1998), however the methodology has been adapted by numerous industries including the automotive industry in the 1980's. The Automotive Industry Action Group published Potential Failure Mode and Effects Analysis (FMEA) in 1993 (Automotive Industry Action Group, 2008), which represented a collaborative effort involving Ford, Chrysler (currently FCA LLC) and General Motors. This reference manual describes the guidelines to prepare design FMEA's (DFMEA) and process FMEA's (PFMEA), furthermore this reference manual outlines the importance of management support as well as the need for a defined process to create, review and revise the FMEA so it can serve as a living document and then allow the organization to realize the associated benefits. Most of the automobile manufacturers require the use of this document and process by sub tier suppliers during design and manufacture of automotive components. With the development of quality standards such as ISO 9000, QS 9000 (obsolete in 1998), and TS 16949 (revised in 2016), the FMEA has become not only a required risk assessment tool, but has also become a significant focus and constituent of quality management systems. As a result, the FMEA has become an important, significant document often reviewed during third party audits, customer audits and internal organizational reviews. However, what is somewhat of a paradox are the "quality" of the FMEA document and the execution of the FMEA process; often the process and document do not reflect the perceived importance of this document. As stated by Netherton (2010) "While it's readily available and one of the most powerful tools in the Six Sigma toolbox, FMEA is one of the most misunderstood and most misused methods" (pg. 13). Furthermore, Ganot (2015) in *Lean and Friendly FMEA Presentation* states: "Eventually, most often it (FMEA) becomes a form filling exercise to provide a deliverable document rather than a tool to focus on preventing problems and reduce risks" and "Many companies do not have the requirements, neither the budget nor the time to conduct a classical FMEA" (Ganot, 2015). Based on this researchers experience in the automotive industry, claims and observations by others such as Netherton (2010) & Ganot (2015), this study seeks to determine the reasons for the lack of robust FMEA development, and alternate methods that can be used in lieu of the "accepted" FMEA process in the automotive industry.

2. FMEA – accepted method, automotive industry

The accepted guidelines for FMEA development in the automotive industry are described in *Potential Failure Mode and Effects Analysis, 4th edition* (AIAG, 2008) published by the Automotive Industry Action Group. In brief, for each constituent in the design process or each function in the manufacturing process, a risk priority number (RPN) is calculated thus relatively ranking risks in a component design or in component manufacture. The RPN values are the product of the severity value (S), occurrence value (O), and the detection value (D). Thus RPN = S x O x D. The severity, occurrence and detection values range from 1 – 10, where 1 represents minimal risk and 10 represents the ultimate risk for each category. Values from 1 – 10 are assigned by using the severity, occurrence and detection ranking tables outlined in Potential Failure Mode and Effects Analysis, 4th edition (AIAG, 2008). In addition to DFMEA & PFMEA development guidelines, the reference manual outlines the FMEA process (i.e. strategy) and offers several sample FMEA forms as well as appendices that suggest alternate approaches to risk assessment. These alternate methods in part address some of the criticisms of the FMEA process outlined in the reference manual. Typical information contained in a Process FMEA (PFMEA) is depicted below:

Process #	Process Step / Function/ Requirement	Potential Failure Mode	Potential Effects of Failure	SEV	Classification	Potential Causes of Failure	OCC	Current Process Controls - Prevention	Current Process Controls - Detection	DET	RPN	Recommended Action	Responsibility & Target Completion Date	Actions Taken & Effective Date	SEV	OCC	DET	RPN

Figure 1. Typical FMEA information

3. Literature Review

The literature review focuses on criticism of the current "accepted" FMEA template, FMEA development process and RPN calculation method. A brief summary of each follows.

Researchers Narayanagounder & Gurusami (2009) proposed a new approach for RPN calculation for a DMFEA using analysis of variance, and offered the following two (2) drawbacks to the accepted FMEA model. The first drawback lies within the RPN calculation. Since RPN is a product of the severity, occurrence and detection, in any given FMEA one could have identical RPN values yet the true risk potential may be different. Thus, the current method lacks true discrete risk ranking which is one of the main reasons that FMEA's are developed. A second shortcoming centers on selection of any particular severity, occurrence and detection value; if FMEA team members disagree, often times an accepted practice is to average the values of the disagreeing team members, the result is potentially an identical RPN value. Narayanagounder & Gurusami (2009) proposed model is designed specially to handle these two drawbacks.

Sankar and Prabhu (2001) described a new method to rank failure for identification of corrective action based on identified shortcoming of the FMEA process. Sankar and Prabhu assert that traditional RPN calculation (S x O x D) is "oversimplified" and does not account for potential weighting differences between severity, occurrence and detection. Furthermore these researchers present an important observation regarding the individual ranking scale; the scales are essentially non linear, thus resulting in relative RPN values where a lower RPN may be far more of a concern for product failure and should be the target of corrective action. Their argument is similar to Narayanagounder & Gurusami (2009) however the alternative model offered is based on risk priority ranks (RPR's) that largely depict the full scale of RPN combinations (i.e. current method) from 1 to 1,000. These combinations are then ranked from low to high risk; therefore the failure mode with a higher assigned rank is given priority for corrective action. The full discussion can be found in Sankar and Prabhu (2009) paper, *Modified approach for prioritization of failures in a system failure mode and effects analysis*.

Yuqing, Z., Jiawei, X., Yongteng, Z., & Jihong, P. (2016) present an improved FMEA method based on weighted geometric operator and fuzzy priority. In their discussion of the FMEA, these authors offer the following shortcoming of the FMEA process: (a) experts are required for risk factor assignment and analysis, however the human aspect (decision uncertainty) can lead to inaccurate estimates; (b) expert estimate of risk are based on each expert's individual knowledge thus significant disparity between resulting RPN's result; and (c) as mentioned by several researchers, the severity, occurrence and detection are given identical weight, when in practice this may not be an accurate representation of risk. The resulting model offered by Yuqing, Z., et. al., (2016), addressed these shortcomings by lowering the expert's weighting thereby accounting for any deviation of the expert's perspective relative to the group consensus.

In addition to the three alternate FMEA methods presented above, several other researchers have offered varied perspectives on how to complete the FMEA and/or calculate RPN values. These include Fiorenzo Franceschini and Maurizio Galetto (2001), Bradley and Guerrero (2011), Ben-Daya and Raouf (1996), Rhee and Ishii (2003), and Chen (2007). This is certainly not a complete list of alternative models; the reader is encouraged to review these methods and explore others as outlined in Narayanagounder & Gurusami's (2009) article "*A New Approach for Prioritization of Failure Modes in Design FMEA using ANOVA*."

Most of the alternate methods reviewed were primarily motivated by the desire to address the shortcomings of the current method to calculate RPN and rank risk. From a technical perspective, each offers a viable alternative. Many are complicated methods that do offer a valid option for RPN calculation while alleviating FMEA shortcomings. However, the motivation for this research is that of a holistic approach to FMEA. Complicated methods may further lead to poor FMEA development or discourage the development of a FMEA to assess risk. This is mentioned due to this researchers experience with the FMEA process. Literature is scant when looking at why the FMEA is not properly used as a risk mitigation tool and what are the reasons for lack of use and/or improper FMEA development. Many papers address mistakes to avoid when developing a FMEA, but there is a lack of research looking to determine why FMEA's are not developed as suggested by the scope and guidelines in the *Potential Failure Mode and Effects Analysis, 4th edition* reference manual (AIAG, 2008).

4. Problem statement & research questions

In this study this researcher explores the following questions:

(1) What are the reasons for incomplete FMEA's, static FMEA's and FMEA's that are not fully developed as suggested by the automotive guidelines in Potential Failure Mode and Effects Analysis, 4th edition reference manual (AIAG, 2008); and

(2) What are suggested practices to evaluate/mitigate risk in lieu of the accepted FMEA method and what can be done to assure development of a robust FMEA under the guidelines of Potential Failure Mode and Effects Analysis, 4th edition reference manual (AIAG, 2008).

