JOURNAL OF MANAGEMENT AND ENGINEERING INTEGRATION

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Development of 3D Geometry of the Foot for FE Plantar Fasciitis Study

Alexander Knapp[1]
Alexandra Schönning[1], Stephen Stagon[1], Beven Livingston[2]
[1]*School of Engineering, University of North Florida*
[2]*Department of Physical Therapy, University of North Florida*
a.knapp.144412@unf.edu

Abstract

Finite Element modeling is a powerful tool that can aid clinicians in making informed treatment decisions that are tailored to the patient's needs. Using Computed Tomography (CT) patient specific 3-D geometry can be generated on as needed basis, but methodologies using open source softwares are limited. In this work, CT scans are analyzed and manipulated using FIJI, an open source image analysis software developed by the National Institutes of Health, to generate three-dimensional models of the bone and soft tissue [1]. These models are further enhanced using a reverse engineering software, Geomagic, to create Non-Uniform Rational B-Spline (NURBS) surfaces [2, 3]. The NURBS models generated are then able to be imported to Finite Element Modeling softwares (such as SIEMENS NX) for analysis by engineers and clinicians [4].

1. Introduction

Musculoskeletal biomechanics is a relatively new field of engineering that has recently seen great advancements due to the increase in availability of computing power for computational modeling and simulation. Such advancements have allowed for reasonably accurate analysis using the finite element method on anatomical models that would otherwise be nearly impossible to analyze by hand without making several limiting engineering assumptions. In 1972, the first finite element model of human bone tissue was developed [5]. With the advent and increased popularity of computed tomography (CT) technology due to the low cost and time required, refined geometrical models of bone structures have been feasible to create and analyze using the finite element method [6, 7, 8]. Because they are time and cost effective, CT data allows for clinicians to develop accurate models for each patient as needed. However, CT scans are not the only method available to obtain such accurate geometries; MRI and ultrasounds have also historically been used to model anatomical geometries, as well as to get elastic material data as in [9,10]. Using the geometrically accurate models that such scans allow for, advancements can be made in the study of stress analysis on biomechanical structures, giving engineering designers and analysts greater insights into patient specific orthotic design and the treatment of ailing conditions, such as in the works of [11-16]. The present work seeks to give an overview of the process of creating patient specific geometry using CT scan slices with open source software. The methodology presented here has the potential to be automated in future endeavors for availability to a wide range of analysts and clinicians.

2. Methodology

In order to create a workable CAD model for analysis, a series of sequential steps were followed as illustrated in Figure 1 [2].

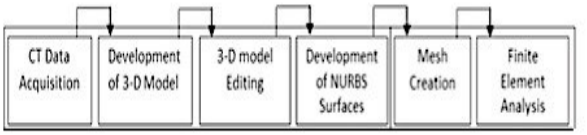

Figure 1. Overview of modeling procedure

Creating such models first required obtaining the desired geometry in the form of scan data. The present work uses CT slices. After editing the slices, the images were stacked to form a rough geometrical model, which can be further refined and then meshed for analysis.

2.1 Model generation

The CT slices used for the present work were made available free of charge through NIH's Visible Human Project [17]. In order to obtain this data, permission must be requested with a formal statement of intent for the slices in question. The data used for this set were the last 278 slices of a set of superior view slices of the entire body taken at 1 mm intervals. The subject in question used for the slices was an adult male of average body size [17]. In order to visualize, edit, and stack the slices into 3D models, the software FIJI was used [1]. Figure 2 illustrates what one of the slices looks like (only a portion of the entire scan slice was used as only one foot was desired and the image set contained both feet).

Figure 2. Sample CT slice

While the goal of the present work is to obtain geometries of all 28 bones in the foot (including the tibia and fibula), the present work will be using the calcaneus for illustrative purposes. The calcaneus is the heel bone of the foot, as demonstrated in the physical foot model in Figure 3.

Figure 3: Calcaneus reference image

In order to develop the desired geometries, each bone was separated from surrounding tissue manually on each slice using the software as illustrated in Figure 4.

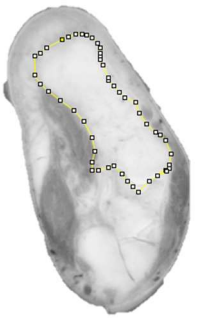

Figure 4. Illustration of slice editing

After tracing each bone as seen in Figure 4, the area of the image outside the traced bone was deleted, resulting in the slice seen below in Figure 5.

Figure 5. Edited slice with only bone remaining

These slides were further refined using threshold techniques as in [8,18] For the present slices, a threshold value of 161 out of 255 was chosen due to it including the areas of interest. This resulted in even smoother models than would be afforded just from the manual editing, leading to the final edited slices such as the one shown in Figure 6.

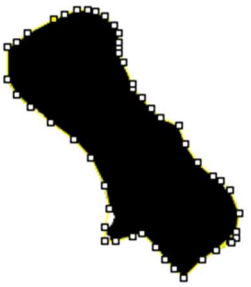

Figure 6. Thresholded slice

Next, a proper scale had to be given for the foot. A representative foot length value of 24.2 cm was used (as no scale was present in the slides) so as to enable the models to be of a representative size similar to that of [9]. The stacking also required scaling of the voxel height, which was chosen to be twice the default scaling value in order to achieve geometry of an appropriate size. After scaling the bones appropriately, the slices are stacked on top of each other to create rough models such as the one in Figure 7.

Figure 7. Rough model generated with FIJI

Due to the 1 mm gap between slices causing edges to not always smoothly transition, the models look rough. Because of this, the models had to be further refined in order to be useful for analysis.

2.2 Model refinement

In order to obtain a usable model for finite element analysis, the above model must be cleaned up. For the present work, the software Geomagic was used [2]. After exporting the stacked model as an .stl file, a NURBS (Non Uniform Rational B-Spline) surface is created using Geomagic. NURBS surfaces can be thought of as a collection of surfaces defined by mathematical expressions that are used to create smooth approximations of geometry, making them ideal for CAD modeling [3]. This process allowed for the model to be cleaned up and smoothed out so as to refine the rough shape that occurred by editing the slides by hand into a workable and more true to life model. Importing the .stl file into the Geomagic software results in an extremely rough model as seen in Figure 8.

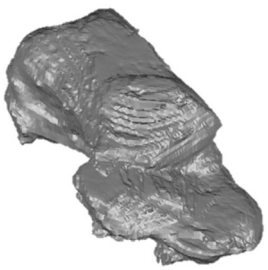

Figure 8. Model as brought into Geomagic

The model needed to be refined in order to be useful for modeling. First, the refining process started by using the automatic cleanup abilities within the Geomagic software to refine the model. This led to an already significantly improved model as seen in Figure 9.

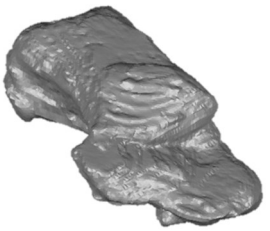

Figure 9. Model after geometry cleaning operations

Next, the model was sculpted on the rough edges, while also using the automatic capabilities of Geomagic to remove spikes in the material, which led to the final model in Geomagic as seen in Figure 10.

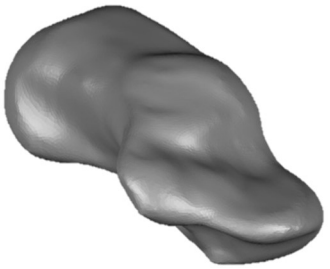

Figure 10. Final cleaned model

Finally, the model had to be converted into a NURBS surface in order to develop a CAD model usable for FE analysis in NX. Using Geomagic's automatic capabilities to generate NURBS surfaces, the model seen in Figure 11 was created.

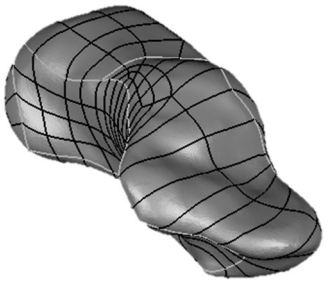

Figure 11. NURBS model

This model is exported into the NX Computer-Aided Engineering software as an .stp file. At this point the model is ready for meshing. A tetrahedral mesh of the model is illustrated in Figure 12.

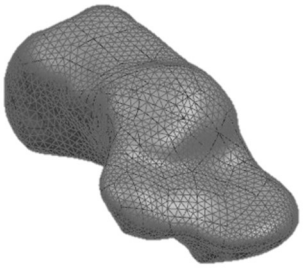

Figure 12. Tetrahedral mesh of calcaneus

3. Applications of Model

The present model has numerous applications for engineers and clinicians. Through the use of the finite element method, loadings based on the average human weight can be applied to models involving complex material models such as that of hyperelastic or viscoelastic materials. This allows for engineers and clinicians to better understand the stress distributions throughout the foot in greater detail than what any hand calculations can allow, which in turn can lead to more informed designs for orthotics and techniques for surgeons and physical therapists. Another highly practical application is the creation of rapid

prototype models such as the one created for the calcaneus shown in Figure 13.

Figure 13: Rapid prototype model of calcaneus

Such rapid prototype models give clinicians the ability to quickly create physical models to represent patient injuries and conditions, giving them a powerful tool for treatment decisions. Using such models in conjunction with that of the finite element model will allow for more informed decisions that ultimately benefit the level of care that can be provided to those in need.

4. Conclusion

A methodology for developing a patient specific 3D model of the foot from CT scan slices using open source software was used for the anatomy of the foot. This method details steps used in generating a model through the use of the free software FIJI, and the reverse engineering software Geomagic which can be imported to CAE softwares such as NX or Solidworks. The use of open source software will allow for more widespread adoption by analysts and clinicians, which will allow for custom tailored engineering solutions for individual patients, increasing the level of care that clinicians can provide.

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The Information Systems and Analytics Curricula: A Requirements Based Synthesis

Fred K. Augustine, Jr.[1]
Monica Mendoza[2], Joseph Woodside[3]
[1, 3] Department of Decision and Information Sciences, Stetson University, DeLand, FL 32720
[2]M.E. Rinker Sr. Institute of Tax and Accountancy, Stetson University, DeLand, FL 32720
faugusti@stetson.edu; monica.mendoza@stetson.edu; jmwoodsi@stetson.edu

Abstract

Information Systems curriculum has been the subject of considerable research and discussion. Developing an undergraduate IS curriculum which will adequately address the needs of the various constituent groups associated with IS education has become increasingly difficult as technology and business continue to evolve. This task has become even more challenging as the skills required of graduates of information systems programs have evolved. This paper proposes a curriculum which is a synthesis of curricula in the areas of information systems and business analytics. The curriculum is based on frameworks developed in both the academic and business environments.

1. Introduction

Economic events subsequent to the Crash of 2008 have caused business leaders and academics to re-examine the economics of their institutions and industries. This is especially true in terms of technology and resource utilization. Technology. For Academic leaders this had led to a need to reassess the relevance of information systems in the context of a university curriculum. These events, coming on the heels of transformational events such as the bursting of the dot.com bubble, the "solution" to the Y2K problem and the subsequent decline of the "tech stock" bull market, have led to a more resource scarce and efficiency centered environment for both business and academic institutions. As businesses evolve, educational institutions are forced to evolve their information systems programs. These programs, by their very nature are often at the forefront of such change. It is a given that the technologies that businesses use to fulfill their operational data infrastructure needs are and will continue to evolve at a rapid pace. But when this type of change is accompanied by changes of a disruptive nature [3] at the level of the industry or even the economy, great pressure is placed on academic institutions to keep pace.

As businesses change the way they operate, the demand for human resources also changes. One example of this is how the demand for "traditional business technology skill sets have fallen significantly" while demand for individuals who can deal with "solving specific business problems or exploiting specific business opportunities." [11, pg. 99] has increased. Thus as the composition of the human resources demanded by industry changes, the requirements placed upon academic programs change in turn. For years these institutions have been able to keep pace by constantly changing and upgrading their information systems programs. These changes typically involved changes in the content, structure and even

delivery of these programs. There was, however, one constant in the overwhelming majority of these program changes. That constant was information systems programs that focused on information systems tools, techniques, technologies and methods.

Because of the extraordinary events of the last seven years this paradigm has changed. Instead of merely requiring new employees with new skills that matched even newer technologies that organizations were employing to meet the competitive needs, we have seen a dramatic shift in the focus of these requirements. Much of this shift in focus came about as a result of the advent of analytics as a key element of competitive strategy. [6]

2. On the Rise of Business Analytics

Business analytics can be defined as "the use of information technology, data, statistical analysis, quantitative methods, and mathematical or computer based models to help managers gain improved insight into their business operations and to make better, fact-based decisions." [7] The term was first popularized by Thomas Davenport in his seminal article "Competing on Analytics" where he describes the use of analytics techniques as not only being critical to an organizations ability to compete, but as a new form of competition. Davenport says that: "Organizations are competing on analytics not just because they can—business today is awash in data and data crunchers—but also because they should be" [6, pg. 98]

This "analytics movement" has been greatly enhanced by the emergence of "big data". The term "big data" refers to very large data sets that can be analyzed using statistical and computational methods in the hope of revealing trends and associations. Big data has become an issue due to the convergence of several technological trends which have increased the volume, velocity and variety of data available to decision makers. Among these trends are the miniaturization of computing technology, the continuous evolution of storage technology and the increasing volumes of data available due to ubiquitous connectivity and social media. The data is an issue precisely because it is big. Computing systems today are generating 15 pizza bites of new information every day eight times more than the combined information and all the libraries in the United States and about 80% of the data generated every day is textual and unstructured data. [4, pg. 2]. But it is not just the size of the data sets to be managed or its complexity or its variety that poses the challenge. It is the complexity faced by organizations in the management of this data. The Gartner Group, in a report published in September of 2011 entitled Gartner's Business Analytics Framework, maintain that: "The program management, technology and complexity of skills associated with the strategic use of business intelligence, analytics and project management increased dramatically as the scope of the initiative widens across multiple business processes" [8]

Thus by its nature, business analytics, while improving our ability to utilize data to gain insight and make decisions, also increases the complexity of our organization and its processes. This of course, increases the difficulties associated with decision-making and the management of organizational processes. It is because of this challenge that it is critical that our educational institutions provide the best possible match between their curricula and the required analytics skill sets of those in business and industry.

3. Business Analytics Curriculum

The efficacy of analytics has been substantiated by numerous successful use cases in business and education. For example, the use of analytics has become such a key element of doing business in the field of professional sports that questioning the validity of the analytics metrics that have been developed is considered to be almost heretical. Given the popularity and use of analytics tools, techniques and methods in industry, it was inevitable that educational institutions would incorporate analytics as

critical elements of their curricula. Mamonov, et.al. Report that: "… more than 130 graduate and undergraduate programs in business analytics have been launched in the past five years yet no commonly accepted model of business analytics curriculum yet exists". [10]

While it's true that there may not as of yet be a commonly accepted model for business analytics curricula it is possible to examine the elements found in a variety of these curricula. A view of business analytics in practice has been proposed, which suggests that business analytical skill sets lie at the intersection of expertise from three domains 1) the specific business domain, 2) technical data management and programming expertise and 3) applied statistics. [5] Similarly, the Gartner Group proposes a framework which labels analytics capabilities as falling under one of three categories of decision capabilities, analytic capabilities and information capabilities. This framework is shown below in Figure 2.

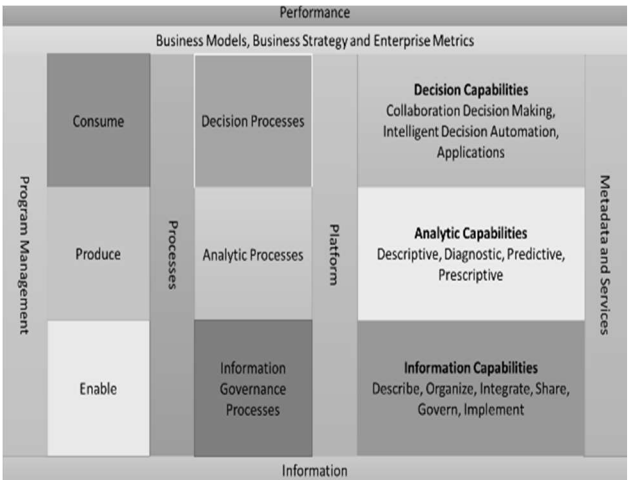

Figure 1. The Gartner Business Analytics Framework

As it has been noted previously, business analytics includes, in addition to statistical analysis, quantitative methods, mathematical models and computer models, both the data and information technology components associated with information systems. As such it is impossible to separate and effective understanding of business analytics from the technology used to manage the data and models which make it possible. This being true, any effective business analytics curriculum must also address information systems topics.

4. The Curriculum for Information Systems

It would seem self-evident that any curriculum designed to support business technology professionals must evolve over time. Much of this evolution is due to the nature of the curriculum itself. Mature business technologies ultimately become obsolete. Technical innovation creates new areas of interest and opportunity that define new skills that must be mastered by her graduates. Perhaps even a more compelling reason for this phenomenon is the evolving role of information technology professionals within today's organizations. There is still a tremendous need for the technology professionals to enhance and maintain the technical infrastructures that buttress organizational excellence. But the focus of business technology expertise today is maturing beyond the purely technical. At the business unit level, IT must address the tactical side of solving specific business problems or exploiting specific business opportunities. At the enterprise level, IT is becoming more centered on supporting and being supported by the overall organization strategic plan [12, pg. 99]. Above and beyond changes necessitated by rapidly evolving technologies, the power of outsourcing has changed the conditions of IT employment. Traditional programming and technology-based curricula will no longer work in an environment in which such traditional skills as programming and development can be moved offshore at greatly reduced costs. The jobs that have not been sent offshore are those which require business as well as technological acumen. [9, pg. 17]. Curricula which produce this type of graduate must include material which allows students to develop their technical capabilities, business and management capabilities and their people and personnel capabilities [9, pg. 19].
Curricula which are able to develop graduates of this type are often housed within business schools. One career advantage that students

graduating from the school of business with a traditional technology (IS, MIS, CIS, etc.) degree have always had is that the students were exposed to a broad spectrum of business concepts simply because they were business school majors. Foundation course requirements ensured that every business major would be introduced to accounting, economics, finance, marketing, management, etc. While exposure to these business fundamentals by new technology graduates has always been something desirable from the standpoint of the corporate recruiter, the key issue for technology programs within business schools continues to be: in an ever changing technology environment, how do we effectively build on this business foundation to produce graduates with the technical skills desired by these same recruiters [12, pg. 101]? One answer is the development of curriculum standards.

4.1 Curriculum Standards

An institution that is intimately involved with the evolution of the university curricula is the Association to Advance Collegiate Schools of Business (AACCSB). As the top level accrediting body, internationally, for business programs, the AACCSB as has published standards for both undergraduate and graduate business curricula. AACSB standard 9 (Curriculum Content) requirements state that (the standard):

"Normally, curricula management processes result in curricula that address the broadly-defined skill and knowledge content areas described by the program types listed below" in Table 1.

Table 1. Standard 9 curriculum content

General Skill Area
Written and oral communication (able to communicate effectively orally and in writing)
Ethical understanding and reasoning (able to identify ethical issues and address the issues in a socially responsible manner)
Analytical thinking (able to analyze and frame problems)
Information technology (able to use current technologies in business and management contexts)
Interpersonal relations and teamwork (able to work effectively with others and in team environments)
Diverse and multicultural work environments (able to work effectively in diverse environments)
Reflective thinking (able to understand oneself in the context of society)
Application of knowledge (able to translate knowledge of business and management into practice)
Economic, political, regulatory, legal, technological, and social contexts of organizations in a global society
General Business and Management Knowledge Areas
Social responsibility, including sustainability, and ethical behavior and approaches to management
Financial theories, analysis, reporting, and markets
Systems and processes in organizations, including planning and design, production/operations, supply chains, marketing, and distribution
Group and individual behaviors in organizations and society
Information technology and statistics/quantitative methods impacts on business practices to include data creation, data sharing, data analytics, data mining, data reporting, and storage between and across organizations including related ethical issues
Other specified areas of study related to concentrations, majors, or emphasis areas

It is important to note that "information technologies" and "Analytical Thinking" represent core skill and content area knowledge requirements articulated in the AACSB standards. Indeed, "information technologies" are mentioned both under General Skill Areas and General Business Management Knowledge Areas while Analytics is mentioned specifically under this same area. Although the standard does not require specific courses or programs, the standard does specify that:

"All general management and specialist degree programs at the bachelor's, master's, and doctoral level would normally include learning experiences that address the following general skill areas and general business and management skill areas …" [1]

In addition to standards developed by accrediting agencies standards are also developed by special interest groups such as the Association for computing machinery (ACM) and the Association for information systems (AIS). The ACM and AIS have partnered to develop curriculum guidelines for undergraduate degree programs information systems. IS2010 is the latest of these cooperative endeavors. This

model curriculum, unlike the standards prescribed by the AACSB, his course based suggesting specific courses which make up the model curriculum as well as the learning objectives and topic coverage for each of these courses. However the IS 2010 model curriculum also suggest that the only solution to matching curricular content with the requirements of business and industry is defined to the academic institutions technology programs and focus on specific outcomes.[1]

Therefore, any curriculum which attempts a synthesis of information systems and business analytics must follow this injunction. It is with this in mind that a proposed curriculum for business analytics and information systems is presented.

5. A Proposed Curriculum

The curriculum proposed below is based on the curriculum for the business systems and analytics major which is housed in the school of business administration at Stetson University in DeLand Florida. This curriculum was developed initially in an attempt to utilize the talents of a department composed of information systems and statistics faculty. As development of discrete curriculum continued it became apparent that the University and the school of business could meet a high need demand for graduates with skills in the area of business, technology and analytics. Table 2 below shows the curricular content of this program with courses categorized based on the Gartner business analytics framework. This framework is used to categorize courses based on organizational capabilities.

Table 2. The business systems and analytics major in the context of the Gartner business analytics framework.

Organizational Capability	Business Systems and Analytics Courses	Prerequisite Courses
Decision Capability	Project Management, Business Process Management with ERP, Business Systems Analysis	Accounting, Finance, Marketing, Management
Analytics Capability	Predictive Analytics, Business Intelligence, Social Media Analytics	Introduction to Business Statistics, Business Statistics
Information Capability	Data and Information Management, Knowledge Management	Management Information Systems

As an alternative representation, Table 3 shows the program with courses categorized based on the framework suggested by Conway's Data Science Venn Diagram. This framework is used to categorize courses based on skill set domains.

Table 3. The business systems and analytics major in the context of Conway's data science Venn diagram.

Organizational Domain	Business Systems and Analytics Courses	Prerequisite Courses
Business Domain	Project Management, Business Process Management with ERP, Business Systems Analysis	Accounting, Finance, Marketing, Management
Applied Statistics Domain	Predictive Analytics, Business Intelligence, Social Media Analytics	Introduction to Business Statistics, Business Statistics
Technical Data Domain	Data and Information Management, Knowledge Management	Management Information Systems

6. Discussion

The proposed Business Systems And Analytics major, consisting of nine courses designed for those students who wish to become analysts, technology fluid project team members, cross functional problem solvers for their organizations. They will obtain their academic business exposure in the required business core courses. This is then followed by courses that given the ability to analyze scenarios understand circumstances recommend technology-based solutions. In addition the students will attain a high level of quantitative literacy. A lack of quantitative literacy is a particular problem for businesses and educational institutions in the United States. Although business schools "… teach how swiftly the business environment is changing, instruction in quantitative methods is barely changed in almost half a century."

It has been estimated that this lack of quantitative literacy among undergraduate business students is responsible for much of the loss of U. S. Competitiveness. For example only six of the top 25 information technology companies are based in the United States. In addition, there are also those who argue that this has accelerated the already existent trend

towards globalization and outsourcing to foreign countries. [11]

This major is designed to produce graduates who are capable of functioning as managers and information technology or analytics dominated environment. By virtue of obtaining a business degree students will be exposed to those critical non-technical skills (people skills, leadership skills, organizational skills, etc.) which are so highly prized by management.

6.1 Applicability of the Courses to the Organizational Domains

In order for the major to fulfill these objectives, the specific courses in the curricula must be applicable to the Organizational Capabilities or Domains shown in Tables 2 and 3.

Courses which correspond to the Business Domain and Decision Capabilities are Project Management, Business Process Management with Enterprise Resource Planning (ERP) and Business Systems Analysis. These courses focus on business and organizational issues which impact the ability of a firm to successfully deploy an analytics program. The focus here is on structure and development. Courses applicable to the Applied Statistics Domain and Analytics Capabilities are those courses which allow students to develop their skills in the use of statistical tools and analytical methods. The courses in the major which fulfill these requirements are Predictive Analytics, Business Intelligence and Social Media Analytics. Finally, courses which are categorized as belonging to the Technical Data Domain and Information Capabilities area are Data and Information Management and Knowledge Management. These technically oriented courses are focused on the data aspects of Business Analytics. In order for data captured and stored by the organization to be used effectively in the analytics context, the data must be effectively structured and managed consistent with its ultimate purpose. As organizations embrace the concept of “big data”, they must increasingly focus on non-database data sources. This focus requires even greater skills in the areas of data and knowledge management.

7. Conclusion

The environment in which educational institutions operate is constantly changing. In order to keep pace, these institutions are faced with constantly refining educational methods and curricula. A major trend that is influencing the environmental forces which work to shape curriculum development is the rapidly increasing use of big data in analytics. This increased use of analytics in organizations is driving the requirement for educational institutions to produce graduates who are skilled in the use of technology and analytics and who also possess a reasonable degree of business domain knowledge. Although accrediting bodies like the AACSB and special interest groups like the ACM and AIS are major contributors to curriculum development in business schools and for information systems programs these bodies do not specify specific curricular choices. It is up to the individual institutions to design and develop appropriate curricular structures which meet the needs of their varied constituent groups. First and foremost among these groups are the organizations that hire these institution’s graduates. It is with these organizations in mind that the business systems and analytics major is proposed. This major is well-positioned to provide graduates with sufficient knowledge of information technology, analytics and business to succeed in today's rapidly changing economic environment.

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Multi-objective Optimization for Exam Scheduling to Enhance the Educational Service Performance

Khaled S Abdallah [1]
[1] *Assistant Professor*
College of International Transport and Logistics
Arab Academy for Science, Technology, and Maritime Transport (AAST)
khaled.seif@aast.edu

Abstract

The exam scheduling problem has been a complex problem. In this paper, we consider planning for the scheduling of examinations of an Egyptian university. We provide and solve different formulations to the problem of scheduling examinations to minimize the total number of students who may have more than one exam at the same time taking into consideration capacity and other operational constraints. We further extend the problem and consider the case where we need to also minimize the number of students that have more than one exam per day, this results in a non-linear multi objective model where the school wants to minimize the number of conflicts (students with concurrent examination) and the number of students with more than one exam per day. We solve the problem using a genetic algorithm and applied it to schedule the final examination in one of the largest universities in Egypt leading to a tremendous reduction of the required man power and a great reduction in the planning errors.

1. Introduction

In recent years, the examination scheduling problem has been getting increasingly difficult as universities are enrolling more students into a wider variety of courses including an increasing number of combined degree courses and hybrid classrooms [1].

In this paper, we consider a large Egyptian university with more than nine campuses nationwide and still expanding, beside other international campuses. More specifically, we consider a school that is operating at near maximum capacity. As the school is operating at near maximum capacity, there is a large number of students registered per course, and most of the times, classes are filled up fast.

The school recommends a set of courses to be registered by students for each term. However, the school does not enforce this recommendation as it adopts a credit hour system. In addition to the already crowded classes, there aren't too many professors available to open extra classes when needed. All of the above, combined with the normal success/failure rates, result in that the students may have to register for other courses that have room available instead of the recommended courses by the school.

Planning for examinations under such dense student enrollment is a hard task as the exam schedule will likely result in a lot of students having 2 or more exams in the same time, not to mention the number of students having 2 or more exams in the same day.

The school under consideration doesn't have an appropriate planning software and relies on experience in developing a tentative schedule that goes through several feedback iterations. Realizing the problem, the author received an award to

build a comprehensive planning algorithm to plan the education process including exam scheduling, examination hall assignment, etc. Phase 1 of the project developed schedules with a minimum number of students with more than one exam at the same time. However, the author wants to go the further step of minimizing the number of students with more than one exam in the same day besides minimizing the number of students with several exams in the same day.

The rest of the paper is divided as follows. Section 2 introduces a literature review for the problem. Section 3 covers the problem description and formulation. Section 4 discusses the solution approach. Section 5 provides numerical results, section 6 provides final conclusion, and section 7 provides future work.

2. Literature review

The exam scheduling problem is defined in the literature as "the allocation of a set of exams to a number of periods (or time slots) so as to satisfy a set of constraints". It follows that different universities have differing views on what constitutes a good exam timetable. This has led to many different formulations of the problem considering different sets of constraints ([2]; [3]; [4]; [5]).

There are generally two groups of constraints: soft and hard constraints. Hard constraints have to be satisfied by any solution, while the soft constraints can be violated to an allowable extent whenever there is an absolute need. Burke et al. [2] discussed some constraints such as: no student should have to take more than one exam in consecutive periods, no student should have to take more than one exam on the same day, large exams should be held earlier in the exam period to allow enough time for marking of the scripts, some exams can only be held in a limited number of periods, and all exams should be scheduled in less than a particular number of periods.

Among the constraints that are mostly case specific, there are two constraints that are universal to all timetabling problems ([6]; [7]). The first is that no student is to be scheduled to take more than one exam at any given time. Violation of this constraint is referred to as a conflict. The second one is that for each period, there must be sufficient seats for all the exams that are scheduled for that period.

Several solution methods are proposed in the literature, however multi-objective models are limited. According to Cheong et al. [9], most of the existing literature in solving the examination scheduling problem use single-objective-based models ([6]; [10]; [11]; [1]; [12], [13]). Wong et al. [14] attempted a multi-objective approach based on a hybrid multi-objective evolutionary algorithm to maximize free time between exams and minimize the conflict. Cheong et al. [9] introduced a multi-objective evolutionary algorithm that minimizes the timetable length as well as the number of occurrences of students having to take exams in consecutive periods within the same day. This paper attempts to solve for minimizing the number of conflicts besides minimizing the number of students with more than one exam in the same day given a fixed length for the exam duration and a fixed number of slots per day.

3. Problem description and formulation

Consider a set of courses V whose exams are to be scheduled in a set of days I each with a set of slots J. The courses are covered in $1,2,\ldots T$ terms with N^c courses per term. $y_{a,t}$ is a binary constant that is equal to 1 when course a is recommended to be taught in term t. There are some courses whose exams must be conducted in the same day as they are taught by another school whose faculty visit us once a week. These courses are represented by a set S of sets of paired courses that should be conducted in the same day. n_a is the number of students registered in course a. Examination rooms have a total capacity of N and individual capacity of N_f for F rooms available. Let $\psi_{a,b}$ be a constant indicating the number of students registered in courses a and b (i.e., conflict if scheduled in the same time). Let $x_{a,i,j}$ be a binary variable with the value of 1 when course a's exam is scheduled in day i and slot j. Now the examination scheduling program for can be formulated as follows:

Minimize

$$\sum_{a,b\epsilon V, a\neq b, i\in I, j\in J} \left(\psi_{a,b} x_{a,i,j} x_{b,i,j}\right) \quad (1)$$

Subject to

$$\sum_{a\epsilon V} \left(x_{a,i,j} n_a\right) \leq N \quad \forall i \in I \text{ and } j \in J \quad (2)$$

$$\sum_{a\epsilon V, j\in J} \left(x_{a,i,j} y_{a,t}\right) \leq 1 \quad \forall i \in I \text{ and } t \in \{0,1,\dots T\} \quad (3)$$

$$\sum_{i\epsilon I, j\in J} \left(x_{a,i,j}\right) = 1 \quad \forall a \in V \quad (4)$$

$$\sum_{j\in J} \left(x_{a,i,j} - x_{b,i,j}\right) = 0 \quad \forall i \in I \text{ and } (a,b)\epsilon S \quad (5)$$

The objective is to minimize the number of students with conflicts. Constraints (2) ensure that the number of students in a certain slot in a certain day does not exceed the total capacity of the examination rooms. Constraints (3) ensure that no more than one course from a specific term is allowed in any examination day. Constraints (4) ensures that any course must be assigned only one slot in any day. Constraints (5) ensures the courses that are supposed to be assigned the same slot are indeed assigned the same day and slot.

The above formulation does not cover all the preferences of the colleges. Other preferences include:

1. Course precedes another course

In this case, we define S^1 as a set of paired courses *(a,b)* where course *a* needs to be scheduled before course *b*, formulated as follows

$$\left(x_{a,i,j} - \sum_{i'=i+1}^{I} x_{b,i',j}\right) = 0 \quad \forall i \in I \text{ and } (a,b) \in S^1 \quad (6)$$

2. Two Courses in the same day

In this case, we define S^2 as set of paired courses *(a,b)* where course *a* needs to be scheduled in the same day as course *b*, but not necessarily the same slot, formulated as follows

$$\sum_{j\in J} (x_{a,i,j} - x_{b,i,j}) = 0 \quad \forall i \in I \text{ and } (a,b) \in S^2 \quad (7)$$

3. In the same slot of another course

In this case, we define S^3 as set of paired courses *(a,b)* where course *a* needs to be scheduled in the same slot as course *b*, but not necessarily the same day, formulated as follows:

$$\sum_{i\in I} (x_{a,i,j} - x_{b,i,j}) = 0 \quad \forall j \in J \text{ and } (a,b) \in S^3 \quad (8)$$

4. In the same time of another course

In this case, we define S^4 as a set of paired courses *(a,b)* where course *a* needs to be scheduled in the same time as course *b*. This means that course *a* will be scheduled in the same day and slot of course *b*, formulated as follows:

$$(x_{a,i,j} - x_{b,i,j}) = 0 \quad \forall j \in J, i \in I, \text{and } (a,b) \in S^4 \quad (9)$$

5. Not in the same day of another course

In this case, we define S^5 as a set of paired courses *(a,b)* where course *a* should not be scheduled in the same day as course *b*, but can be scheduled in the same slot.