5. Methodology, sample and data analysis strategy

A phenomenological based research design was used to investigate the research questions. According to Creswell (2007), "Phenomenological study describes the meaning of several individuals of their lived experience of a concept or phenomenon. Phenomenologists focus on describing what all participant have in common as they experience a phenomenon" (57 – 58). Phenomenology was used to determine factors affecting FMEA development among experienced engineers in the automotive component manufacturing sector.

5.1. Sample Strategy

The population for this study are all engineers employed by Tier I automotive component supplier that are responsible to develop FMEA's for their respective organizations in North America. The selected sample used a convenience sampling strategy combined with criteria for selection of participants. Each participant must:

(1) have responsibility for FMEA development and

(2) have completed formal training in FMEA development.

Twenty engineers were identified as potential participants and 13 agreed to participate. According to Creswell (2007), "Polkinghorne recommends that researchers interview from 5 to 25 individuals who have all experienced the phenomenon" (p. 61). To validate the number (sample size) of participants, this researcher sought validation from Englander (2012) who asserted: " Now, if one can achieve the goal of representativeness and generalizability from a small number of research participants, then a qualitative method such as phenomenology can meet this general scientific criterion as well as a statistically-based approach" (p. 20). Additionally, Englander (2012) stated: "On the other hand, if a researcher has a qualitative purpose and a qualitative research question, he or she seeks knowledge of the content of the experience, often in depth, to seek the meaning of a phenomenon, not "how many" people who have experienced such phenomena" (pg. 21). In this research the intent is purely qualitative and the corresponding research questions are qualitative. Based on Englander's rationale and Polkinghorne's sample size suggestion, the sample size of 13 is deemed appropriate for this study. Each participant was informed that specific answers would not be associated with their identify, their respective organization would remain confidential, their identity would remain confidential, responses would remain anonymous and results of the study would be made available upon request.

5.2. Data Collection Method/Instrument

The primary method for data collection is an interview with eight open-ended questions. Each participant was asked each question and the answer documented by the researcher. Follow up questioning by the researcher provided additional data when clarification was needed or where additional information was beneficial to support answering the research questions. The questions are listed in Appendix A.

5.3. Data Analysis Strategy

This researcher used a strategy presented by Creswell (2007) that represents a modified version of Stevick-Colaizzi-Keen method. The modified version as presented by Moustakas (1994) entails the following steps used for data analysis in this study.

(1) The researcher describes his/her experience with the subject being investigated.
(2) The lists of significant statements are compiled from the data source by the researcher. In this study the data source are the 8 open ended questions presented to participants.
(3) Compile the significance statements into central themes or “meaning units”.
(4) Develop a description of the participants experience with the subject; in this description, enhance with participant specific examples. This is deemed the “textural description”.
(5) Describe *how*, and in *what setting* the participants experienced the subject or phenomenon. This step constitutes the “structural description”.
(6) Culminate the participants experience by combining the textural and structural description into a final, composite paragraph that describes what and *how* participants experienced the phenomenon.

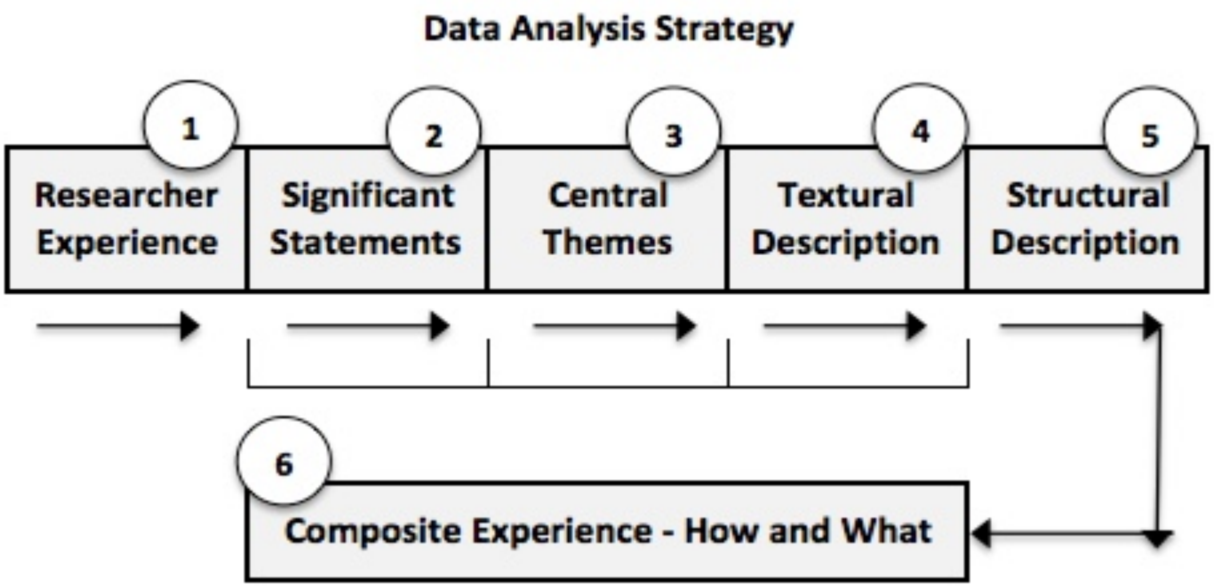

Figure 2. Data analysis strategy

6. Limitations & delimitations

Survey questions are limited to PFMEA development within automotive component suppliers, the DFMEA is not considered. PFMEA experience varied from 2 years to 8 years among participants. Product differences are not considered in this study, each set of engineer’s respective organizations manufactured different components. Customer requirements for FMEA development are not considered in the survey, thus requirements for PFMEA could affect the PFMEA process and participant response.

7. Data analysis and results

7.1. Researcher Experience

As a former quality professional in the automotive industry, with a majority of the time spent in a Quality Management role, this researcher was either directly or indirectly responsible for FMEA development and/or supporting those within the organization and the supply base for FMEA development. In brief, this researcher observed poor FMEA development, third party audit trivial non-conformances, customer dissatisfaction with the FMEA, and frustration with the entire process by individuals, engineers, and managers involved in the process. Most of those involved did not see the value in the process when compared against the time to complete the FMEA properly, meaning conforming to AIAG guidelines. When asked to conduct FMEA training for process engineers with a tier I automotive company, the first question posed to the training group was "who has already had FMEA training", most in the room responded as "yes" and the follow up question was "Why do we feel we need further training"; the spirited discussion that followed led to this research.

7.2. Significant Statements

Significant statements offered by the participants were compiled from the 8 interview questions. In cases where no majority theme existed, it is noted in the textural description. Significant statements include (1) responsibility for PFMEA development are the engineering and/or quality departments within the organization; (2) while most participants believed the PFMEA was an effective tool, most did not have the PFMEA as a high priority compared with other duties; (3) All subjects agreed that prior training did adequately prepare one for developing a PFMEA properly (AIAG Standards); (4) Most participants did not receive positive feedback on PFMEA's by the customer and auditors. Some had never been through a third party audit; (5) Most described reasons for PFMEA disparity by customer and auditor due to inaccurate RPN or S, O, D values, generic wording, lack of links to the control plan, vast/complicated guidelines to develop and statements of failure modes and effects not agreed upon. Most believed subjectivity, lack of experience with the process and trivial findings drove the unacceptable status; (6) Some participants felt management did not support them with time and/or resources, others mentioned lack of resources but supported management because the PFMEA is not a priority. Several mentioned the inherit subjectivity, lack of a PFMEA process, and few believed the process was too complex vs. the benefits reaped from the PFMEA; (7) Most participants expressed a common theme that PFMEA can add value, however most added that it was too tedious, subjective, a paper exercise, created only to satisfy a requirement. Many disliked the process of team PFMEA development. No participants offered any tangible benefits with the exception that the PFMEA serves as a good brainstorm exercise; (8) Suggestions and alternate approaches ranged from single scale risk assessment, error proof matrix, and criticality ranking by detection technology. Participants stated that the customer was not embracing alternate methods. Furthermore, this researcher presented the alternate methods from the literature review and asked participants if these alternate methods would be considered in lieu of the typical PFMEA. Unanimously, all subjects agreed on a similar theme; "too complicated" for our application and would not use.

7.3. Central Themes

The following are the central themes derived from participant significant statements:

- While the PFMEA can be a valuable tool, due to tedious development, vast and intricate guidelines, subjectivity, and complicated RPN's, the PFMEA method is not properly utilized or developed as suggested by current guidelines.

- The PFMEA is deemed unacceptable due to subjective evaluation, trivial critique, generic language, and disagreement regarding RPN's and S, O, D values.
- The PFMEA is not a priority for a majority of participants as other job duties are more important.
- PFMEA development is poor due to lack of resources, minimal emphasis or placed on the PFMEA and PFMEA development process, lack of management support and minimal benefits realized from the PFMEA.
- Alternate methods exist and have been utilized by participants as a PFMEA alternative; all offer a far more simplistic approach.

7.4. Textural, structural and participant cumulative experience

PFMEA guidelines are outlined by AIAG and reviewed by the internal customers, external customers and third party auditors. This represents the setting with which the participants experience PFMEA development. Within this setting, the participants overall impression of the PFMEA is that the PFMEA can serve as a value added tool, however due to subjectivity of the severity, occurrence and detection values and the varying perception at the time of writing the PFMEA, the PFMEA document is generally viewed differently by others (customer & auditors) thereby causing PFMEA to be critiqued in a trivial fashion and often deemed unacceptable. Furthermore, in the scope of the participants' job duties, the PFMEA was generally low on the priority list due to lack of management support, the required effort to complete the PFMEA versus, the return on effort, the intricacy of the current guidelines and/or customer expectations, requirement to develop using a cross functional team, and the lack of resources to support robust PFMEA development. The PFMEA is often reviewed/revised when it is going for review by the customer or may be subject to an audit. As a result, the PFMEA becomes a non-value added paper exercise resulting in participant's unwillingness to develop fully to accepted guidelines. Since all participants are engineers responsible for robust process development, the need for structured risk identification and ranking method is recognized as a critical need. However a more simplistic approach in lieu of a fully developed PFMEA is desired. Many participants shared alternatives; based on the various alternatives, a final alternate PFMEA method has been constructed. This represents a simplistic, yet effective method to assess risk and track improvement as a *key process indicator* (KPI) over time.

7.5. Alternate method – Process KPI

An alternate method and example is as follows:

Process Risk KPI	
Process	Assembly Process - Automotive
Total Process Steps	100

Grade	Number of process steps with grade of:	Status
1	19	Green Status
2	23	
3	18	
4	25	Yellow Status
5	15	Red Status

Overall Error Proof KPI	**60.0%**	**G**
	25.0%	**Y**
	15.0%	**R**

Error Proof Grade	Criteria	Error Proof Scale
Grade 1	Can not **MANUFACTURE** a defect	1
Grade 2	Can not **PASS** defect to next process	2
Grade 3	Can not **ACCEPT** defect from prior process	3
Grade 4	MAY **prevent** defect	4
Grade 5	MAY **detect** defect	5

Figure 3. Process risk scale - KPI

This method was a combination of suggestions by participants and knowledge gained in FMEA participant training offered by Prezign Inc., (Meilke, 2014). In this method, each step of the process is evaluated based on the degree of error proof within each step of the process. Those process steps with an error proof score of 4 and 5 become the focal point for recommended actions. On a monthly basis, the objective is to reduce the red and yellow grades and increase the green grade. While the red and yellow are not "ranked" this has an advantage by allowing the limited team to discuss and determine which process represents the best candidate(s) for action based on customer needs, resources, etc. The subjective nature of the RPN is removed with this process since the top three "grades" are discrete. Grade 4 & 5 can offer subjectivity, however both of these categories are in the "action required" grade. Furthermore, the percentage green value is then tracked as a process *Key Process Indicator* (KPI) over time as shown below in figure 4.

Figure 3 represents an example of the proposed alternate method. In this example, an automotive component assembly process consists of 100 process steps. When analyzing all 100 steps in the process and using the criteria in figure 3 to assign the error proof grade, it was determined that 19 process steps classify as grade 1 error proof, 23 process steps as grade 2 error proof, and 18 process steps as grade 3 error proof. Thus 60% of the process falls into the green error proof category and does not require action. Looking at the remaining 40 process steps, 25 process steps fall into the grade 4 or yellow error proof category and thereby action to mitigate risk in these processes may be necessary. The remaining 15 process steps fit into the grade 5 or red category where action to prevent risk is suggested (unless economical reasons or practical reasons do not dictate action). Plotting this data against time results in the Process Risk KPI that depicts the relative process risk over time and demonstrates a quantitative measure of continual improvement. This is shown in figure 4 below.