This can be performed by adding the following constraints

$$0 \leq \sum_{j\in J} (x_{a,i,j} + x_{b,i,j}) \leq 1 \quad \forall i \in I \text{ and } (a,b) \in S^5 \quad (10)$$

6. Not in the same slot of another course

In this case, we define S^6 as a set of paired courses *(a,b)* where course *a* should not be scheduled in the same slot as course *b*, but not necessarily in the same day; formulated as follows:

$$\sum_{i\in I} (x_{a,i,j} + x_{b,i,j}) \leq 1 \quad \forall j \in J \text{ and } (a,b) \in S^6 \quad (11)$$

7. Not in the same time of another course

In this case, we define S^7 as a set of paired courses *(a,b)* where course *a* should not be scheduled in the same time as course *b*; formulated as follows:

$$(x_{a,i,j} + x_{b,i,j}) \leq 1 \quad \forall j \in J, i \in I, \text{and } (a,b) \in S^7 \quad (12)$$

8. One course per term per day

Constraints 3 guarantees that no more than one course from the recommended courses for a specific term is to be selected. These constraints can be relaxed when the exam duration is less than the number of terms.

9. A course is not assigned a room

When an examination does not need to be assigned an examination hall, then the capacity requirement for that course is not added to the total requirement. Define R_a as a binary constant that indicates whether the capacity requirement for course a should be included, or not, formulated as follows:

$$\sum_{a\epsilon V}\left(x_{a,i,j}n_aR_a\right) \le N \;\; \forall i \in I \; and \; j \in J \; (13)$$

10. Scheduled on a specific Day

When a course needs to be scheduled on a specific day, the following constraints can be added:

$$\sum_{j\in J}(x_{a,i,j}) = 1 \qquad for \;\; given \; a,i \;\; (14)$$

11. Scheduled on a specific slot

When a course needs to be scheduled on a specific slot, it is formulated as follows:

$$\sum_{i\in I}(x_{a,i,j}) = 1 \qquad for \;\; given \; j,a \;\; (15)$$

12. Scheduled in Day and slot

When a course needs to be scheduled on a specific time, it is formulated as follows:

$$x_{a,i,j} = 1 \qquad \text{for given } j \text{ and } i \;\; (16)$$

13. Course/s that need specific Room/s

In this case, the capacity of all the courses that need the same rooms are checked against the available capacity when the courses are assigned the same time. Define S^8={(S_1^C, S_1^R), (S_2^C, S_2^R), ……., (S_k^C, S_k^R)} as a set of pairs (S_k^C, S_k^R) representing some courses and the rooms requested for them where $S_k^R = \{S_{k,1}^R, S_{k,2}^R, \ldots\ldots, S_{k,P}^R\}$ is the set of rooms that are to be assigned to courses in set S_k^C.

Then we add constraints that check the number of students enrolled in the courses in S_k^C provided that they are scheduled in the same time against the capacity of their associated rooms in S_k^R. If we define S_K^C as the capacity of room, then this can be formulated as follows

$$\sum_{S_{K,q}^C \epsilon S_K^C}\left(x_{S_{K,q},i,j}n_a\right) \le \sum_{S_{K,p}^R \epsilon S_K^R}\left(N_{S_{K,p}^R}\right)$$

$$\forall k \in K, p \in P, q \in Q \qquad (17)$$

It should be noted that S^8 needs also to be extended to include rooms that are included in several course/room combination. Let's for example assume that a certain room is common in (S_1^C, S_1^R), (S_2^C, S_2^R), and (S_3^C, S_3^R), then all of the combinations of these sets need to be added to S^8. So the following combinations are added ($S_1^C \cup S_2^C$, $S_1^R \cup S_2^R$),($S_2^C \cup S_3^C$, $S_2^R \cup S_3^R$),($S_1^C \cup S_3^C$, $S_1^R \cup S_3^R$), and ($S_1^C \cup S_2^C \cup S_3^C$, $S_1^R \cup S_2^R \cup S_3^R$).

14. Same schedule for different languages tracks

This can be achieved by two ways: the first method is by adding constraints that relate to other languages' courses to the English track. Let the number of tracks be n_L. In this case, one language's courses are indexed from 0 to |V|/n_L-1, while the second language's courses are indexed from |V|/ n_L to 2|V|/ n_{L-1}, etc. Then, the following constraints are added

$$(x_{a,i,j} - x_{a+l*\frac{|V|}{n_L},i,j}) = 0$$

$$\forall \, l \in n_L, j \in J, i \in I, \qquad a = 0,1,.\frac{|V|}{n_L} - 1 \; (18)$$

A better alternative is to use the formulation for the English track and incorporate the other language requirements into the constraints (e.g., the capacity check will include the capacity of classes taught in all languages.)

15. Excluded in the schedule

Some courses may not be scheduled for different reasons such as when there is no final exam for them. In this case, we define S^9 as a set of the courses that are excluded from the schedule. Hence constraints (4) are replaced by:

$$\sum_{i\epsilon I, j\in J} x_{a,i,j} = 1 \qquad \forall a \in V/S^9 \;\; (19)$$

16. Excluded from term check

Some courses are not included in the recommended plan but are known to be taught in certain terms under specific conditions such as non-credit language courses. The college may want to exclude this course from the one course per term per day. Define S^{10} as a set of courses that need to excluded from the term check.

Constraints (3) can then be adjusted as follows:

$$\sum_{a \epsilon V/S^{10}, j \in J} \left(x_{a,i,j} y_{a,t}\right) \leq 1 \quad \forall i \in I \text{ and } t \in \{0,1,\dots T\} \quad (20)$$

17. Minimizing number of students with more than one exam in different slots per day

In this case, the objective function becomes much more complex by adding several terms to compute the number of students that have 2,3….and up to *J* exams per day as follows

$$\sum_{u=2}^{J} \sum_{\substack{a_1<a_2<,\dots\dots<a_u \epsilon V \\ and \\ j_1,j_2,\dots\dots j_u \epsilon J}} \left(\psi_{a_1,a_2,\dots\dots a_u} x_{a_1,i,J_1} x_{a_2,i,J_2} \dots \dots . x_{a_u,i,J_u}\right) (21)$$

The inequality $a_1 < a_2 <, \dots \dots < a_u \epsilon V$ ensures that the different combination of courses are not computed at different times by using the exact same courses but in different order.

This term when added to the objective, it becomes non-linear. Moreover, there are multiple objectives in this formulation. The first objective is to minimize the number of students with conflicts, and the second group of objectives minimize the students with 2 or more exams in the same day but in different times, called hereafter as clash. The objective is formed by a linear combination of both.

All of the above formulations except for the objective of minimizing students with clash are actually quadratic integer models that can be solved efficiently using IBM ILOG CPLEX given enough time.

4. Solution approach

In order to solve the problem, a genetic algorithm is developed. The algorithm starts with constructing chromosomes formed of two columns. The first column represents assigned examination day ranging from 1 up to the examination duration, and the other column represents the assigned slot. Each row represents a course's assigned examination day and slot. Each group of courses that belong to the same term are grouped together in blocks. A block has a length equal to the exam duration, with any extra row not assigned a course represents a dummy course. As a result of the equal size blocks, some of the constraints will always be maintained during the search as discussed later.

All courses that are not assigned specific terms in the recommended course plan are grouped together in another block. The total number of blocks is equal to the number of terms plus 1. A complete chromosome is shown in figure 1.

4.1. Initial solution

An initial solution of 100 chromosomes is formed using the following approach. For each block representing a term, random generated combinatorial integers from 1 to exam duration are assigned to days. Note that being combinatorial integers, no integer is repeated. Hence, there are not any courses from the same term that are assigned the same day. Then a randomly generated integer from 1 to the allowed number of slots per days is assigned to each row. Note that a slot may be repeated several times within a block, but does not affect feasibility.

It should be noted that the generated initial solutions don't necessarily have to be feasible. An example is shown in figure 2.

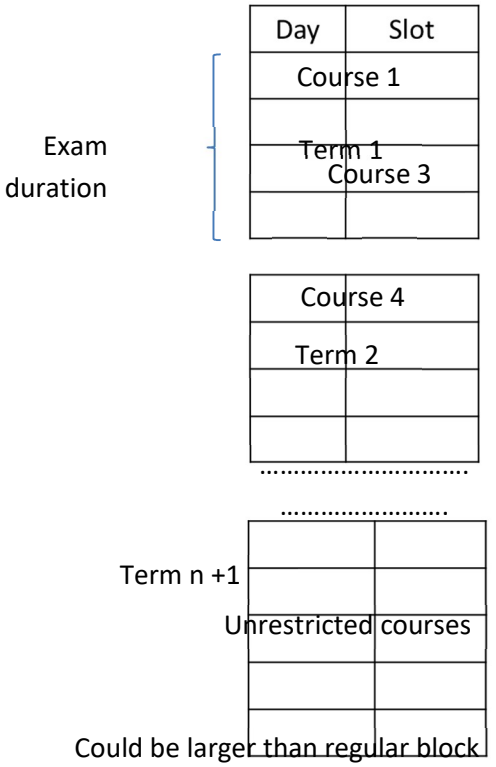

Figure 1. A complete chromosome setup for a possible solution

Day	Slot
2	1
1	1
3	2
1	1
3	2
2	1
…..	…..
4	1
4	2
2	2
1	1

Figure 2. A chromosome with initial solution for three days examination duration

4.2. Fitting function

In order for the algorithm to evaluate how well a solution is, it first loops through each pairwise courses within a slot. Two values are computed. The first value is the share of conflict per course which means the conflict resulting from a course being scheduled in the same time with other courses in the current chromosome. The second value is the total conflict resulting from all the courses being scheduled in the same time in the current chromosome. The next step is to loop through all the courses scheduled in a given day to compute the share of the same day clash contribution of one course, and total clash for each day.

The total conflict and total clash of a schedule are computed concurrently while computing the above values along with a check of the capacity requirement and other precedence requirements.

In the first ten iterations, we allow infeasible solutions; however, later when there is infeasibility, the total conflict for an infeasible solution is considered a huge value.

Finally, the fitting function computes which is a weighted sum of the total same slot conflict and the total same day conflict.

4.3. Search operations

As the current chromosome setting allows the exchange of the days and slots of one block with another block without violating the term requirements, we allow cross over as follows.

In the first half of allowed iterations, we select candidate parents randomly to allow appropriate exploring of the solution space. In the second half, we select parents using Roulette wheel selection with

$$P_i = \frac{\exp(-2 * \frac{conflict}{worst\ conflict\ in\ the\ pool})}{\sum_{j=1}^{N} \exp(-2 * \frac{conflict}{worst\ conflict\ in\ the\ pool})}$$

Two children chromosomes are generated by exchanging the day and slot assignments of the two blocks that have the maximum number of students with conflict as shown in figure 3.

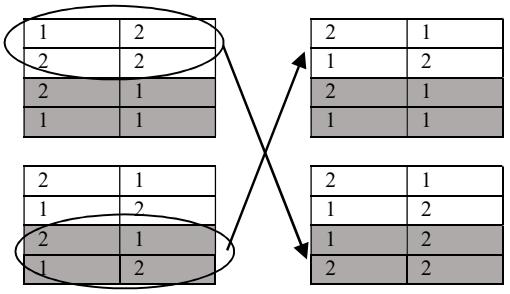

Figure 3. Crossover of regular courses.

The cross over for the unrestricted is different. We use the same parent selection as before. We select the parent with the maximum number of conflicts between the two parents. A start point and end point are selected based on a cumulative relative frequency of the number of conflicts resulting from a course relative to the total conflict of the unrestricted courses block as shown in figure 4.

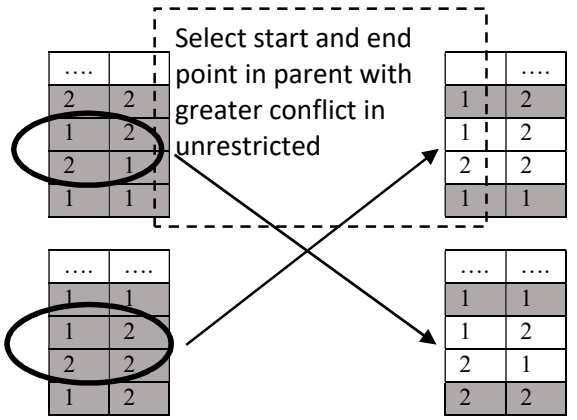

Figure 4. Crossover of unrestricted courses.

The algorithm also does a slot cross over. A chromosome is randomly selected. Then the day with the most conflict is selected. Within the selected day, the course with the maximum and minimum share of conflicts are selected and their slots are swapped as shown in figure 5.

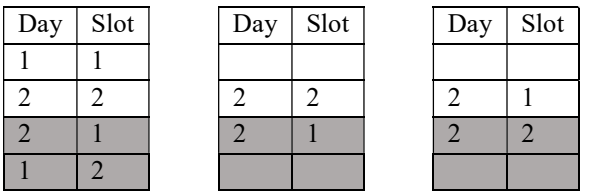

Figure 5. Slot crossover

As the number of conflicts decrease with the progression of the algorithm, there is more than one course that does not contribute in any conflict. In this case, selection of the two courses with the maximum and minimum conflict contribution wouldn't be the best action. It will be better to choose a course among the top 3 courses according to their conflict contribution, and another course among the top 3 with the least conflict contribution.

In order not to get stuck in a local sub optimal solution, the algorithm performs mutations in two ways: day and slot mutations. For both cases the algorithm selects a chromosome randomly. Based on the cumulative frequency of each course's conflict contribution relative to the total conflict of the selected chromosome, the algorithm generates a probability that is transformed into an equivalent course selection for mutation.

With a course selected for mutation, the algorithm can mutate the slot directly by choosing a value from 1 to the maximum slots available per day other than the current value.

For day mutation, when the day of the selected course is mutated, it is then assigned a day that is already assigned to another course in the same block. The other course should then be assigned the day originally assigned to the selected course.

Instead of randomly assigning a new day to the selected course, a third approach is adopted. We randomly select one course among the top three courses with the most conflict contributions and another course among the top three courses with the least conflict contribution. After swapping the days of the two selected courses, there would be two courses with the same assigned day within their respective blocks, so we switch the assigned day of the other course within each block with the assigned day originally assigned to the respective selected course as shown in figure 6.

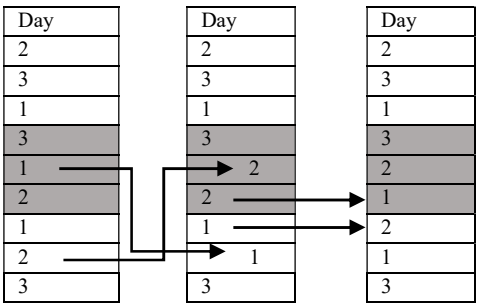

Figure 6. Mutation of Days

4.4. Obtaining Multi-objective solution

While progressing through the iterations, infeasible solutions are allowed half way through the iterations. Then infeasible solutions are assigned a very high value in order not to be selected in later iterations.

Due to the combinatorial nature of the

problem, many chromosomes could be generated despite having the same solution, but arranged in different orders. So, only unique solutions are allowed after half way through the iterations.

For a single objective, the new pool of solutions is arranged according to the conflict after an iteration ends. While for the multi-objective of minimizing the clash in addition to the conflict, the algorithm selects new generations in two techniques:

Case 1: Arranging the new generation according to conflict then clash. This is equivalent to the Pareto importance, as the former objective is far more important for the school than the latter.

Case 2: Arranging according to conflict then according to a weighted average of conflict and clash.

In later iterations and as the algorithm converges to the optimal solution, we allow non-unique solutions to improve the quality of the second objective, i.e., by minimizing clash after the algorithm had already minimized the number of conflicts. This setting allows both approaches to favor the objective of minimizing conflict as it is more important.

The algorithm steps are as follows:

1. Set GA parameters.
2. Initial population.
3. Run fit function for each chromosome.
4. Repeat for the max number of iterations.
5. Term crossover via random selection for the first half iterations then via Roulette wheel selection.
6. Apply unrestricted term crossover.
7. Apply regular slot mutation.
8. Apply slot mutation.
9. Apply day mutation.
10. Apply mutation for unrestricted courses.
11. Append new solutions to the population.
12. Arrange ascendingly according to conflict, then according to clash or weighted average of conflict and clash.
13. Halfway through iterations, the best chromosomes are kept, then later, the best unique solutions are kept. And loop.

5. Numerical Results

The algorithm is tested on a large school. It offers two languages tracks, each with three majors. Most of the courses are taught in the three majors. The school has eight terms with six courses per semester. There are about 1,285 students with more than 6,500 course student enrolments. There are 21 examination halls available, each with a capacity of 30 students.

The quadratic model developed in this paper was solved using two hours run of IBM ILOG Cplex 32 bit on a laptop with Intel i3-4030U CPU clocked at 1.9GHz and 4GB ram. The results are shown in table 1 and 2 for two slots and three slots per day, respectively.

Table 1. Results of running the exact Quadratic model for 2 slots per day.

Days	6	7	8	9	10
Conflict	86	40	49	21	2
Clash	579	512	414	325	377

Table 2. Results of running the exact Quadratic model for 3 slots per day.

Days	6	7	8	9	10
Conflict	10	9	1	1	0
Clash	694	685	486	595	474

Although the exact model was successful in finding good solutions, the values of the clash are, however, very high.

The Genetic Algorithm is then applied to the same set of data. Two cases are analyzed: Case 1, when the GA arranges the pool according to conflict then clash, and case 2 when GA arranges the pool according to conflict then weighted average conflict and clash. The results are shown in figures 7 and 8 for conflict and clash, respectively, for three slots per day. Figures 9 and 10 show the same for two slots per day.

It is observed that for 3 slots per day, case 2 consistently results in lower conflict compared to case 1, but case 1 results in lower clash when the duration is not tight (i.e., greater than the number of terms).

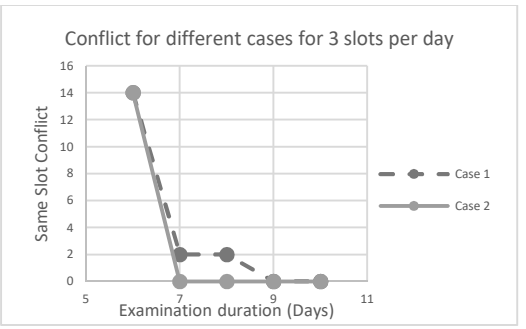

Figure 7. Conflict for 3 slots per day.

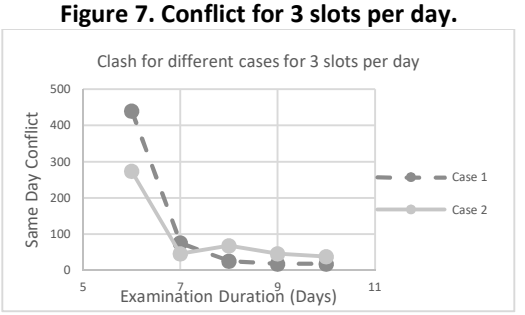

Figure 8. Clash for 3 slots per day.

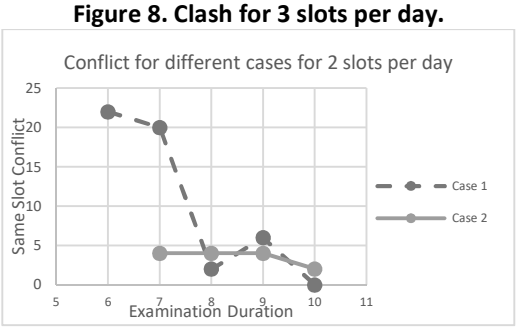

Figure 9. Conflict for 2 slots per day.

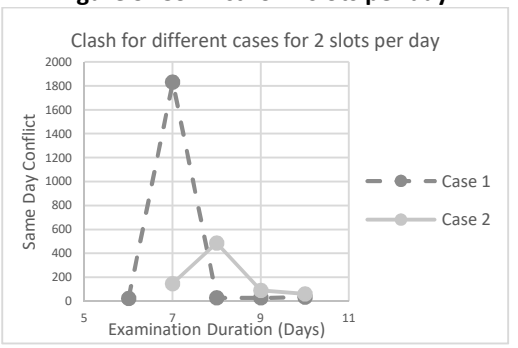

Figure 10. Clash for 2 slots per day.

Once again, it is observed that case 2 generally results in lower conflict compared to case 1, but case 1 results in lower conflict when the schedule is not tight. Moreover, case 2 was unable to obtain a solution when the schedule was very tight with number of days equal to the number of terms and two slots per day.

6. Conclusion

In this paper, two types of models are introduced for exam scheduling: an exact quadratic model to minimize number of conflicts, and a genetic algorithm that adds another objective to minimize the number of clashes in addition to the number of conflicts.

The models take into consideration a large number of operational constraints that are general in nature and not only tied to the Egyptian university school under consideration, but they can also be applied at other universities as well.

Both models performed well and consistently provided a good solution for the conflict. However, the quadratic model doesn't always result in a small number of clashes.

The proposed GA consistently resulted in a good number of clashes. Within the proposed GA model, two cases are suggested to select the pool of chromosomes between iterations. From the numerical results, it is recommended to use case 2 for tight schedules and case 1 for loose schedules.

7. Future Work

A possible extension to the proposed model is to develop a model to add another objective to the objectives considered in this paper to minimize room sharing between colleges when the exam duration is very tight and the capacity would not be enough to build a schedule.

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Use of 3D Printers to Design, Build, Test and Fly a Quadcopter Drone

R. Radharamanan[1]
Ana Carolina Martins Rosa, Benedito Domiciano Neto, Victor Ferreira Bispo Santos
[1]*Mercer University, Macon, GA 31207 USA*
radharaman_r@mercer.edu

Abstract

The body, arms, and legs of a quadcopter drone were designed using two design softwares, 123 D Design and MeshMixer. These parts were printed using two 3D printers: The MakerBot Replicator 2X was used to print the arms using ABS (Acrylonitrile butadiene styrene) material and the Flashforge Creator Pro printed the body and legs using PLA (Polylactic acid) material. The printed parts were tested for dimensional accuracy and surface roughness. The electronic parts for the drone consisted of one flight control, four electronic speed controllers, one transmitter, one receiver, four motors, four propellers, and one GPS. The 3D printed parts and the electronic components were assembled to make the prototype of the quadcopter drone. Through this hands-on project, the senior mechanical and industrial engineering students of Mercer Summer Engineering Experience (MeSEE 2015) course were trained in two new and emerging manufacturing technologies: 3D printing and rapid prototyping as well as drone technology. Some of the difficulties encountered by the student team include assembly errors, sizing issues, and software incompatibility. Flight tests were performed and the errors identified and corrected. The results of the flying quadcopter drone designed, built, and tested are presented and discussed.

1. Introduction

The 3D printers are capable of producing three-dimensional solid objects drawn in 3D software through an additive process, wherein the feedstock is applied layer by layer to form the three-dimensional object (3D Printing Basics, May, 2014; Petronzio, March, 2013; Evans, 2012). The drones are instruments controlled from a distance by electronic and computational mechanisms. Many of them seem to be aero-modeling toys or even remote control helicopters, but the differences are in the technologies employed, usually much more complex than mere toys. Its utilities go beyond conventional, they can be used either for leisure, commercial or military work (History of the Drone, February 22, 2015).

Uniting these technologies, a drone was designed, built, and tested. All of the parts of the drone were printed with the 3D printers: arms, body, and legs. The electronic parts were bought separately: motors, battery, charger, electronic speed controllers (ESCs), and remote control. All printed and purchased parts were put together and tested for the drone to fly.

Two softwares were used to design the parts of the drone: 123D Design and MeshMixer. These are compatible with the 3D Printers. Two 3D printers used to print the parts are: the MakerBot Replicator 2X and the Flashforge Creator Pro. Currently, both printers are available for training students in the additive manufacturing/rapid prototyping laboratory at Mercer University School of Engineering. The MakerBot Replicator 2X was used to print the arms using ABS, a common thermoplastic polymer, very rigid and light, with a

good balance of strength and flexibility. The Flashforge Creator Pro printed the body and legs using PLA, a biodegradable thermoplastic polyester, more efficient in certain types of molding than the ABS, because it tends to deform less after the application and releases less smoke upon reaching its melting point. The printed parts were measured for dimensional accuracy and the surface roughness measurements were made using a surface roughness tester. Also, flight tests were performed and some errors were corrected for the drone to fly without errors.

2. Background research

2.1 The 3D printer

The 3D printer is a machine allowing the creation of a physical object from a three-dimensional digital model, typically by laying down many thin layers of a material in succession (Evans, 2012). This is the main characteristic that distinguishes the 3D printers from other numerically controlled (CNC) machines where the production process is subtractive, meaning that the final object is achieved by removing the raw material using different mechanical tools (Gibson et al, 2010; Gebhardt, 2012).

The 3D printer has become a good ally of Rapid Prototyping, because the process of this technology is easy to design, rapid to create, or replace (Chua et al, 2010; Dryden, 2014). Manufacturers and product developers used to find prototyping a complex, tedious, and expensive process that often impeded the developmental and creative phases during the introduction of a new product and with this new term and the 3D printer, all of this process has become easy to manage and fast to accomplish (Dryden, 2014). Laser-based rapid prototyping and other related technologies are also available for making 3D parts (Venuvinod and Ma, 2004)

2.2 The drone

The drones or unmanned aerial vehicles (UAVs) were designed for military purposes. Inspired by the German flying bombs, the V-1 type, and those harmless radio-controlled airplane models, these flying machines of the latest generation are designed, engineered and built to be used on very dangerous missions that cannot be performed by humans in the areas of military intelligence, support and control of artillery fire, air support for infantry and cavalry troops on the battlefield, cruise missiles control, urban patrolling, coastal, environmental activities and borders, search and rescue activities, among others (History of the Drone, February 22, 2015).

Storm and tornado tracking, warning, and relief response using UAV systems were presented as a demonstration of analysis techniques. Also, UAV application of a civil unmanned system to a disaster relief mission with the intent on saving lives was presented. The concept utilizes unmanned aircraft to obtain advanced warning and damage assessments for tornados and severe thunderstorms. Overview of a tornado watch mission architecture as well as commentary on risk, cost, need for, and design tradeoffs for unmanned aerial systems are also provided (DeBusk, 2009).

Kückelhaus (2014) discussed the use of UAVs in logistics, a DHL (a division of a German logistics company) perspective on implications and the cases for the logistics industry including delivery at rural areas. Clothier et al (2015) highlighted the risk perception and the public acceptance of drones. Churchill (2015) presented and discussed ethical and psychological issues of drone warfare. Crutsinger, Short, and Sollenberger (2016) discussed the future of drones (UAVs) in ecology, an insider perspective from the Silicon Valley drone industry. Ducard (2009) proposed practical methods for fault-tolerant flight control and guidance systems for small unmanned aerial vehicles.

2.3 The electronic parts of the drone

Every drone has the basic parts that are required for it to fly and each part has its functionality and usefulness. Starting with the ESC (Electronic Speed Controller), it does two important things for the drone. First it converts the battery voltage down to 5V, for which the receiver runs. Second, it converts the DC power from the

battery to an AC current, which is required by the motor (ESC- Electronic Speed Controller, July 14, 2015). The Turnigy 9X is a radio channel dedicated to 2.4 GHz 8-channels and is manufactured by Flysky as the FS-TH9X. This has the remote control and the transmitter. When programming both, one can send the transmitter the correct information to the remote control and see it flying.

The DJI Naza-M V2 is a powerful flight controller for enthusiast, commercial and industrial flyers. It is easy to install, simple to configure and above all, extremely stable. The Naza-M V2 boasts have the extraordinary stability one would expect of all DJI flight control systems and combines it with unparalleled maneuverability with and without GPS. Built into it are automatic GPS course correction plus GPS and compass interference monitoring, which combine to offer more stable flight and minimal magnetic interference. If the connection between the multirotor and the remote control are disconnected during the flight, a failsafe system will activate. Provided there was enough GPS signal at the time of the disconnection, the multirotor will fly back to its point of takeoff and land automatically (Naza-M V2 Features, July 14, 2015).

3. Methodology

3.1. Design of the Drone

The 123D Design software helped to give the shape to the parts: arms, body, and legs; then the MeshMixer helped to fix the corner from the part using the tool, make it solid, that gave the final look to the part. Figure 1 shows the CAD of the arm in the MeshMixer ready to print.

The four arms were printed in the MakerBot Replicator 2X (MakerBot Replicator 2X User Manual, July 14, 2015) 3D printer using ABS material. The ABS has a good balance of strength and flexibility besides being very rigid and light, it was a better choice for the arms than the PLA. The temperature used to print the arms was 230°C; the platform temperature was 110°C; the layer height was 0.20mm; and the infill was 75%. Figures 2(a) and 2(b) show details of dimensions and print settings respectively for the arm.

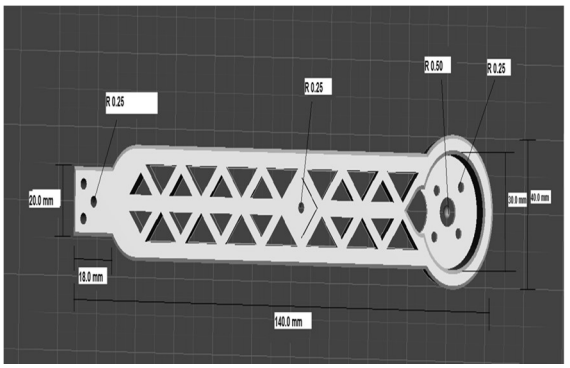
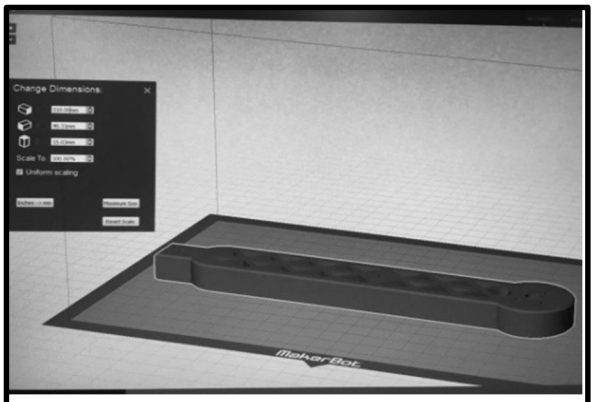
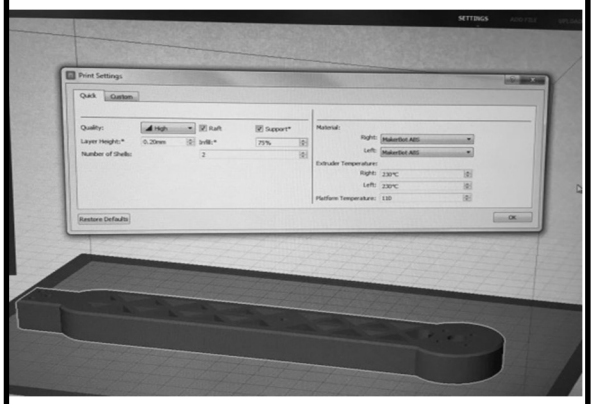


Figure 1. CAD of the arm



(a) Dimensions used to print the arm



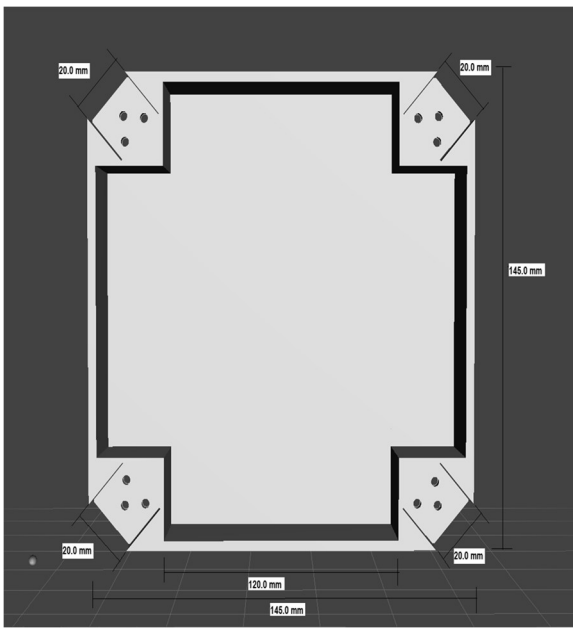
(b) Print setting of the arm

Figure 2: Details of dimensions and print setting for the arm

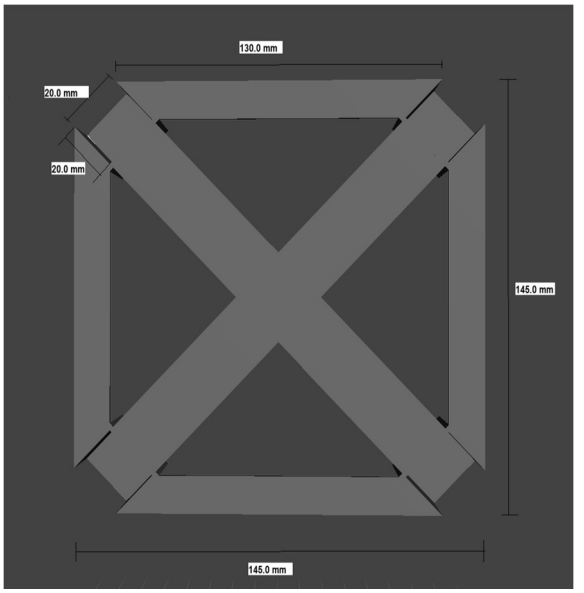
The body was divided in two parts, the bottom part and the top part, when put together it becomes a box. It was printed in the Flashforge Creator Pro (Flashforge Creator Pro 3D Printer User Manual, July 14, 2015) 3D Printer using PLA

material. The PLA is more efficient in molding than the ABS; also, because it has a lower melting point, it results in more resistant objects at the end. Furthermore, because the PLA is less viscous when in liquid state, it requires less force of the extruder to expel the material, which can ensure a little more durability for the equipment. Thus, the body in which the electronic parts are connected and assembled to form the brain of the drone, must be protected from drops, and PLA can ensure better protection than ABS. The temperature used to print the body was 220°C; the platform temperature was 110°C; the layer height was 0.20mm; and the infill was 75%. Figures 3 and 4 show the CAD drawings of the bottom/top of the box and leg respectively, both were printed in PLA material in the Flashforge Creator Pro.