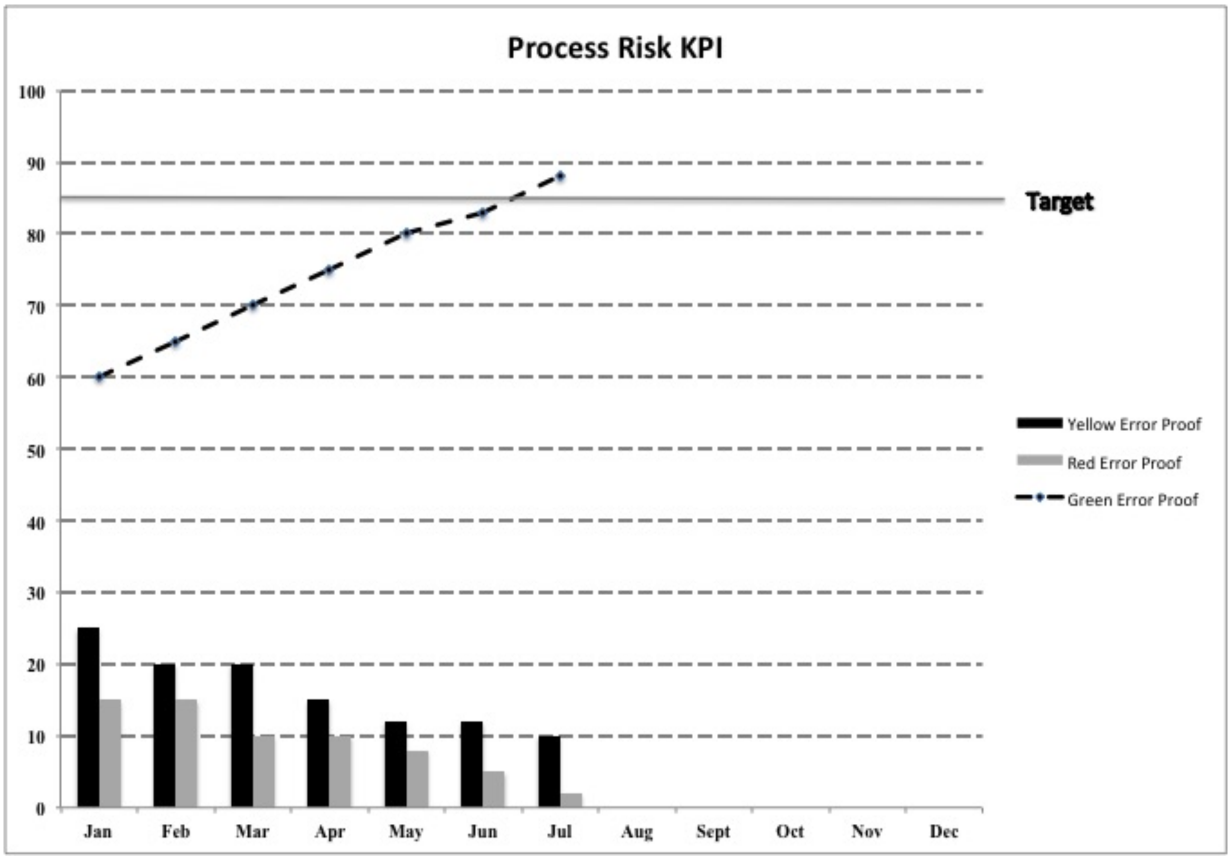

Figure 4. Process risk KPI

8. Conclusions and further research opportunities

This research documented the many criticisms and real life application concerns of those who are required to use the accepted model of the PFMEA as a risk analysis and mitigation tool. While most participants did acknowledge the importance of the accepted PFMEA as a valid risk assessment tool, the inherent reasons for poor, inaccurate, nonconforming and out of date PFMEA's have been identified. Using these concerns, an alternate approach is offered to minimize many of the non-management related concerns. The issues associated with poor PFMEA development identified in this study can be used for both future researchers and practitioners as a baseline for improvement of the PFMEA tool and PFMEA process. A future researcher may further validate this study by interviewing additional subjects and the practitioner can use or alter the proposed method to develop an improved PFMEA to satisfy the customer and improve internal processes. Additionally, the future researcher may investigate the management and organizational culture related reasons why PFMEA's are generally in need of improvement. Soliciting the perspective of the customer and third party auditors in a similar study could also help determine the issues associated with PFMEA and the future of PFMEA guidelines. The PFMEA is considered a defect prevention and risk reduction tool; a correlation study between robust PFMEA development and product quality, reliability, customer quality rating and/or vehicle recalls could validate the use of the current PFMEA process. An OEM endorsed comparison trial between the AIAG FMEA process and those offered by participants in the research and literature review could validate an alternate method. One may investigate and summarize participant experience and perception with use of the alternate tools to determine if they are effective. While the solution offered in the research may not be flawless, this alternative approach to FMEA along with others such as Ganot (2015) distinctly considers the current environment of FMEA development and incorporates the voice of the user, i.e. those who are responsible for FMEA development, defect prevention and risk reduction. In an era where failure has been widely publicized (automotive recalls, cell phone batteries exploding, various food recalls) this may be the ideal time to develop an efficient, effective FMEA tool and FMEA development process to assure quality and mitigate risk to the consumer.

9. References

Automotive Industry Action Group, (2008). *Potential Failure Mode and Effects Analysis, Reference Manual, 4th edition.* Copyright Chrysler LLC, Ford Motor Company, General Motors Corporation.

Bradley, J., and Guerrero, H. (2011). An Alternate FMEA Method for Simple and Accurate Ranking of Failure Modes. *Decision Sciences*, 42(3), 743 – 771.

Ben-Daya, M., and Raouf, A. (1996). A Revised Failure Mode and Effects Analysis Model. *International Journal of Quality & Reliability Management, 13*(1), 43 – 47.

Chen, Jih Kuang (2007). Utility Priority Number Evaluation for FMEA. *Journal of Failure Analysis and Prevention*, 7(5), 321 –328

Creswell, J. (2007). *Qualitative Inquiry and Research Design; Choosing Among Five Approaches*, *2nd edition*. Thousand Oaks, CA: Sage Publications, Inc. pg. 57 – 58.

Englander, M. (2012). The Interview: Data Collection in Descriptive Phenomenological Human Scientific Research. *Journal of Phenomenological Psychology, 43*(1), 13 – 35. doi:10.1163/156916212X632943

Franceschini, F. and Galetto, M. (2001). A New Approach for Evaluation of Risk Priorities of Failure Modes in FMEA, *International Journal of Production Research*, *39*(13), 2991-3002.

Ganot, Amnon (2015). *Lean and Friendly FMEA.* Presentation to International Applied Reliability Symposium, Tucson Arizona, June 4th 2015. Retrieved from http://www.isq.org.il/wp-content/uploads/Quality_2015_lectures_2.4_2_Ganot_PP.pdf

Meilke, Todd (2014). *Manufacturing Tools. Process Failure Modes Effects and Analysis and Process Control Plan*. Prezign, Inc.

Military Specification MIL-P-1629 (1949). *Procedures for Performing a Failure Mode Effects and Criticality Analysis*, Department of Defense.

Military Specification MIL-STD-1629 Rev A, Notice 3 (1998). *Procedures for Performing a Failure Mode Effects and Criticality Analysis,* Department of Defense.

Moustakas, C. (1994). *Phenomenological Research Methods*. Thousand Oaks, CA: Sage Publications.

Narayanagounder, S. , Gurusami, K. (2009). A New Approach for Prioritization of Failure Modes in Design FMEA using ANOVA. *World Academy of Science, Engineering and Technology, International Science Index 25, International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering, 3*(1), 73 - 80.

Netherton, Gary, S. (2010). Making the Most of It. *The Six Sigma Forum Magazine, 10*(1), 10 – 14.. Milwaukee, WI: ASQ Quality Press.

Ravi Sankar, N., and Prabhu, B. S. (2001). Modified Approach for Prioritization of Failures in a System Failure Mode and Effects Analysis. *International Journal of Quality & Reliability Management, 18*(3), 324-336. doi:10.1108/02656710110383737

Rhee, S. J., and Ishii, K. (2003). Using Cost based FMEA to Enhance Reliability and Serviceability. *Journal of Advanced Engineering Informatics,* 17, 179-188.Zhou, YQ., Xia, JW., Zhong, YT., and Pang, J. (2016) An improved FMEA method based on the linguistic weighted geometric operator and fuzzy priority, *Quality Engineering, 28*(4), 491-498, doi: 10.1080/08982112.2015.1132320

10. Appendix A – Interview questions

(1) What department and/or individual is responsible to develop, review and approve PFMEA's in your organization.
(2) Offer your perspective (i.e. agree, disagree, explain) on the importance of the PFMEA as risk mitigation tool and describe the relative importance of PFMEA development vs. your other job duties.
(3) The formal FMEA training that I received in the past: (a) prepared me to complete a FMEA properly, (b) did not prepare me to complete a FMEA properly. Offer your comments and a specific example to support you answer.
(4) In general, have the majority of your PMFEA's been considered acceptable by (a) the customer, and/or (b) outside auditor?
(5) Describe the reasons (from the perspective of the customer or auditor) why the PFMEA is not considered acceptable. Offer specific examples where possible. If they have been acceptable, reply "not applicable".
(6) From your perspective (internal reasons) describe why the PFMEA's are not prepared properly and are not acceptable to the customer and outside auditor.
(7) Do you feel that the PFMEA adds value and is an effective risk reduction and defect prevention tool? Offer any benefits and shortcomings for PFMEA use.
(8) Offer your suggestions to improve the FMEA process including alternative approaches to PFMEA that you have used or would like to use in lieu of the FMEA

Antithetic Multimodal Random Variates

Dennis Ridley, Ph.D.[1]
Pierre Ngnepieba, Ph.D.[1]
[1]*Florida A&M University*
dridley@fsu.edu; pierre.ngnepieba@gmail.com

Abstract

Antithetic random variates are a pair of random variate and its transformed random variate for which their correlation coefficient is minus one. One application is antithetic time series analysis where the transformation is a power transformation. In all applications so far, the assumption is that the subject random variate is unimodal. The case of a multimodal random variate is investigated to verify that the original and power transformed random variates continue to be antithetic.

1. Introduction

Several methods and studies have been made for improving random numbers and computer simulation. Hammersley and Morton (1956) proposed antithetic random numbers r and 1-r. Each was used to perform a computer simulation. The responses from the two simulations were then averaged to obtain a new response expected to have smaller variance. If this were always true, the length of the simulations could be shortened and the precision increased. As it turns out, the variance is reduced some of the time, but sometimes the variance increases (Kleijnen, 1975). For additional information and studies see Cheng (1982), Kroese, Taimre and Botev (2011).

Ferrenberg, Landau, and Wong. 1992) were concerned with the precision of applications in physics. They found that small traces of serial correlation led to bias error in the response, even when using so called good random numbers of Marsaglia (1961,1964,1968), Proykova (2000). See also, Park and Miller (1988). Another application is antithetic random variables in time series analysis and forecasting (Constantini, Gunter, and Kunst, 2017). , (Kaczynski, Leemis, Loehr, and McQueston, 2012)., (Ridley, 1995, 1997, 1999, 2016), (Ridley, Ngnepieba, and Duke, 2013)., (Ridley and Ngnepieba, 2014) and (Soize, 2015). That application involves a power transformation. In all applications so far, the assumption was made that the subject random variable was unimodal. In this paper the case of multimodal random variates is investigated to verify that the original and power transformed random variates continue to be antithetic.