Print settings used for the bottom box in the MakerBot software: standard quality with raft and support; the layer height of 0.20mm; the infill rate of 75%; and the number of shells of 2. The corresponding dimensions of the bottom box were: X = 145mm; Y = 145mm; Z = 28.02mm; and Scale = 100%



(a) Bottom box



(b) Top box

Figure 3. CAD of bottom and top of the box

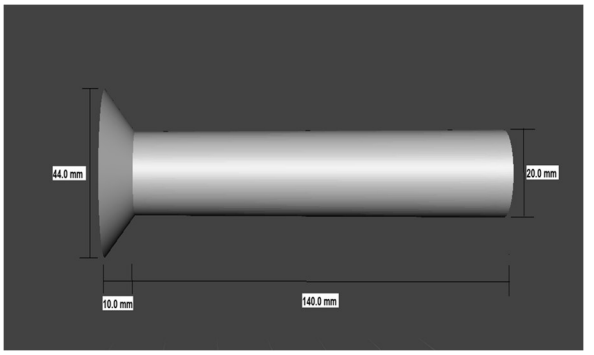


Figure 4. CAD of the leg

3.2 Materials for the Electronic Assembly of the Drone

To truly have a drone and see it flying the following list of materials are needed:

1. 4 motors - NTM Prop Drive Series 28-26A 1200kv / 250w
2. Propellers - 10x4.5 SF Props 2pc Standard Rotation/2 pc RH Rotation (Black)
3. 4 ESC - TURNIGY Plush 30amp Speed Controller
4. Remote control and transmitter - Turnigy 9X 9Ch Transmitter w/ Module & 8ch Receiver (Mode 2) (V2 Firmware)
5. Battery - Turnigy nano-tech 3000mah

3S 25~50C Lipo Pack
6. Charger for the battery - Turnigy Accucel-8 150W 7A Balancer/Charger
7. Flight Controller - DJI Naza-M V2
8. Wires - 20AWG Soft Flexible Silicone Wire – Black + Red and 16AWG Soft Flexible Silicone Wire – Black + Red
9. Connectors - XT60
10. Screw - M3x30x0.5
11. Zip ties
12. Sockets - 3 x 30mm Socket Head Cap Screw 10pcs Class 12.9 Hard Alloy Steel
13. CA Glue (Cyanoacrylate Adhesive)
14. Banana Plug

3.3 Building the Drone

Mounting the Motors

With the parts printed, it is possible to start the construction of the drone. Each arm requires a motor and an ESC. First, each motor was fit to the location designed for it and fixed with four screws.

Mounting the Electronic Parts

Now it is time to wire up the transmitter, the flight controller, and the ESCs. The DJI Naza-M V2 is the flight controller, and in its box there is the main controller, the servo cables, LED module, PMU (Power Management Unit) module, the GPS and compass module. First, the PMU module was soldered to the battery, the red wire to the positive pole and the black one to the negative pole of the battery. After soldering was completed, the main controller was mounted. The arms 1 and 2 were chosen to be in the nose direction of the aircraft, so the arrow on the main controller must be the same as the nose direction, here the locations were defined as M1, M2, M3, and M4, the M1 matches with arm 1, M2 matches with arm 2, and so on. Each ESC has a 3PIN signal line to be connected into the main controller, so it was connected from M1 through M4 port on the main controller one by one. Then the 3PIN port of the PMU was connected to the X3 channel on the main controller, the 4PIN port on the PMU to the EXP channel of the main controller, and the LED module to the main controller. After, the transmitter was connected to the Naza using a servo cable. The S-Bus receiver in the transmitter was connected to the X2 channel of the Naza. At the end, the GPS module was plugged into the GPS port on the PMU. Figure 5 shows all electronic parts connected and fitted in the bottom box.

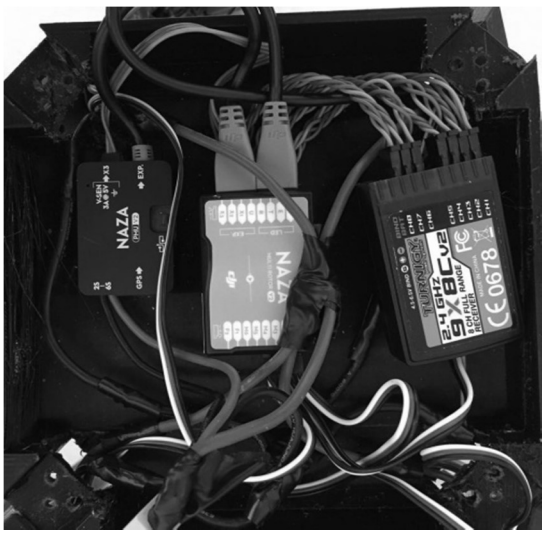


Figure 5. Electronic parts connected and fitted in the bottom box

3.4 Configuration

Electronic Speed Controller (ESC) Calibration

Electronic speed controllers are responsible for spinning the motors at the speed requested by the autopilot. Figure 6 shows a Turnigy-Electronic Speed Controller used. Most ESCs need to be calibrated so that they know the minimum and maximum PWM (Pulse Width Modulation) values that the flight controller will send. Before calibrating ESCs, make sure that the copter has no propellers on it and that the APM (ArduPilot) is not connected to a computer via USB and the Lipo battery is disconnected.

Figure 6. Turnigy ESC 30A

The four ESCs were calibrated following these simple steps:

1. Connect the ESC to channel 3, which is responsible for the throttle channel, in the receiver.
2. Turn on the transmitter, move the stick throttle to the top, and turn on the ESC.
3. Wait for the ESC emit the musical tone, the regular number of tones indicating the battery's cell count, in this case 3 beeps = LIPO 3S. Then an additional two beeps to indicate that the maximum throttle has been captured.
4. Pull the transmitter's throttle stick to its minimum position.
5. The ESC should emit a long beep indicating that the minimum throttle has been captured and the calibration has been completed (Electronic Speed Control Calibration, July 14, 2015).

Flight Controller Calibration NAZA-M V2

The NAZA-M V2 is a powerful flight controller that is composed for the MC (Main Controller), PMU (Power Management Unit), LED, and GPS/Compass. The controller Turnigy RF 9X V2 and the Dji NAZA-M V2 flight controller were configurated using the Dji NAZA Assistant software (Naza-M V2 Features, July 14, 2015).

Naza-M-V2 Compass Calibration

Calibration for the GPS module - Calibration Procedures:

1. Switch on the transmitter, and then power on autopilot system (DJIAuto Pilot System Control Modes, January 21, 2013).
2. Quickly switch the control mode switch from Manual Mode to GPS ATTI Mode and back to Manual Mode for 6 to 10 times, The LED indicator will turn on constantly yellow.
3. Hold the multirotor horizontal and rotate it around the gravitational force line (about 360°) until the LED changes to constant green, and then go to the next step.
4. Hold the multirotor vertically and rotate it (its nose downward) around the gravitational force line (about 360°) until the LED turns off, meaning the calibration is completed.
5. If the calibration was successful, the calibration mode will exit automatically. If the LED keeps flashing quickly Red, the calibration has failed. Switch the control mode switch one time to cancel the calibration, and then restart from step 2.

Turnigy 9X Transmitter Configuration

The transmitter was configurated in type Acro and mode 2, as shown in Figures 7 and 8, which are the best settings for a quadcopter drone. When the Turnigy 9x transmitter is in mode 2, the left stick controls the throttle and the rudder, and the right stick controls the ailerons and the elevator (DIY Drones, January 4, 2013).

Figures 7. Turnigy transmitter configuration

Figure 8. Mode 2 configuration

Mounting the propellers

An easy way to find out the direction of the propeller is looking at it visually. When spinning clockwise, the leading edge should always be in the front. But the easiest way to tell if a prop is counterclockwise is by looking at the letters and numbers on it.

4. Results and discussions

The dimensions of the 3D printed parts, body, arms, and legs were measured using dial gages and found to be within the tolerance limits. A surface roughness tester, SRT-620 (Bikesu, 2014) was used to measure the surface quality of the printed parts (Figure 9). This test presented the surface quality of the material printed in numerical form, making it easier to analyze.

Figure 9. Surface roughness tester, SRT-6210

Surface Roughness Test

Surface roughness is a component of surface texture. It is measured by the deviations in the direction of the normal vector of a real surface based on its ideal form (Bikesu, 2014). Large deviations show that the surface is rough and small deviations present a smooth surface (Surface Roughness, May 17, 2015). The surface roughness parameters are measured using the equations presented in Table 1.

Table 1. Surface roughness parameters

R_a	$R_a = \frac{1}{n}\sum_{i=1}^{n}\lvert Y_i\rvert$	
	Arithmetic Average	
R_z	$R_z = \frac{\sum_{i=1}^{5} Y_i + \sum_{i=1}^{5} Y_v}{5}$	Where: Yi = Maximum Height Yv = Minimum Valley
	Average Height of 5 Highest Peaks and 5 Lowest Valleys	
R_t	$R_t = Y_{max.} - Y_{min.}$	
	Maximum Height of the Profile	
R_q	$R_q = \sqrt{\frac{\sum_{i=1}^{n} Y_i^2}{n}}$	
	RMS (Root Means Square) Value	

Results of Roughness Measurements

Tables 2 and 3 present the roughness measurements (Ra, Rz, Rt, and Rq) made on printed parts using ABS and PLA materials. From the results, it can be concluded that the two materials show a very similar quality, with slight advantage for the PLA material. Also, it can be noted that the average roughness using PLA is more regular, while with the ABS shows a greater variation between prints (Rosa et al, 2015).

Table 2. ABS parts - Roughness measurements in µm

ABS Material						
		Arm 1	Arm 2	Arm 3	Arm 4	Average
R_a	Mean	2.740	4.781	5.331	2.343	3.798
	SD	1.065	1.557	0.779	0.792	1.048
R_z	Mean	7.748	13.518	15.073	6.625	10.741
	SD	3.013	4.402	2.202	2.241	2.965
R_q	Mean	3.357	6.751	7.281	3.306	5.228
	SD	1.359	2.657	1.157	1.239	1.603
R_t	Mean	7.825	13.651	15.223	6.691	10.848
	SD	3.042	4.446	2.225	2.264	2.994

SD = Standard Deviation

Table 3. PLA parts - Roughness measurements in µm

PLA Material				
		Upper Box	Lower Box	Average
R_a	Mean	3.844	3.656	3.750
	Standard Deviation	1.400	0.892	1.146
R_z	Mean	10.869	10.339	10.604
	Standard Deviation	3.957	2.522	3.240
R_q	Mean	4.944	4.824	4.884
	Standard Deviation	1.555	1.111	1.333
R_t	Mean	10.978	10.440	10.709
	Standard Deviation	3.997	2.547	3.272

Flight Tests

Test 1 - In the first flight test, there were some problems, including the failure of one of the propellers - Figure 10 (a). The propeller was glued and some of the control settings revised, including changing the flight mode to one in which the GPS is not used. The test was not successful.

Test 2 - Again, some problems occurred with the drone, two of the propellers went higher than others, causing it to turn and, once again, breaking some propellers - Figure 10 (b). A new kit of propellers was purchased for replacement, and finally the problem was found, the configuration of the propellers was wrong, the engines were reversed. The test was not successful.

Test 3 - With new propellers and engines in the right order, the third test finally worked. The drone could take off, stay stable, and reach the expected altitude. The test was successful this time.

(a)

(b)

Figure 10: (a) Test 1 - One broken propeller; (b) Test 2 - Three broken propellers

Figure 11: Completed ready to fly drone

Figure 11 shows the completed ready to fly drone (Rosa et al, 2015). The link for the video of the flying drone is:
https://youtu.be/JwQzwoAvHg8

5. Conclusions and recommendations

The students were trained in using 123D Design and MeshMixer and two emerging technologies: 3D printing and rapid prototyping as well as drone technology. The students learned to use 3D printers and print parts using two different materials (ABS and PLA). They were able to measure the printed parts for dimensional accuracy and surface roughness and compare the results. They were able to build, calibrate, and make the drone to fly. The overall objective of this project was to design, build, test, and fly a drone and it was successfully achieved by the student team. Several 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. Some parts were replaced such as propellers, for example, due to a fall that broke them during a flight test.

Some of the limitations identified in this project include: students' minimal experience with flight mechanics and with some of the electronic components that were required - remote control and transmitter and flight control; use of careful testing procedures and thorough testing before any situations presenting considerable risk; and limited time of only ten weeks to complete the

project.

Excluding unforeseen problems and limitations mentioned above, there were the challenges of understanding the operation of each part and each component. 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. Measurements for dimensional accuracy and surface roughness were made on the 3D printed parts. After finishing all the configurations and assemblies, flight tests of the completed drone were performed. Focus and dedication of the student team was the key to successfully complete the project and making the drone fly. As a recommendation for anyone who wants to make their own drone, read carefully the related materials, watch online tutorials, never do anything when you are not sure, and take proper safety measures while conducting the flying tests.

6. Acknowledgment

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Applying Experimental Design to Improve Phased Array Radar Performance

J. Morgan Nicholson[1]
Sampson Gholston, Ph.D. [1]
[1]*University of Alabama, Huntsville*
Jmn0013@uah.edu; gholsts@uah.edu

Abstract

The purpose of this study was to develop a methodology for efficient radar detection processor parameter tuning and optimization. This research demonstrates the feasibility of applying experimental design techniques to analyze main effects and interactions between parameters in order to improve phased array radar throughput and small object detection.

1. Introduction

Throughput performance of phased array radars is often very difficult to measure and even more difficult to optimize. This is especially true for space surveillance radars that detect, track and identify Earth orbiting satellites and debris. The reason for this difficulty is the high variability in the size, geometry and quantity of targets in the radar field of view at a given period of time (Hejduk and DePalma 2010). Additionally, these space surveillance radars are owned and operated by the United Stated Air Force and are "24/7" weapon systems. Therefore, non-operational test time is at a premium.

The challenge posed in this paper was to develop an approach to optimize the performance of a space surveillance radar detection processor. The detection processing of the generic radar involved a two-stage Constant False Alarm Rate (CFAR) algorithm and a Sidelobe Blanking (SLB) algorithm. These algorithms consist of a series of hypothesis tests to make a decision about whether a target return is detected or if only noise is present. Each hypothesis test has a settable bias parameter to set the threshold at a level relative to the mean and achieve a desired Type 1 error (false alarm) and Type 2 error (missed detection). Depending on the expected target return and radar function (search or track) determined by the radar mission planning software, a different set of bias parameters can be selected by the radar. In total, there are ten parameters that required tuning in order to achieve adequate system performance. The results of this experiment yielded an operationally significant improvement in throughput performance (5%) and small object detection performance (14%).

2. Background

Detection processing for phased array radar involves making the decision for every receive sample if there is a target present or if the sample contains only noise. To accomplish this, the detection processor performs a series of hypothesis tests—each with some probability of a Type 1 (missed detection) or Type 2 (false alarm) error (Kolawole 2002). Each hypothesis test consists of setting a threshold value and comparing each Analog-to-Digital Converter (ADC) sample to the threshold. Targets tend to exceed the detection thresholds while noise samples are statistically unlikely to exceed the threshold.

The fundamental tradeoff in radar detection processing is setting the detection threshold in order to achieve acceptable detection probability while maintaining an acceptable probability of

false alarm. Typical radar Concept of Operations (CONOPS) involves committing additional radar resources for each detection. Typically, a verification pulse is transmitted to confirm a target is present and, if verified, additional track pulses are scheduled (Curry 2005). Therefore, thresholds set too close to the receiver noise floor cause increased false alarms and result in wasting radar resources on verification of false alarms. Conversely, thresholds set too far from the noise floor result in a degraded detection performance and throughput reduction.

3. Methodology

3.1 Simulation Details

In order to perform this study, a radar simulation was developed.

3.2 Target Simulation

The simulation propagated target Element Sets (ELSETS) and targets were converted to radar coordinates of Range, Azimuth and Elevation. The radar cross section (RCS) fluctuation was simulated using a Swerling 2 fluctuation characteristic (Swerling 1960).

3.3 Radar Simulation

Targets within the radar field of view during the simulation were subjected to detection processing at the time of predicted target maximum Signal to Noise Ratio (SNR). The radar performed constant false alarm rate and sidelobe blanker processing. If the target was detected during search processing, the radar switches to a track mode and attempts to collect up to fifteen pulses worth of data on each target.

For search and track, the radar simulation used different range window widths and bias parameters. That is, the number of range samples collected is greater in search than in track. The bias parameter for setting the detection threshold was different between search and track modes. For a constant false alarm rate, because track windows have fewer range samples and, therefore, make fewer detection decisions, the threshold can be dropped to achieve better probability of detection without degrading the FAR.

An additional simulation parameter in the radar model is different bias parameter values based on the expected SNR of the target. If the target SNR is expected to be large, the radar will select a different set of bias parameters for search and track to improve the probability of false alarm. The simulated radar parameter selection is shown in Figure 1.

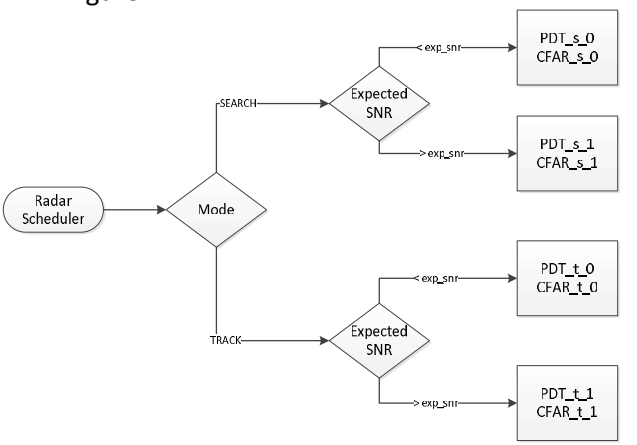

Figure 1. Simulated Radar Threshold Decision Logic

3.4 Optimization Metrics

In order to efficiently improve radar detection performance, several competing parameters must be balanced. For example, dropping the detection thresholds will reduce the Type 2 error and increase the Probability of Detection. However, the Type 1 error (probability of false alarm) will increase. A false alarm results in the radar expending additional resources attempting to verify the target return in order to perform a track. Therefore, the net effect can be to reduce overall throughput performance. Conversely, the thresholds can be raised in order to reduce the probability of false alarm but the detection performance will degrade (Curry 2005).