2. Uniformly distributed random number

Consider a random number *r~U(0,1)*, uniformly distributed on the interval from 0 to 1 with mean ½ and variance 1/12. From these we generate a normally distributed random variate from the sum of K contiguous uniformly distributed random numbers $r_1, r_2, \dots, r_K; r_{K+1}, r_{K+2}, \dots, r_{2K}; r_{2K+1}, r_{2K+2}, \dots, r_{3K}; \dots$.

3. Unimodal normal distribution

A set of m unimodal approximately normally distributed random variates with mean μ_1 is summarized as follows.

$$X_i = \mu_1 - \frac{1}{2} + K^{-1}\sum_{k=1}^{K} r_{(i-1)K+k}\,, i = 1,2,..,m$$
where $r \sim U(0,1)$ and $X_i \sim N(\mu_1, 1/12K)$, $\mathrm{K} \geq 12$.

A second set of m unimodal approximately normally distributed random variates with mean $\mu_2 > \mu_1$ is summarized as follows.

$$X_{i+m} = \mu_2 - \frac{1}{2} + K^{-1}\sum_{k=1}^{K} r_{(i+m-1)K+k},$$
$$i = 1,2,..,m$$
where $X_{i+m} \sim N(\mu_2, 1/12K)$, $\mathrm{K} \geq 12$.

The means $\mu_1 = 0.1$ and $\mu_2 = 0.2$ were chosen large enough to avoid any negative values for X_i. The histogram for the unimodal distribution is plotted in Figure 1a.

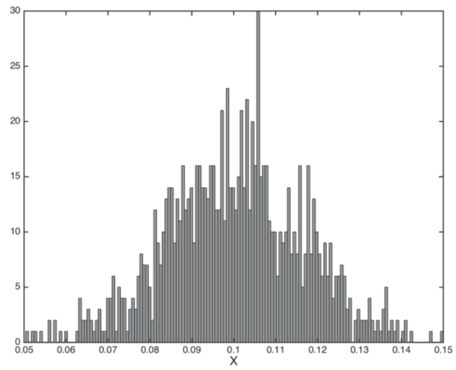

Figure 1a. Histogram for a unimodal distribution

4. Correlation

Antithetic variates X_i and X_i^p are variates that are perfectly negatively correlated. To illustrate this, the sample correlation coefficient is calculated from

$$\hat{\rho} = \lim_{p \to 0^-} Corr(X_i, X_i^p)\,, i = 1,2,3, \ldots, m$$

where $\hat{\rho}$ is the sample correlation for the finite population of size m. The sample correlation for the unimodal distribution is shown in Figure 1b.

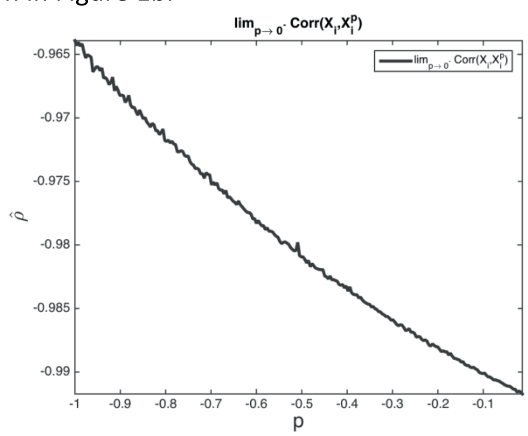

Figure 1b. Sample correlation for an antithetic unimodal distribution

5. Bimodal distribution

A set of bimodal normally distributed random variates with mean μ_1 and μ_2 is constructed from

$$X_1, X_2, X_3, \dots, X_m, X_{m+1}, X_{m+2}, X_{m+3}, , , X_{2m}.$$

The histogram for the bimodal distribution is plotted in Figure 2a.

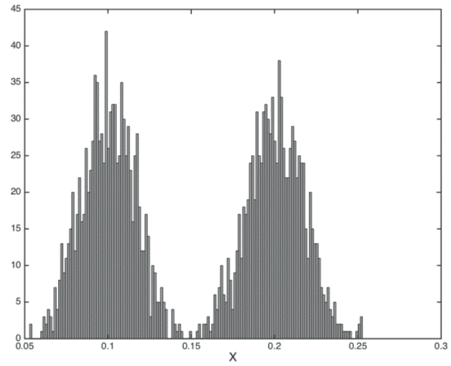

Figure 2a. Histogram for a bimodal distribution

The sample correlation $\hat{\rho} = \lim_{p \to 0^-} Corr(X_i, X_i^p)$, $i = 1,2,3, \dots$,2m for the bimodal distribution is shown in Figure 2b.

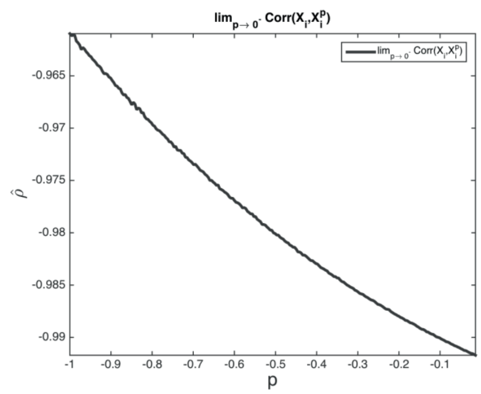

Figure 2b. Sample correlation for an antithetic bimodal distribution

By extension, a third set of unimodal normally distributed random variates with mean μ_3=0.3 is constructed. All three unimodal random variates were concatenated to form a trimodal distribution. The histogram for the trimodal distribution is plotted in Figure 3a.

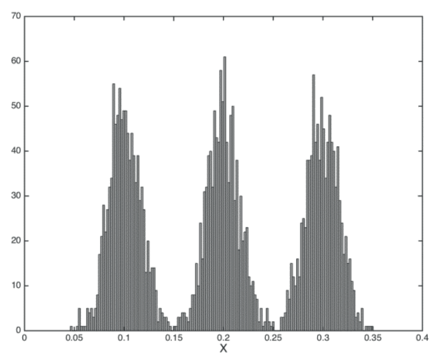

Figure 3a. Histogram for a trimodal distribution

The sample correlation $\hat{\rho} = \lim_{p \to 0^-} Corr(X_i, X_i^p)$, $i = 1,2,3, \ldots, 3m$ for the trimodal distribution is shown in Figure 3b.

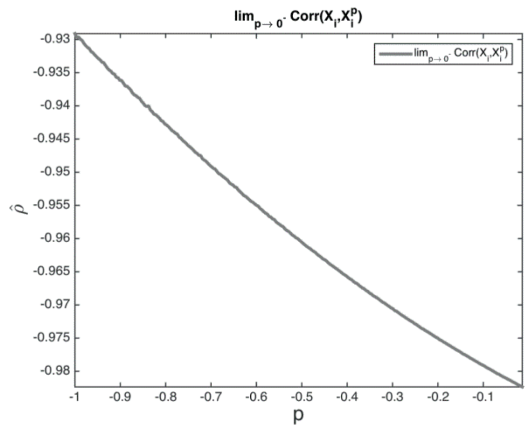

Figure 3b. Sample correlation for an antithetic trimodal distribution

6. Conclusions

Three sets of normally distributed random variates were constructed. One set unimodal, one bimodal and one trimodal. In each case the correlation between X_i and $X_i^p \to -1$ as $p \to 0^-$. Therefore, antithetic variates applies not only to the unimodal distribution, it also applies to the multimodal distribution.

7. References

Cheng, R.C.H., (1982). The Use of Antithetic Variates in Computer Simulations, *J. Opl Res. Soc.* 33, 229-237.

Constantini, M., Gunter, U. & Kunst, R. M. (2017). Forecast combinations in a DSGE-VAR lab, *Journal of Forecasting,* 36, 305-324. DOI: 10.1002/for.2427.

Ferrenberg, A.M., Landau, D.P. & Wong. (1992). Monte Carlo Simulations: Hidden errors from "good" random number generators, *Physical Review Letters*, 69(23), 3382-3384.