Due to the dependencies described above, false alarms and detections cannot be considered separately. Also, depending on the radar tasking, the number of receive windows is highly variable. Therefore, the metrics must be normalized by the number of receive windows opened (number of hypothesis tests performed) in the data collection period.

The radar data collected consists of Total Detections, Total Search Detections, False Alarm Rate (FAR) and receive windows. Total Detections are defined as rejecting the null hypothesis in all hypothesis tests (PDT, CFAR and SLB) and declaring a target present. Total Search Detections are defined as the total number of detections when the radar is in search mode. Total Search Detections is a subset of Total Detections. False Alarms are recorded when the radar detects a target in search mode and the corresponding verification pulse does not result in a detection. False Alarms are accumulated over the simulation and reported as False Alarm Rate in units of False Alarms per Minute.

To optimize total throughput, the following metric was developed:

$$Metric_1 = \frac{TotalDetections - FAR * Time}{Total\,\mathrm{Re}ceiveWindows}$$

The total number of detections over the test interval minus the total false alarms over the test interval, normalized by the total number of receive windows opened over the interval.

To optimize small object detection, a very similar metric was selected.

$$Metric_2 = \frac{TotalSearchDetections - FAR * Time}{Total\,\mathrm{Re}ceiveWindows}$$

Instead of Total Detections, Total Search Detections is used. This is because the primary difficulty in small object performance is detecting the target in search mode. Once in track, the receive window can be reduced and the detection threshold dropped, maintaining the same detection probability and Type 1 and 2 error probabilities.

3.5 Tunable Parameters

There is a large set of tunable parameters in the simulated radar system Detection Processor that need to be evaluated. These parameters come in four general categories: Constant False Alarm Rate (CFAR) threshold bias parameters, Peak Detection threshold (PDT) bias parameters and Sidelobe Blanker (SLB) bias parameter. All of these parameters help determine the location of the threshold of a hypothesis test to determine if a target is present. Each range gate in a range window is subjected to one PDT test, one CFAR test and the SLB test. A range window is a period of time the receiver opens and samples the input at the antenna (Richards 2005). Each sample in a range window is called a range gate and is represented by two numeric values output from the analog-to-digital converters (Kingsley and Quegan 1999). They are the In-phase and Quadrature (I&Q) samples for each receiver channel. There are nine receiver channels and a Sidelobe Blanker channel. The simulated radar detection processing steps for this study are shown below in Figure 2.

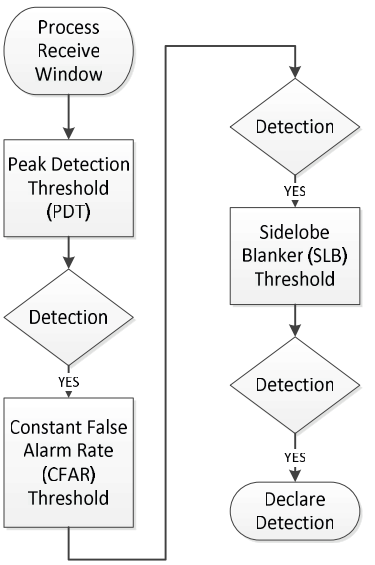

Figure 2. Simulated Radar Detection Processing Flow Chart

3.5.1 *Peak detection threshold*:

The peak detection threshold (PDT) is a coarse (high Type 1 error) threshold check to determine a set of potential range gates that contain a target. The PDT test is accomplished by computing the mean amplitude in each range gate in the range window and setting the threshold to the sum of the mean range gate voltage and the PDT bias parameter. The primary purpose of this test is to determine a set of potential target returns (with a

low Type 2 error) to both exclude from the CFAR cell-averaging (described in the next subsection) and to subject to the following series of threshold tests (Kingsley and Quegan 1999). Only a candidate return found in the PDT test that passes all subsequent tests is considered to be a target detection.

3.5.2 *Constant False Alarm Rate (CFAR) threshold:*

The Constant False Alarm Rate (CFAR) test is similar to the PDT test. The difference is that any potential target return (as determined by the PDT test) is excluded and only range gates containing noise should remain. The remaining noise gates are averaged and added to the CFAR bias parameter (Richards 2005). Any range gate that passes this test (lower Type 1 error than PDT) remains in consideration as a target detection. Targets that fail the CFAR test are discarded as noise.

3.5.3 *Sidelobe Blanker (SLB) Test:*

The receiver samples the receive channel and the SLB channel simultaneously. The SLB is an omnidirectional antenna that has less antenna gain than the antenna main beams and more gain than the antenna sidelobes. Therefore, returns in the sidelobes should have more energy in the SLB channel and returns in the main beam should have more energy in the main beam. Each candidate return that passes the CFAR test is compared to the magnitude of the return of the SLB at the same range gate. If the sum of the SLB channel and the SLB Bias Parameter is greater than the candidate return, it is rejected as a SLB return (Jeffrey 2009).

3.5.4 *Parameter abbreviations:*

The parameters included in the experiment are abbreviated and described in Table 1. The set of parameters used for any range window is computed by the mission software based on the type of waveform (search or track) and the expected size of the target being acquired or tracked. For a larger target, a larger signal-to-noise ratio is expected and, therefore, a higher threshold bias can be used to reduce the Type 1 error and maintain the desired Type 2 error.

For each range window, a single PDT bias and CFAR bias is selected a priori. Every range window uses the same SLB parameter.

Table 1. Parameters used in Experiment

Variable	Description
pdt_s_0	peak detection theshold bias, search, low snr
pdt_s_1	peak detection theshold bias, search, high snr
pdt_t_0	peak detection theshold bias, track, low snr
pdt_t_1	peak detection theshold bias, track, high snr
cfar_s_0	CFAR theshold bias, search, low snr
cfar_s_1	CFAR theshold bias, search, high snr
cfar_t_0	CFAR theshold bias, track, low snr
cfar_t_1	CFAR theshold bias, track, high snr
exp_snr	expected snr threshold for selecting bias 0 or 1
slb	sidelobe blanker threshold bias

3.6. Experimental Design

In order to more efficiently assess the effect of each parameter and their interactions, a designed experiment was utilized. The experiment was setup as a 2^{10-5} Fractional Factorial Completely Randomized Design (CRD). The experiment was designed in two blocks, four center pointes per block as a resolution IV design (Montgomery 2010). Each simulation run was planned to be twenty minutes in length. The total number of simulation runs for this experiment was forty.

4. Analysis and Results

The normal plot of standardized effects for Metric 1 (throughput) is shown in Figure 3.

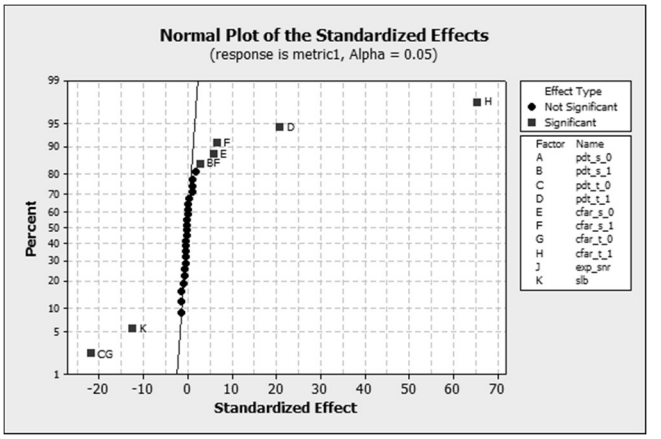

Figure 3. Standardized Main Effects for Metric 1

Several main effects and interactions were found to be significant. Significant main effects were pdt_t_1, cfar_s_0, cfar_s_1, slb, and cfar_t_1. Significant interactions were pdt_s_1*cfar_s_1 and pdt_t_0*cfar_t_0. The results of the Analysis of Variance (ANOVA) for the Main Effects is shown in Table 2.

Table 2. Metric 1 ANOVA Results for Main Effects

Main Effects		
Parameter	F	P
pdt_s_0	3.27	0.07
pdt_s_1	0.11	0.74
pdt_t_0	0.02	0.90
pdt_t_1	322.8	0.00
cfar_s_0	23.3	0.00
cfar_s_1	85.4	0.00
cfar_t_0	0.78	0.38
cfar_t_1	5375.9	0.00
exp_snr	0.72	0.38
slb	624.8	0.00

The residuals were analyzed and were reasonable for the assumptions of equal variances, normality and independence.

The same procedure was performed for the second (small object detection) metric. The standardized main effects are shown in Figure 4.

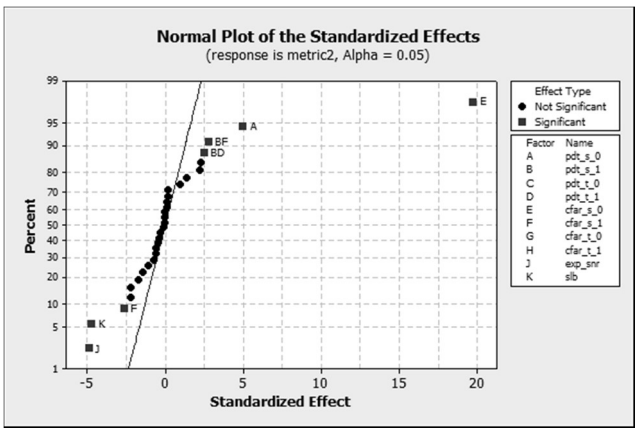

Figure 4. Standardized Main Effects for Metric 2

Several main effects and interactions were found to be significant. Significant main effects were pdt_s_0, cfar_s_0, cfar_s_1, slb, and exp_snr. Significant interactions were pdt_s_1*pdt_t_1 and pdt_s_1*cfar_s_1. The results of the Analysis of Variance (ANOVA) for the Main Effects is shown in Table 3.

Table 3: Metric 2 ANOVA Results for Main Effects

Main Effects		
Parameter	F	P
pdt_s_0	5.89	0.02
pdt_s_1	1.35	0.25
pdt_t_0	0.35	0.56
pdt_t_1	0	0.99
cfar_s_0	284.7	0.00
cfar_s_1	201	0.00
cfar_t_0	1.52	0.22
cfar_t_1	0.05	0.83
exp_snr	6.34	0.01
slb	45.5	0.00

Again, the residuals were analyzed and were reasonable for the assumptions of equal variances, normality and independence.

4.1. Response Optimization

The parameters were adjusted using the Minitab response optimizer in order to (1) maximize throughput, (2) maximize search detections and (3) minimize FAR. The resulting adjustments are summarized in Table 4.

Table 4. Parameter Adjustments

Variable	Adjustment
pdt_s_0	+1 dB
pdt_s_1	-1 dB
pdt_t_0	+1 dB
pdt_t_1	-1 dB
cfar_s_0	+1 dB
cfar_s_1	-1 dB
cfar_t_0	-1 dB
cfar_t_1	+1 dB
exp_snr	-1 dB
slb	-1 dB

4.2. Validation

The changes were made and a simulation performed for a twenty-four hour duration. Figures 7 and 8 show the validation data (each

observation is a four hour test block) using control limits based on baseline data using the original parameter settings. The results for Metric 1 are shown in Figure 5.

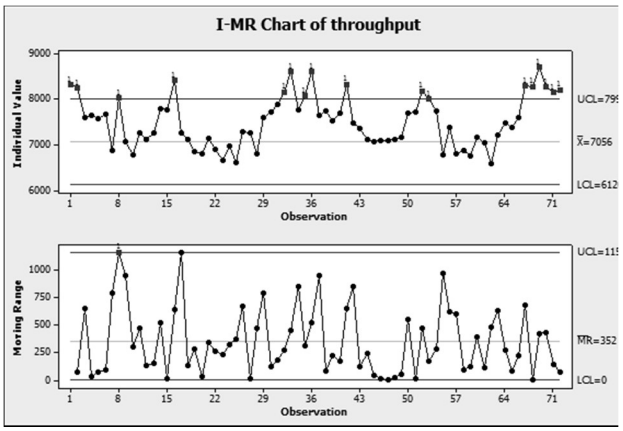

Figure 5. Control Chart for Throughput

Total throughput increased by an average of 5%, yielding a noticeable number of assignable causes on the control chart. For a space surveillance radar that might generate 16 million satellite observations per year (Stuckey 2011), this equates to 800,000 additional observations per year.

Metric 2 was evaluated in the same fashion. The control chart is shown in Figure 6.

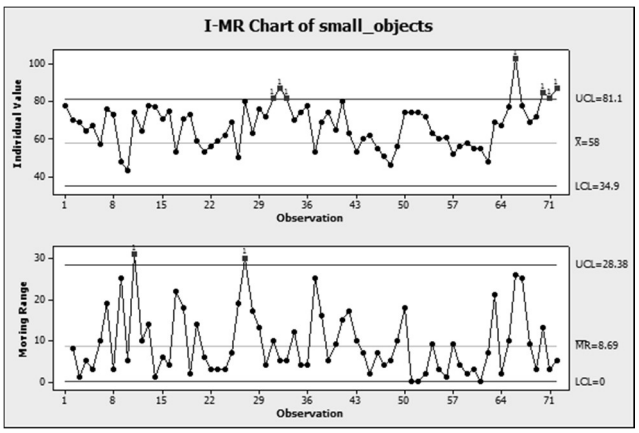

Figure 6. Control Chart for Small Objects

The parameter adjustment resulted in a 14% improvement in small object detection performance. This can be seen by the seven assignable causes that appear on the control chart.

5. Conclusion

Experimental Design was utilized to accomplish performance optimization of 10 parameters on a highly variable radar Detection Processor application. This could feasibly be accomplished in two 12 hour test days at an operational radar system. The simulated radar used in this study realized operational significant improvements in throughput performance (5%) and small object detection performance (14%) demonstrating that this approach is an attractive methodology to implement on operational sensors.

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The Entrepreneurial Community

Dennis Ridley, Ph.D.[1]
[1]*School of Business & Industry, Florida A&M University, Tallahassee, Fl 32307*
dridley@fsu.edu

Abstract

Communities vary in their mindset and propensity for entrepreneurship. The variables impact members of the community, including government, law makers, bankers, other business participants, consumers and students. Some previously unexplored determinants of mindset are discussed. Based on those factors, some approaches to increasing the rate of entrepreneurship are suggested. These include university curriculum, active experiential learning, and community integration.

1. Introduction

Entrepreneurship involves the process of starting a business or other organization. It is the single most important factor in determining whether a region or community achieves its full potential (Mugge [1] 2005). Entrepreneurship education can be linked to the creation of business enterprises that transform communities and raise economic success. Well known examples of university support for economic and technological models of regional development are the Silicon Valley in Northern California, the Route 128 Corridor in Massachusetts, and the Research Triangle in North Carolina. Ridley and Davis [2] and Ridley, McKinley-Floyd and Davis [3] paid special attention to strategy for entrepreneurship education and community transformation in the case where there is no prior tradition in entrepreneurship.

Interest in entrepreneurship has spread from private business to public enterprise and academia (Berglund and Holmgren [4]). Many colleges and universities now offer courses in entrepreneurship (Gartner and Vesper [5]). Still, not much has been written about the creation of an entrepreneurship mindset. This paper discusses some of the factors impacting community mindset and propensity for entrepreneurship and what can be done to change mindset through entrepreneurship education. Focus is on the implication of low or no entrepreneurship in family background. The absence of entrepreneurial family background can lead to confusion about the factors governing economic success and ultimately to the perpetual avoidance of entrepreneurship.

The remainder of the paper is organized as follows. Section 2 reflects on the degree of capitalism, democracy, and rule of law as a driver of global economic success. Section 3 proposes a campus-wide entrepreneurship center (EC). The EC provides a framework for improving entrepreneurial brainware and mindset in the university and the community. Section 4 includes concluding remarks.

2. Capitalism-Democracy-Rule of Law

The purpose of a business incubator is to provide a home where a new company gets its start. But, it can also be a bonafide institution where capital can find investment opportunities. Therefore, it may be wise to recall the purpose of the company itself. We recall from Ridley and Davis [2] that this great invention that impacted the lives of more people than any other is the instrument of capitalism (Smith [6]). Before that (circa: the turn of 19th century and the industrial

revolution), with the exception of feudal lords, all people were poor. Capitalism is the mechanism for capital formation. In addition, shareholders demand democracy and the rule of law. Nothing can be more motivational than recognizing the vast wealth that this mechanism has created (Micklethwait and Wooldridge [7]). Figure 1 illustrates the approximate relationship between per capita GDP and the degree of capitalism (C), democracy (D) and rule-of-law (R). GDP is shown to increase with CDR. Although no formal measure exists for CDR, the broad relationship depicted in Figure 1 is indisputable today. Therefore, we present it here as sufficient evidence of its existence. It is a critical component of entrepreneurial education which if not understood, can stymie all other efforts. Despite evidence to the contrary, it is easy to mistakenly conclude that economic development is attributable to natural resources (N), not CDR.