Hammersley, J.M., & Morton, K. W. (1956). A new Monte Carlo technique: antithetic variates, *Mathematical Proceedings of the Cambridge Philosophical Society*, 52(3), 449-475.

Kaczynski, W. , Leemis, L., Loehr N., & McQueston, J. (2012). Bivariate Nonparametric Random Variate Generation Using a Piecewise-Linear Cumulative Distribution Function, *Communications in Statistics - Simulation and Computation*, 41, 469–496.

Kleijnen, J. P. C. (1975). Antithetic variates, common random numbers and optimal computer time allocation in simulation, *Management Science*, 21(10), 1176-1185.

Kroese, D. P., Taimre, T. & Botev, Z.I. (2011). *Handbook of Monte Carlo Methods*. New York: John Wiley & Sons.

Marsaglia, G. (1961). Expressing a random variable in terms of uniform random variables, *Annals of Mathematical Statistics*, 32(3), 894-898.

Marsaglia, G. (1964). Generating a variable from the tail of the normal distribution, *Technometrics*, 6, 101-102.

Park, S. K., & Miller, K.W. (1988). Random Number Generators: Good Ones Are Hard To Find. *Communications of the ACM,* 31 (10), 1192–1201.

Proykova, A. (2000). How to improve a random number generator, *Computer Physics Communications*, 124, 125-131.

Ridley, A.D. (1995). Combining Global Antithetic Forecasts, *International Transactions in Operational Research,* 2(4), 387-398.

Ridley, D. (1997). Optimal Weights for Combining Antithetic Forecasts, *Computers & Industrial Engineering*, 32(2), 371-381.

Ridley, D. (1999). Optimal Antithetic Weights for Lognormal Time Series Forecasting, *Computers and Operations Research*, 26(3), 189-209.

Ridley, D., Ngnepieba, P. & Duke, D. (2013). Parameter Optimization for Combining Lognormal Antithetic Time Series, *European Journal of Mathematical Sciences,* 2(2), 235-245.

Ridley, D., and Ngnepieba, P. (2014). Antithetic time series analysis and the CompanyX data, *Journal of the Royal Statistical Society,* A, 177(1), 83-94.

Ridley, D. (2016). Advances in antithetic time series: separating fact from artifact, *Operations Research and Decisions*, 26(3), 57-68. DOI: 10.5277/ord160304.

Soize, C. (2015). Polynomial chaos expansion of a multimodal random vector, *SIAM/ASA Journal on Uncertainty Quantification*, 3 (1), 34 - 60.

Ramp Readiness Risk Management in a Global Supply Chain at Intel

Elyse Hallstrom[1]
Bing Hu[1]
[1]*Intel Corp.*
elyse.m.hallstrom@intel.com; bing.y.hu@intel.com

Abstract

To assess the readiness of a product or process for high volume manufacturing, it is necessary to know that all points of the manufacturing process are ready and qualified to run. Previously, each segment of the line would assess risk and readiness in their own way in disparate systems. There was no comprehensive tool to view this information. Most of this data was stored in spreadsheets versus database systems so historical records were not easy or sometimes even possible to retain. A large quantity of the data used in these spreadsheets was collected manually instead of pulling from standard systems. This meant that there could be mismatches between systems that could negatively impact the readiness of the entire process for ramp of a product.

To address these concerns, a global system to track the ramp readiness of a product and process was created. Certification Tracker (CertTracker) is a web-based tool used to track important dates for both internal benchmarks as well as benchmarks at upstream suppliers to make sure that manufacturing will be able to meet release timelines. This system connects to other database systems to keep important information such as product/process information and milestone dates current. This interconnection between systems ensures that all are working from the latest information to make the best decisions possible. Risk assessments are created in order to identify problem areas that need additional focus. Management can view high level summary reports to ascertain if manufacturing is ready to ramp. CertTracker serves as a scalable model to manage supply chain ramp risk efficiently.
Keywords: Risk Management, Supply Chain Management

1. Introduction

A modern semiconductor manufacturing process may consist of hundreds of unit processing steps (May, and Spanos, 2006) . Coordinating the ramp of a product that must go through these many disparate processes is no small task. Manufacturing planners worked hard on timely delivery to decrease or avoid over-due date penalties (Yen-Fei, Zhibin, Huai, Chen-Pin, Zamri Darudin, and Deer, 2007).

Semiconductor manufacturing is a series of sequential process steps (May, and Spanos, 2006) . It starts with silicon wafers patterned with die. Wafers are processed through the fabs where the transistors and metal interconnects are built in the latest process technology. From there, the wafers go to die preparation. Individual die are cut from the wafer. Then the die is put together with the substrate to form an integrated circuit (IC) package. Finally, the IC test is performed to finish the process.

More generally, semiconductor manufacturing is a process converting raw silicon materials into microprocessors as illustrated in Figure 1. Its associated operation system takes suppliers, raw materials and equipment as inputs to generate finished commercial products (see Figure 2).

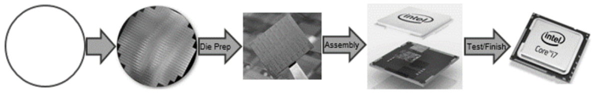

Figure 1: Semiconductor Manufacturing

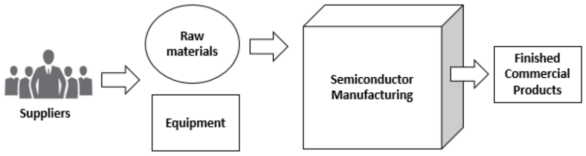

Figure 2: Semiconductor Manufacturing Operation

Due to the high number of processes involved with semiconductor manufacturing, it is easy to run the business in silos where each segment of the process manages their ramp individually. An important part of understanding a product's ramp viability is to assess if the upstream suppliers are ready to support the ramp as well as the individual segment's ability to run the product or process.

All of these concerns reflect the importance of ramp readiness risk management. Generally, risk management processes include risk identification, risk assessment, risk reduction, and risk monitoring (Dan, and Zan, 2007). Research has identified eleven factors that are involved in risk management which include agility, information sharing, risk sharing, risks knowledge, strategic risk planning and so on (Solomon, Ketikidis, Choudhary, 2012) Key aspects of an efficient risk management system for a supply chain is to allow interaction with up-to-date knowledge all the time for effective decision making (Mandal, 2011), (Fan, Cheng, Li, and Lee, 2016)

The term "ramp readiness" means the ability for all segments of the supply chain to support scaling a product from introduction to high volume manufacturing. It includes equipment installation and qualification metrics like Spare Parts, Delivery, Safety, Equipment Configuration, Reuse, and more. It also requires that Tier One and Tier Two suppliers are qualified and ready to provide the components needed to support product manufacturing. All of these facets demand coordination across large groups of people on statuses, qualification dates, and the potential risk that these components put the company in to miss meeting their product ramp requirements. It requires there to be good communication across organizations, alignment on processes and timelines, and standardization on risk level definitions for each metric.

Before this effort, each group had their own methodology for tracking each process or product to show that it was ready for ramp or highlight where issues existed. There was no way to view the data from the beginning of the process to the end to determine the overall ramp readiness. Most of these assessments were managed in spreadsheets on SharePoint sites. Only monthly or quarterly roll ups of data were created from these spreadsheets to share with management since these reports were so cumbersome to generate.

1.1. **Problems**

Originally, most groups were tracking process data in spreadsheets, which posed its own set of issues. Some groups would "archive" versions of the spreadsheets by creating a saved version monthly and then do a rough trending by pulling together data from these archived versions. In general, however, there was no way to review the history of a risk assessment easily. Even for the groups that were taking snapshots of data, the files could easily be deleted or never even taken in the first place.

Another issue with this old process revolved around data quality. All of the data were manually entered into these spreadsheets, even if the data was also stored in a database. This meant that there was always a risk of a transcription error or data being stale compared to what was updated in the database. Data was only updated at a set cadence, versus being updated whenever there was a change. If a product milestone date changed, for example, it was only updated weekly, versus at the time the date was changed.