Concerns are often expressed regarding the rapaciousness of capitalism, and its unsuitability for civilized conduct when compared to its socialist counterpart. Of course, we are not proposing capitalism in the absence of democracy and the rule of law. For, in isolation, capitalism is as subject to abuse as any other tool or instrument. A surgeon's knife can save life, but in the wrong hands it is an efficient killer. The upshot of all this is that the relationship in Figure 1 is independent of the visible characteristics of the people in a country. As counterintuitive as it may seem to a certain mindset, the primary factors are not natural resources. Economic success is dependent on the institution of policy to adopt and engineer high CDR.

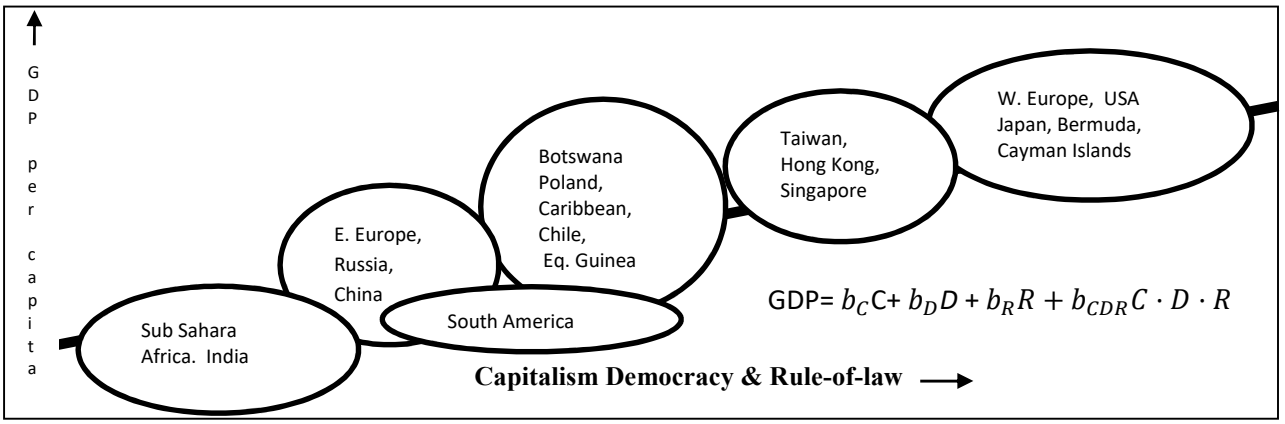

Figure 1
GDP per capita vs Capitalism Democracy & Rule-of-law

Aside from a few tiny oil rich principalities and micro nations, USA, Western Europe and oil free Japan are prominent economic world leaders. However, notice how Botswana, Poland, Chile and Equatorial Guinea were able to break quickly away from their geographic neighbors once they adopted CDR policies. Bermuda and Cayman Islands, themselves small, are greater long standing beneficiaries of CDR than their Caribbean neighbors. China has not made the switch to CDR and they are where they are. A mere accusation that Russia entered Ukraine counter to rule of law, and despite being awash in oil and gas, their post-communist economic growth collapsed once again.

3. Entrepreneurship Center

In this paper we examine the potential impact on mindset of entrepreneurship through a campus wide EC. One of the theories of the company is that it can outlive its creators. However, for this to occur, it demands maximal transparency provided by the rule of law. Like the company, if the EC is to outlive its creators, full transparency is an operational imperative.

The Mission

We explain below why the EC must be an independent institution on the University campus. In like manner, it must also have a unique mission. A suitable mission for the EC might be stated as follows: To promote interdisciplinary entrepreneurship education across all colleges and schools of the University, with special attention given to the expansion of the pool of entrepreneurs by changing the mindsets of underrepresented communities and governments to enable their cooperative participation and to employ the principles of capitalism, democracy and the rule of law to expand and lift their minds to see over the obstacles that might otherwise defeat them.

Impact on institutional mindset

Some members of society have no examples of entrepreneurs within their families and community. They cannot imagine the inner workings of business. They are not part of any meaningful conversation on business planning or day to day business operations. There is a poor dad but no rich dad (Kiyosaki [8]). They see a restaurant as a place to eat, not a place where business is being conducted. It may seem strange that a person can work and earn at one place of business, make purchases at another, and yet, not be able to decode the inner workings of either business. But, it is no stranger than illiterate persons living amongst people who read newspapers every day, and seeing signs that are all around them, yet themselves never learning to read. *Cogito ergo sum* in reverse.

Fayolle and Gailly [9] showed that the positive effects of an entrepreneurship education program are all the more marked when previous entrepreneurial exposure has been weak or inexistent. See also Jang [10] on mentoring systems and incubators, Ilouga and Mouloungni [11] on personal dynamics and psychological mechanisms, Haus et. al. [12] and Schlaegel and Keonig [13] on indirect effects of entrepreneurial traits, personality traits, entrepreneurial exposure and education. Close relatives have been found to be positive role models (Mathews and Moser [14], [15]; Scott and Twomey [16]; Shapero and Sokol [17]). This is consistent with the proposed framework that an entrepreneurship course should give special attention to the thought process of students who have no business ownership in their family background.

If the members of a community are historically oppressed, then the further back they look into their family history, the less likely they are to find an entrepreneur. Real life examples of this occurred in the communist countries of Eastern Europe, Russia and oppressed minorities in the United States of America. Both sets of people were forcibly segregated from the modernizing world. Even after the oppressive forces are lifted, there is almost a total inability to compete with existing business owners. The likely outcome is the noble practice of getting an education and finding a job. Not entrepreneurship.

Further to the above discussion of the CDR index, we recognize that wealth derives from ownership of the means of production. Technology as a means of production is an intellectual outcome. Therefore, wealth creation is an indirect product of the imagination of the mind and study by the mind. “Since new developments are the products of a creative mind, we must therefore stimulate and encourage that type of mind in every way possible (Carver [18]).” This is distinctly different from the mere transfer of wealth through invasion, colonization, enslavement and stealth. When the members of a deprived community own no means of production, they are almost absent of wealth. Furthermore, their poor economic condition is persistent. The least among them may even experience what is often referred to as a cycle of poverty. Any transfer of wealth through welfare systems is soon returned to its owner via consumption, plus labor value added, minus unproductive government agency employee payments. And, the wealth gap increases. The days are long but the decades are

short and no progress has been made. More time will not cure this.

The only way for formerly oppressed communities to compete in business and acquire means of production is through extensive introspection, and academic and experiential entrepreneurship education via an institution such as the EC. The EC might take its guidance from scientist George Washington Carver: "Education is the key to unlock the golden door of freedom." "Where there is no vision, there is no hope." "There is no short cut to achievement." "Life requires thorough preparation - veneer isn't worth anything." "How far you go in life depends on your being tender with the young, compassionate with the aged, sympathetic with the striving and tolerant of the weak and strong. Because some day in your life you will have been all of these." (Carver [18]). Teaching entrepreneurship is about encouraging students to dream big, then showing them how to act on those dreams.

Encouragement and development amongst the formerly oppressed that are underrepresented in business, is a good investment that the mainstream should welcome. For, if anywhere, somebody produces products at a lower price with the same quality or produces better quality at the same price, the total economic pie must increase for all to benefit.

Fayolle and Gailly [9] also showed significant counter effects of the entrepreneurship education program on those participants who had been exposed to entrepreneurship. A realistic entrepreneurship course must point out the fact of high failure rate by business startups (Gerber [19]). Initially, those facts, being alarming, might very well temper enthusiasm on the part of students who by virtue of prior exposure to entrepreneurship, can appreciate what is being presented. This suggests that an entrepreneurship course should provide a good understanding of the CDR effect, explain the common misconceptions and mistakes that may easily be avoided, as well as provide for interdisciplinary collegiality and experiential learning opportunities, and analytical and computer simulation methodology that raises risk management skills and builds confidence. Even then, students may need access to incubators, angel investors, and future venture capital. These are consistent with the proposed framework that follows. Indeed, they are the motivation.

Student clubs

Inventions are often considered irrelevant by the many persons who do not see their applications. Indeed, many of the applications will not have been invented as yet. For that reason, entrepreneurship can be very lonely. Entrepreneurial type students need solace. Where better for them to find that than in an entrepreneurs club. They need to be among likeminded students. A genius is the one most like himself (Monk [20]). Student clubs can contribute constructively to a sense of family away from home. Similarly, the student entrepreneurs club can help organize and run summer entrepreneurship camps for high school seniors. The exposure to entrepreneurship is invaluable. Moreover exposure to the University campus will pay large dividends in future freshman recruiting.

Student clubs are independent. They function under the rules of the host university. But, they are of necessity developmental, albeit under the advice of faculty. Students must be allowed to make decisions. They must learn and practice intra and inter networking, learn and practice the conduct of meetings, Robert's rules of order (Zimmerman [21]), how to take minutes that record agreed on assignments of responsibility, and measure and monitor task completions. Students must make the election to pursue the scientific method and approach: Measure what is measurable, and make measureable what is not so (Galilei [22]). Faculties come and go, but widespread student and alumni involvement is the only way to build tradition and achieve longevity. Academic curricula, research and management activities are discussed below.

Interdisciplinary Entrepreneurship course

The ultimate objective is the creation of new business start-up based on the commercialization of technology, and lifestyle and social entrepreneurship. It is always possible to obtain these objectives on a one off basis or on a short term basis. Great early American inventors did it entirely on inspired vision (Bell [23]; Carver [18]; Edison [24]; Morse [25]). However, to create a sustainable long term effort and raise the rate of entrepreneurial success, a targeted curriculum in entrepreneurship education must be developed.

Sometimes it is the people who no one imagines anything of, who do the things that no one can imagine! See screen playwright (Moore [26]) "the imitation game" on Alan Turing's crypt-analytical disambiguation of the Nazi German enigma cyphers. Only a few sui generis people invent, most people are required to implement. To be helpful they need to have the requisite mindset. Intrapreneurship is the practice of entrepreneurship within large organization. It may include corporate ventures in which subsidiary organizations are spun off. Intrapreneurial leaders must take risks and exercise initiative, taking advantage of market opportunities by planning, organizing, and employing resources, to innovate new or improve existing products.

For these reasons, an entrepreneurship curriculum must educate three types of graduates. It must develop entrepreneurially minded graduates. These are the majority of graduates who go to work in various fields of endeavor, various professions, and various employments. For example bank employees and officers need to be entrepreneur friendly and adaptable to change. An entrepreneurship program must educate entrepreneurial consultants. These are typically "A" students who remember all the theories, methodologies, strategies, rules, and regulations. Of course, an entrepreneurship program must create graduates who become entrepreneurs. These are the small minority that generate path breaking ideas and are willing to take the risks that are required to create new enterprise. Often, these are solid "C" students.

Course Description

An entrepreneurship course must provide a framework for developing students campus-wide, including freshmen through senior level, with an entrepreneurial mindset across the management education curriculum. Special attention must be paid to the thought process of those who have no business ownership in their family background. Indeed, it is the reason for early freshman introduction. First, students must be introduced to the foundational theories and concepts of entrepreneurship in the core topics. They must be instructed in Parliamentary procedures, types of business, taxation, intellectual property rights, business financing, personal financial management, and estate planning. This can be followed by courses that are typical of a standard business curriculum.

They must be given the opportunity to learn, practice and reflect on skills necessary for entrepreneurship. The student entrepreneurial mindset can be assessed and further developed through internal mock business plans and external business case competitions. Next, students must be provided with opportunities to apply the concepts and theories via co-curricular activities such as student-run companies that are housed within business, science, engineering and technology incubators. Finally, the course must enhance student preparation for a senior level entrepreneurship course when they will prepare a full business plan based on real data. Unlike many university courses that use textbooks, the course must utilizes published research papers and professional books. A vocabulary list will enable meaningful access to the assigned reading.

In addition to classroom lectures, students must spend some time in the incubators to receive some part of 4 credit hours. See Liao [27] for some discussion on interdisciplinary activities. Students may work on company or

entrepreneur sponsored ideas to assess opportunities and validate ideas, develop and demonstrate pretotypes and prototypes, identify target markets, and create business plans. Planned activities must take students out of their departmental silos frequently enough to have lunch with students from other colleges and departments. Students must learn the difference between entrepreneurship and business management, and how to transition from entrepreneurial innovation to startup business management activities such as selling, phone answering, order acquisition, order processing, order fulfilment, payroll, services, and income tax returns, etc.

Not all elements of success can be reduced to a scientific method. As much as we would like entrepreneurship to be formulaic, no two incubators are the same. As a result, their related problems are by definition episodic. They are nuanced and ambiguous. Students should recognize that many bad practices are known to lead only to bad outcomes, while good practices, although not guaranteed, can lead to good outcomes. Therefore, it is critical that students learn to develop the best of practices. No chance of classroom texting and browsing since multitasking while learning is humanly impossible (Beland and Murphy [28], Rosen [29]), delayed gratification (Mischel and Ebbesen [30]), time management and the development of good personal study habits.

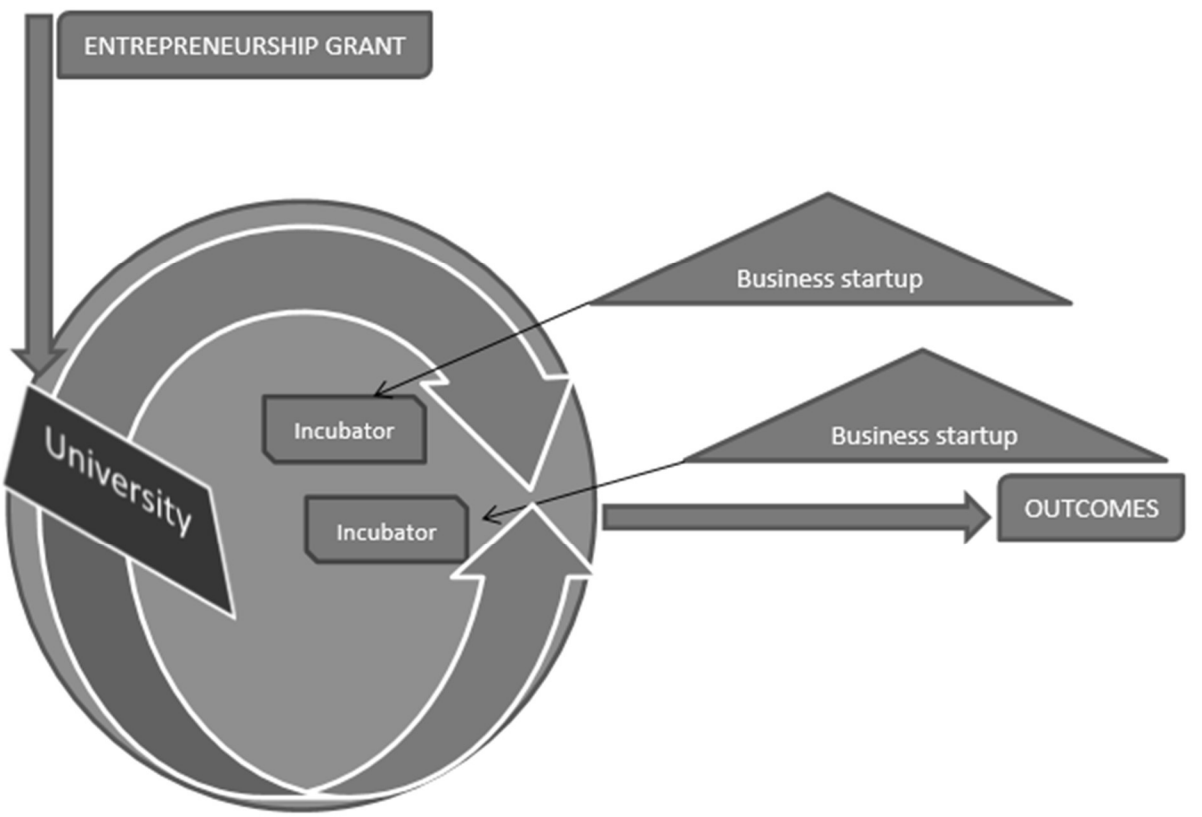

Figure 2
Integrated relationship: Excellent outcomes. Victory for student, faculty and University development through campus wide involvement, education, course work, institutional memory

Organizational structure

There are two possibilities of interest for establishing the organizational structure. Each has its pros and cons for success. In one possible scenario, an entrepreneurship grant is given to an academic unit, college, department or institute in the University. All activities are centered within that unit. This structure is relatively easy to manage. So is the assignment of responsibilities and monitoring of accountability. The physical facilities can belong to the academic unit. One such example of an academic unit is the business school. This appears to be reasonable since entrepreneurship has so much to do with business. Classes can be designed for business majors, and non-majors can be allowed to take them. However, while the results can be excellent, there might be little or no impact on the rest of the University.

The preferred alternative is an integrated scenario (see Figure 2). An entrepreneurship grant is given to the University for integration campus wide, and community development. The managing unit is independent of all colleges, schools, departments and institutes. The operation is designed and directed to serve all university constituents equally. Non business entrepreneurs are identified in the professional schools such as law and medicine, engineering, science and technology. Technology, lifestyle and social entrepreneurship can grow out of various alliances on campus. The results are equally excellent outcomes, but greater in scope than the peripheral relationship, and with a lasting impact on the university and the community (see Table 1).