Furthermore, security was another major issue with the existing systems. It was difficult to restrict users' access to data within segments of a spreadsheet without making the system cumbersome. Security often limited people's access to the overall file, but not by what elements they could see. Additionally, these files were stored either on people's hard drives or SharePoint sites, meaning that the servers this data was on were not any more secure. This was a concern considering that a lot of these risk assessments brought together product/process details, important milestone dates, supplier information, etc. which combined make the information extremely sensitive.

As was mentioned, there was no standard assessment form or process from one segment of the line to the next. This meant that there was no way to easily compile the data to get an overall view of the entire line. This lack of standardization not only was from the form of assessment, but to reporting and security.

Reporting on the data in these old processes was only available at a certain cadence and not on demand. For example, reports would be made monthly for management review so that problem areas could be identified and targeted for increased focus. This means that larger, systemic problems across suppliers could potentially not be identified and addressed in a timely manner. Trending data would sometimes be included in these forums to help identify at risk segments early, but again it was difficult to compile this data so it was not always completed.

Meanwhile, the complexity and quantity of these risk management processes made the scope of building a global system that tracks ramp readiness of a product and process huge. Traditional development methods could not accommodate the fast change in industry requirements as the business grew and the needs changed (Highsmith, 2002), (Albadarneh,Albadarneh, Qusef, 2015)It was a challenge to develop a global system with a generic model that met all segments needs in a timely manner.

1.2. **Solution**

For all of these problems with the current methodology for tracking ramp readiness, it was clear that a database tool was needed. Connecting to existing database systems was required to reduce transcription errors and staleness of the data. Better-managed roles by users were necessary for security reasons so that customers could only see the information in their commodity. Built in reporting that could be accessible on demand was necessary have feature. Finally, the tool must be responsive enough to be used live in meetings so that there was never any lag between decision-making and changes in the reporting. Thus, the Certification Tracker (CertTracker) was born to serve as a scalable model to manage supply chain ramp risk efficiently.

The packaging substrates team, a segment of the manufacturing process, identified the need for a database tool to run their ramp risk process, but it was anticipated that they were not the only ones with this problem. Before development time was even committed, they reached out to as many segments of the line as was possible to see if there was a similar need. Once additional groups were identified for inclusion in this theoretical tool, the owner for the project met with each group to understand their current business process and needs, identify commonalities and unique requirements between groups, and came up with a proposed user interface that would allow for as much economy of scale as possible while still meeting the individual needs of each group. The critical component of this risk requirement identification, characterization, analysis, and refine process was that the group/project lead well understood each group's process and was able to break down their vertical silo requirements into general use cases which in turn were easily translated into specific development deliverables. The general use cases shared risk requirement knowledge across multiple groups horizontally. (See Figure 3.)

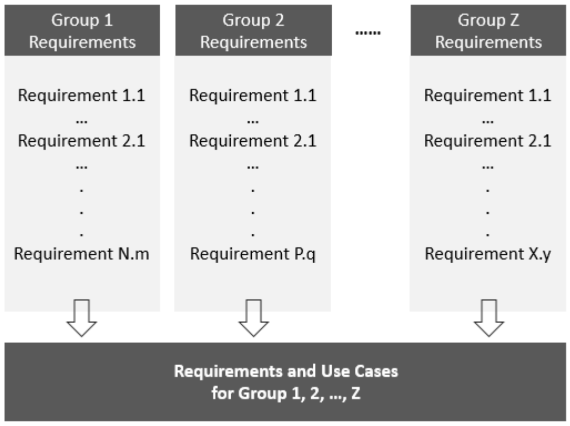

Figure 3. Group Requirements and General Use Cases

Although the need was global, the actual development effort started out in one specific commodity. This was in order to have a concrete set of deliverables that would make a development process effective and flexible. While the tool was initially created with only one commodity, its framework was built for easy expansion. An Agile development process was adopted to build this global system by adding commodity segments one by one incrementally. In Figure 4, each phase had its application release for the associated commodity to use the tool so benefits could be seen immediately instead of waiting for complete deployment.

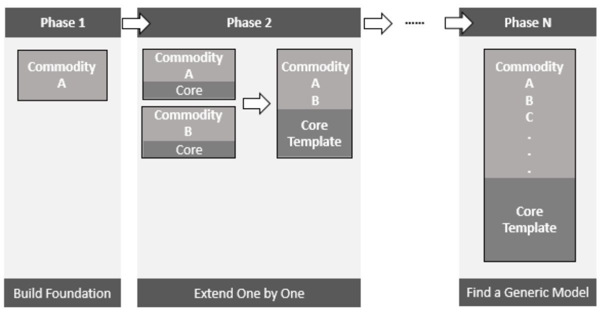

Figure 4. Agile Development Process

2. A global system: Certification Tracker (CertTracker)

Certification Tracker (CertTracker) is a database-based web application for tracking ramp readiness activities and managing risks at all points of a process/product line to ensure the entire system is on track. (See Figure 5.)

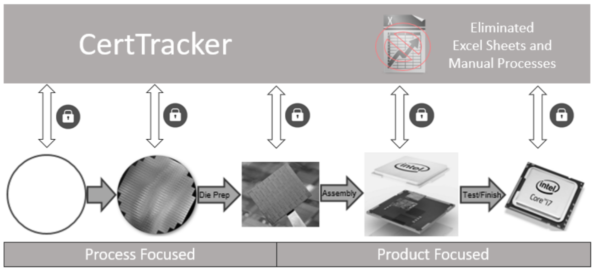

Figure 5. CertTracker and a Process/Product Line

2.1. System design and architecture

CertTracker was designed based on the Data-Information-Knowledge-Wisdom (DIKW) pyramid (Rowley, 2007). It enables the synthesis of data into sharable and standardized information and knowledge for ramp readiness risk management. Data sources come from user inputs and data warehouses. The application collects information from data source and builds up knowledge from ramp risk management key dates. Then it provides Business Intelligence (BI) reports and web-based reports for users to make decisions effectively. (See Figure 6 and 7.)

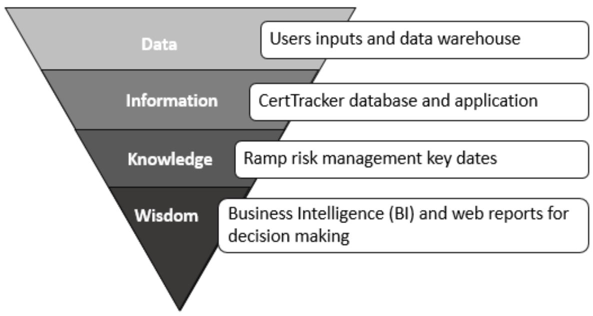

Figure 6. CertTracker DIKW Pyramid

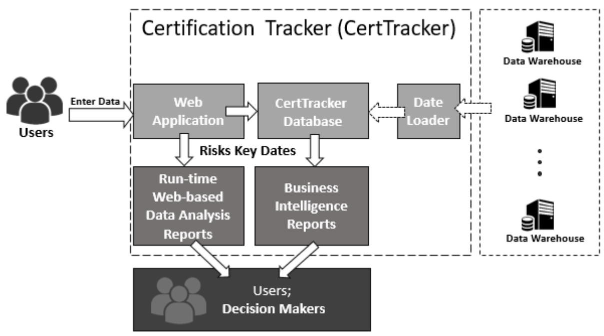

Figure 7. CertTracker System Design

2.2. Risk management

Certification Tracker uses customized risk assessments and real-time reports to manage various risks effectively.

Each segment can create their own risk assessment to identify and control problem areas that need additional focus. Critical categories for assessing risk were defined by each segment and definitions of risk levels for each of the categories were created and agreed upon. For example, the substrates material teams track risk levels for meeting supplier qualification dates to support ramp as well as the risk associated with being able to build enough material inventory prior to ramp to support potential “pull ins” or “upsides” in demand. Equipment teams track installation/qualification timelines and milestones, safety indicators, spare parts availability, etc. to determine if a toolset is going to be able to support the ramp. Each level of risk has a definition so there is no ambiguity on what the indicator means. Each risk assessment also includes details around impact, containment plans, and owners so everyone knows who is responsible and whether or not it needs to be escalated.

Risk assessments can be rolled up to a higher level and the summary can be illustrated in a Business Intelligence (BI) report or a web-based data analysis report. These reports provide strategic level information to locate risks. Commodity managers can identify potential risks at process/product level. Management can view high level summary reports to ascertain if the ramp is ready or not. Risk reports can also provide information for a user to predict a trend in a specified area for better risk management planning at a monthly or yearly level. A user can easily see the problem by looking at color coded risk indicators. For example, high risks are in red, medium risks are in yellow, low risks are in green. Containment plans and owners are identified so management can determine if extra focus is needed and if the issue is controlled.

2.3. **Suppliers management**

CertTracker tracks important dates for both internal benchmarks as well as benchmarks at upstream suppliers in order to make sure that release timelines will be able to be met on schedule. Certifications dates are the major category of supplier risk management. Because it houses the certification dates at upstream suppliers, CertTracker also stands as a record of origin for strategic sourcing plans.

2.4. **Data management**

CertTracker collects data from both users and a few data warehouses into its own database. It uses a data loader to pull data at a recommended frequency to keep data fresh. Data is updated daily up to four times a day depending on how frequently it might be changed or reviewed.

CertTracker tracks historical data to meet business needs. Whenever users change any data in the tool, they are also required to add a comment as to why the date is being changed. This allows others to understand what is going on and helps identify reasons behind trends later. These comments also include containment plans so it is clear what is being done to address the issue. This historical data enables users to track down details and resolutions, and also provides information to help users view or predict risktrends along with their risk indicators at monthly or yearly levels.

2.5. **Information security management**

CertTracker has more than one internal segment users. Security became an important function requirement because of the sensitivity of the data. All users are required to apply for access to view or edit data based on their business segments and job roles.

Towards this end, the CertTracker database is located in an IT high trust zone (HTZ) environment. Data is only allowed to be pulled into this protected high security environment and is not allowed to be copied over to another system. CertTracker BI report analysis database is placed in the same server where the web application exists for this reason.

3. Results

The CertTracker system is an efficient ramp risk management system for an end-to-end supply chain. It has been a huge success at Intel. It is now the record of origin for supplier certification schedules and risk assessments for many commodities in a global supply chain. A new commodity has been added into its capabilities at the pace of roughly one per quarter. It only took a few months to build an initial base foundation and release it for use. Both equipment and materials teams are using the system (See Figure 8). Fab equipment teams are using the tool to track the ramp readiness of new processes. Assembly Test equipment teams are using CertTracker to track the readiness of each new product. Substrates materials are using it to track the readiness of their suppliers and their associated qualification dates. Substrates raw materials are tracking Tier Two suppliers. Additional materials groups are also using it to track their ramps as well.

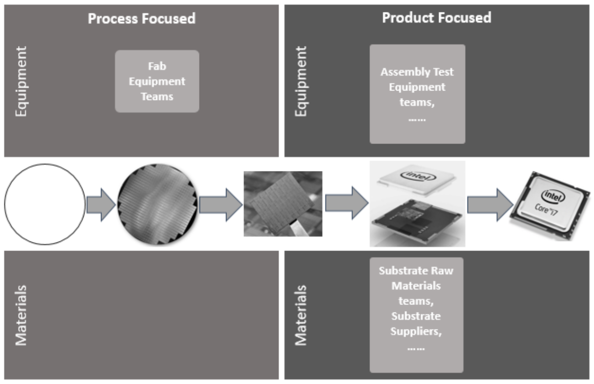

Figure 8. Equipment and Material Teams in a Process/Production Line

CertTracker is ingrained in the business. It is now being used live in meetings to update dates and risks so that issues can be responded to and plans can immediately be made. The real time reporting has allowed everyone from commodity managers to upper level management to see summary and trending data. It has allowed the business to be more aware of and responsive to issues that might arise.

The CertTracker has also increased communication between sister organizations. Technology Development teams now sit in meetings with their Commodity Manager partners and update the tool together, discussing implications and contingency plans. It has increased accountability with the clear roles and timelines that have been established within and around the tool.

4. Future work

One area for future development effort that will continue to occur with expansion is refactoring. While the tool was created with expansion in mind, each commodity has their own specific needs that need to be addressed when they are included in the tool. This increases the overhead in the tool. From time to time, development energy will need to be spent to refactor the tool so that it run smoother and more efficiently.

A final additional feature that has been a goal since the beginning is the overall process and product views of the data for summary of the entire line. Being able to see where potential ramp issues are in the entire line from bare silicon to finished good will be invaluable to upper level management. This view never was possible previously since all of the assessment processes ran separately, but now, thanks to the CertTracker, there is a clear path towards integration. This functionality is under development.

5. Conclusion

CertTracker is a global system that manages ramp readiness risks of products and processes for a global supply chain at Intel. It is a database web tool to track important dates for both internal benchmarks as well as benchmarks at upstream suppliers to make sure that all components are able to support ramp. CertTracker uses a database to store historical data and provide real-time reports to enable decision making. The database was located in a high security environment and user access was restricted according to their job roles, aligning with the sensitivity of the data.

CertTracker transforms a risk management Excel file system into a database web tool. The CertTracker system reduces human error and eliminates manual risk management processes. It enables more efficient supply chain risk management. CertTracker provides a scalable model to manage the ever-growing complexity of ramp risk in a supply chain with multiple groups.

Other industries can benefit from the experience of the CertTracker. In large manufacturing processes, it is easy to run the business in silos due to the difficulty of standardizing disparate systems. The experience of the CertTracker team is that it is worthwhile to reach outside of the individual organization's scope to learn where efficiencies can be gained. Doing these comparisons before development begins helps build a foundation that will make expansion easier because the common and unique needs are known and can be designed for. By having all the data for risk management in one system, additional insights can be found and a more holistic view of line health can be determined. Furthermore, being able to list the potential benefits realized by all groups helps more easily justify the development investment needed to create a new system. Other industries could adopt these strategies to build a scaled system with centralized and shared knowledge across multiple business segments and silos.

Additionally, the success of the CertTracker can largely be attributed to the Agile development methodology employed. By having one concrete use case to take on while maintaining scalability for the future, the development and business teams were able to create a useable tool within one quarter instead of trying to take on all segments at once in a several years-long effort. This incremental software development approach would enable teams to develop a global tool in a rapid pace.

6. Acknowledgement

This work was supported by Jim Provins, Tom Newcomer, Rick Scannell, James (Jay) Turpin and Intel Application Development & Sustaining (AD&S) team.

7. References

Albadarneh, A,, Albadarneh, I., Qusef, A., "Risk Management in Agile Software Development: a Comparative Study", 2015 IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies

Dan, W., Zan, Y., "Risk Management of Global Supply Chain", IEEE, International Conference on Automation and logistics, August 18-21, 2007, Jinan, China.

Fan, H., Cheng, T.C.E, Li, G., and Lee, P., "The Effectiveness of Supply Chain Risk Processing Capability: An Information Process Perspective", IEEE transactions on Engineering management, Vol. 63, No. 4, November 2016.

Highsmith, J., "Agile Software development Ecosystems", Boston, USA, Addison-Wesley Longman Publishing Co. Inc., 2002

Mandal, S., "Supply Chain Risk Identification and Elimination: A Theoretical Perspective", The IUP Journal of

Supply Chain Management, 2011, 8(1), 68-86.

May, G., Spanos, C., “Fundamentals of Semiconductor Manufacturing and Process Control”, John Wiley & Sons.Inc, 2006

Rowley, J., “The wisdom hierarchy: representations of the DIKW hierarchy”, 2007, Journal of Information Science 33(2): 163 – 180

Solomon, A., Ketikidis, P., and Choudhary, A., “A Knowledge Based Approach for Handling Supply Chain Risk Management”, ACM, BCI’12, September 16-20, 2012

Yen-Fei, L., Zhibin, J., Huai, Z., Chen-Pin, K., Zamri Darudin, M., Deer, Y., “A Study of Time Variable Multiple Objectives Scheduler for Wafer Fabrication”, IEEE, 2007 International Symposium on Semiconductor Manufacturing (ISSM), 15-17 Oct. 2007.