Table 1. Organizational Structure

	Academic unit	University
Management	Easy	Complex
Responsibility	Easy	Complex
Accountability	Easy	Complex
Courses	Intra-disciplinary	Inter- disciplinary
Impact	Local	Collaborative
Development	Local	Community

Incubators

There are different types of incubator depending on the stage of development of the business idea. Some technology based ideas require prototyping, testing and proof of concept. An incubator of that type is shown in Figure 3a. Such an incubator may be special purpose in design, but unrelated to University education. Therefore, it could be operated by an off-campus contractor. The special purpose features may include rapid prototyping CNC/CAD/3D machines for making electronic circuit boards and device containers, etc. That element of the process is vocational in nature, not academic. Renting space may be the best option. Ideas that leave incubators 3a as working devices then go to the commercial startup incubator (figure 3b).

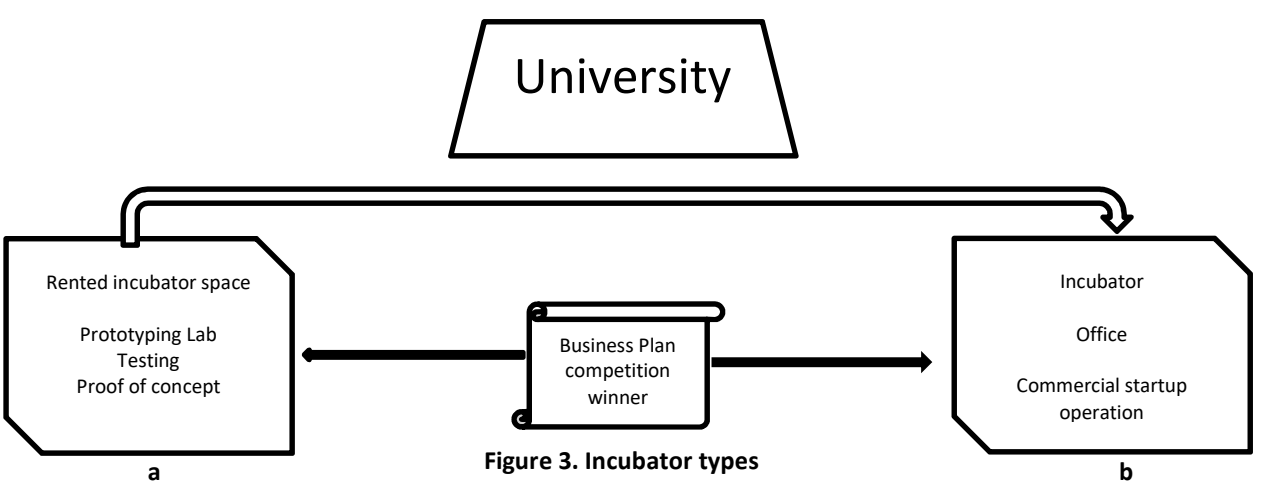

Figure 3. Incubator types

Students are almost invariably cash poor. The university can provide startups with rent free incubator space in return for equity. The equity can reflect the value of rent for one year plus help from university administrators and staff, expert faculty, small business development center (SBDC), service corps of retired executives, and exposure and visibility to corporate visitors and other potential investors. The percentage equity can be standardized. Standardized investment is not unheard of. Altman [31] explains why for expediency, Y Combinator venture capital offers a standard $120,000 for 7% equity. In that model, all startups are assumed to be worth $1,714,285. The rationale is that once they decide that they like the new business idea, they place most of the value in the passion and commitment of the entrepreneur. This latter measure is approximately the same in all of their selections. In cases where the startup arose from on-campus research involving university facilities and/or Office of Technology Transfer patent acquisition help, the university can apply a standard faculty profit sharing agreement.

University Entrepreneur's Day

Prior to entrepreneur's day, the university is engaged in a number of entrepreneurship activities. Those are academic activities. But, the University must have an annual event related to the entrepreneurs themselves. It is a day for the application of entrepreneurship by the campus entrepreneurs. On that day there are a number of activities. One activity is a business plan competition. A business plan forces the students to think through and understand their business. It can also be used to seek financing. The competition creates a winning business that receives a first prize cash award, recognition, and an opportunity to enter a commercial startup operation incubator for one year (Figure 4). At the time of the business plan competition the participants must sell their ideas.

One year after exiting the incubator, or on an even multiple of years thereafter, the business can return to the university campus on entrepreneur's day where they can sell their income statement and balance sheet to venture capital investors. Their idea may have been impressive on the day when they won the business plan competition, but the venture capital investors will want to know how well their idea was implemented and how well it was received by customers.

Integration

In addition to being cash poor, we are concerned with technology based entrepreneurship where larger investment and knowhow is required than for lifestyle and social entrepreneurship. The objective is to positively impact the university and the related community. An integrated approach starts with multidisciplinary student teams brainstorming and mining faculty research for commercial ideas (see schematic diagram in Figure 4). This activity can be greatly enhanced with help from student members of the entrepreneurs club. There should also be physical and electronic notice boards for faculty to display ideas and inventions.

In addition to the interdisciplinary entrepreneurship course discussed earlier, extra-curricular student activity can increase student wisdom when enjoined by experienced business people from the external community. For example, the local chamber of commerce is a one stop shop for potential advisors and angel investors. Student members of the chamber can learn from the speakers who address the chamber. This can be a live term paper source of information for courses that they are taking in business, economics, journalism, government, etc. A local technology association can be a source for students taking information technology courses. The Institute of Electronic and Electronic Engineers is a source for science and engineering students, and so on. Of these external organizations, the chamber is one of particularly great interest for networking because they comprise many bankers and investors. Members of the chamber can speak at student club meetings, especially on the topic of

business plan writing. They are a readily available source of angel investors. Other sources of investment are family, friends and alumni angel investors, venture capital, crowd funding and grantors.

We know from Gladwell [32] and Ridley and Davis [2] that professional competence requires 10,000 hours of dedicated experience. That is, the equivalent of forty hours per week for five years. By definition, students will not have this experience. This poses an insurmountable problem. Only some of this experience can be obtained through corporate internships. Therefore, the remaining lack of experience must be supplemented by placing an experienced angel investor on the startup management team or advisory board, as needed.

The Small Business Development Center (SBDC) and the Service Corp of Retired Executives (SCORE) are sources of advice on business plan writing, financial planning and loan acquisition. The University Office of Technology Commercialization is available to assist with intellectual property acquisition such as copyrighting, patenting, and licensing.

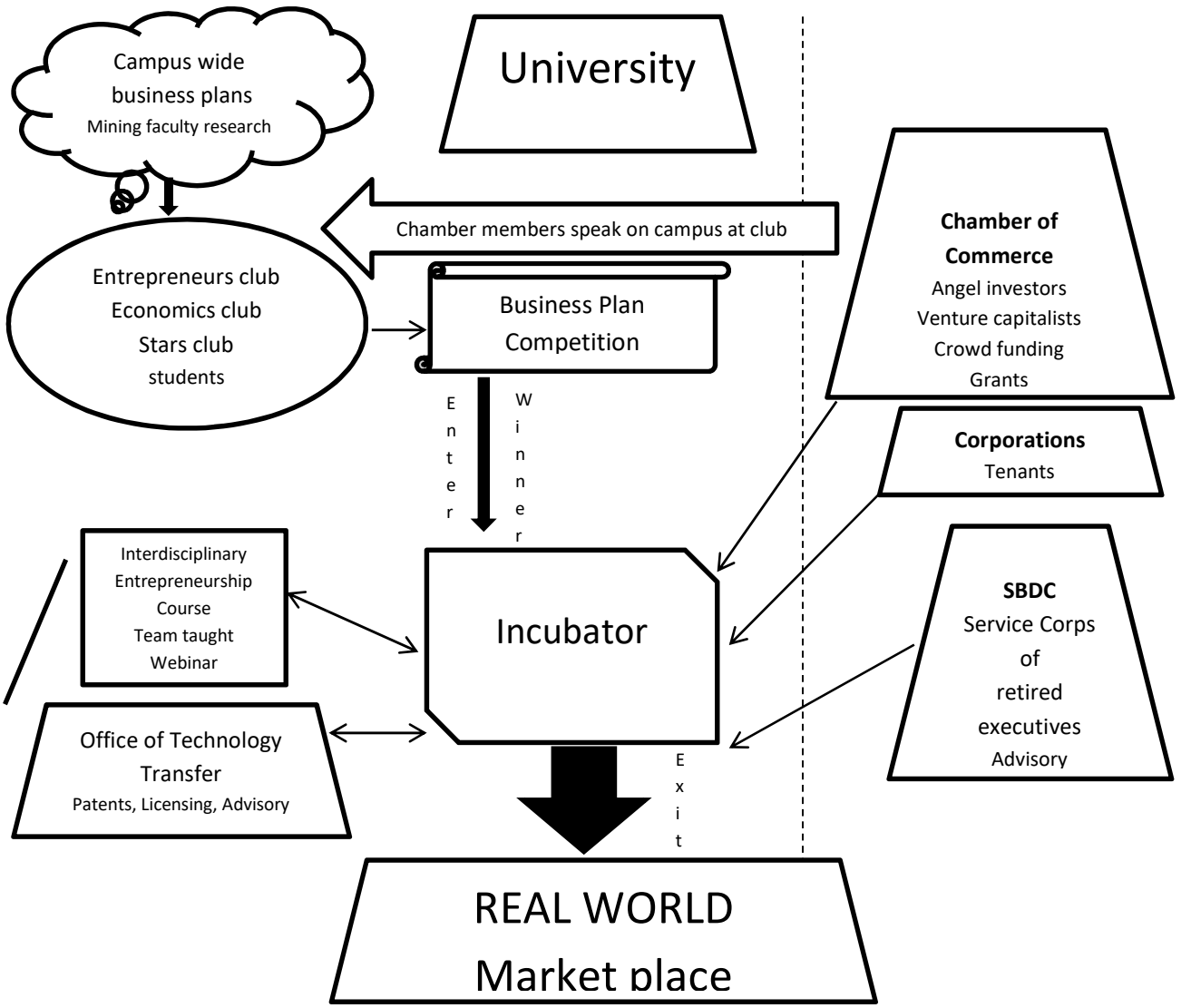

Figure 4. Integrated incubator support mechanism schematic.

Executive education

If there is one constant throughout the vicissitudes of time, it is change. Technology is continuously evolving, demanding the periodic renewal and upgrading of skills. To that end, entrepreneurs who have attained an undergraduate degree and who have been practicing in the real world business for two or more years can benefit from executive education. They and other business leaders can study for a graduate certificate in entrepreneurship.

4. Concluding Remarks

Teaching entrepreneurship by lecture and case study methods is now well established. A logical extension for creating an entrepreneurial mindset is technology based dynamic live case study with color graphics animated computer simulation. Students can create key elements of a case, collect the related data, analyze them and develop comprehensive pro forma technical and economic evaluations, cash flow and income statements, and balance sheets. These are required to understand the business and to apply for financing. When obtained by computer simulation, these documents are more realistic. Live case study provides some experiential learning and real life contact with real business operations. That notwithstanding, the creation of startup business by students presents the insurmountable problem of student professional inexperience. This demands the presence of an experienced angel investor on the startup management team, or advisory team, as needed.

In addition to structured education, entrepreneurial students need a club to provide a family away from home. Time spent in entrepreneurially munificent incubators provide needed guidance, nurture and visibility. Visits to local and other incubators provide needed exposure to complement the entrepreneurial mindset. A weekly televised forum on entrepreneurship involving students, faculty, and visitors, and broadcast on the university TV channel and/or satellite radio, can provide special interest exposure of incubator companies to potential investors, general exposure to potential university freshman recruits, and favorable public relations in general.

To succeed, entrepreneurship requires community support. The successful community must respect capitalism, democracy and the rule of law. Students must be educated in this paradigm. This will help to correct the misconceptions that economic success is a function of natural resources, and a concomitant zero net economic gain mindset. In the archetypal model for entrepreneurship education, diversity has the potential to expand the pool of innovators and thereby increase the size of the world's economy, to the benefit of all people. That is, create a plus sum mindset in which the best ideas can rise to the top.

Entrepreneurship involves risk. Experienced people know not to try anything new. Students know that they should try everything new. A meeting of these two mindsets might produce the requisite synergy.

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A Human Centric Approach to Research, Design and Development of an Innovative Workstation Module for the National Aeronautics and Space Administration (NASA)

Dr. Pamela McCauley, PH.D., CPE.[1]
Brian Strevens[2], Karissa Hall[3], Leo Shane[4], Sylvia Di Paulo[5]
[1,2,3,4,5] *University of Central Florida*
Pamela.McCauley@ucf.edu; b_strevens@knights.ucf.edu; karissahall93@gmail.com; leoshane@knights.ucf.edu; sylviadipaulo@knights.ucf.edu

Abstract

The objective of this research was to assess and design a National Aeronautics and Space Administration **(**NASA) firing room to meet the dynamic and evolving needs of a diverse aerospace community. The University of Central Florida team was tasked to design a human centric firing room module. The cognitive demands of tasks in the NASA Firing Room which require extended focused attention for long periods of time, have been taken into consideration in the development of design recommendations, technology, and software. Each module is designed to mitigate the risk of work-related injuries and repetitive tasks that can be caused from long term usage. The team consulted with NASA subject matter experts, senior officials and studied historic designs as well as the scientific literature in the development of the final module design and facility layout. Three-dimensional renderings of the module were created, and from the rendering a functional prototype was built. The innovation of the module design was key in the success of accomplishing the necessary overall task and aiding in the completion of all the essential needs of the workstation. This area of focus of the module allowed for a workstation to be designed that excels within its requirements while also being durable.

1. Introduction

A launch team member working inside of NASA's firing room can spend long hours at his or her workstation. The purpose of this design is to mitigate both mental and physical risks associated with working for long periods of time. The mental risks associated to long-term work include mental and visual fatigue, slow response times, and poor judgment. Physical risk can be derived from repetitive tasks and motions that can include musculoskeletal and cardiovascular disorders. The workstation module design is based off of NASA's specific needs and ergonomic guidelines as a means of reducing these risks while also delivering an innovative look.

2. Materials and methods

A comprehensive review of literature was first performed along with discussions with NASA officials and a complete investigation of current technologies. The basis of the literature was ergonomics of the human body and ergonomics involved in creating a workstation. The technology research performed was for ergonomic computer monitors and module accessories that are to be used. Also, dimensions of NASA's current firing room modules were recorded along with the dimensions of the firing room in general. This allowed for a proper count of the desk modules that will be added to the firing room.

Upon performing the literature review,

guidelines for creating a proper ergonomic desk were recorded. These provided a basis of what the module needed to be built around and how to properly assess the ergonomic soundness of the model. Also, the literature provided a basis for the structure upon which the designs were built around. The discussion with NASA officials provided insight toward their requirements of the module, all of which are highly important to ensure are added. Lastly, the technology investigation assured that the best and most ergonomic choice was selected for the desired monitors and technology equipment.

The ergonomic focus of the design is separated into various areas. The two main aspects to consider are the anthropometrics and ergonomics of the technologies. The user should be able to see all of the information that is on the screen in front of them while also being able to have access to the virtual keyboard that is on the screen. The user should not have any unnecessary strain or have to extensively reach to use any of the areas of the touch monitor. [3] According to the Computer/Electronic Accommodations Program (CAP), all of the dimensions will need to fit within the ergonomic guidelines of a workplace computer station.

One of the main factors when analyzing the anthropometrics of the design is correct body posture. While having to sit for a long period of time and performing repetitive tasks, it is important for the user to keep correct posture. As seen within the CAP diagram, this includes 90-degree angles for the knees, the lower back, and the elbows. CAP's regulations will need to be included in the selection of a proper desk chair. These regulations include lumbar support, a waterfall edge, an armrest, tilted seat pan, and adjustability.

The desk module was uniquely designed to provide aspects of common modules while incorporating NASA's requests. One request for the design was the ability for the user to be able to write if desired. We also wanted the user to have as much storage area as possible. These two aspects were combined within a single design so that user can have both. This design can be seen within the 'Results' section below.

A 3D rendering of the module was created based upon all the exact specifications, ergonomic needs, and chosen technologies for the desired design. The rendering aided the design team in visualizing the design and making any necessary adjustments during the modification stage. For example, some requirements were a specific touch monitor to be used and the M/Flex (monitor screen mount). These requirements were created and placed within the 3D rendering to ensure that the modifications are feasible and can be applied within the dimensions of the design.

3. Literature Review

There are many research papers centered around the ergonomics of workstations and human factors. It was important that we familiarized ourselves with many of the ergonomic communities' accepted practices so that our design met the standards set forth. The database the research team has built is comprised of 26 different articles that cover various factors that would affect the feasibility of the workstation being proposed to NASA. Examples of some specific topics include proper angulation for monitor viewing, as well as musculoskeletal and anthropometric considerations. References to these articles can the found in the locations in which they are discussed.

4. Theory/Calculation

Ergonomic design factors are important to keep in mind while designing a new workstation module. These factors can vary from cognitive to physical means. The cognitive demand associated with working within a firing room can be strenuous, and precautions should be set up in order to provide mental breaks from working. This will help to reduce mental fatigue and eyestrain after viewing a computer monitor for extended periods of time. By providing the ability to move around within the desk module and from module to module with ease, the risks mentioned previously can be reduced as well.

Physical risks include repetitive motions and improper body posture. Proper anthropometric guidelines for desk modules, along with other ergonomic studies, have been researched in order to help design the workstation module. The physical features of the module have all been put in place so as to lessen repetitive motions or to allow the user to have breaks from the station.

Also, all of the technology equipped is designed to promote correct body posture. With correct body posture, one will be able to work for longer periods of time within a comfortable setting

A study titled "The relationship between musculoskeletal symptoms, postures and the fit between workers' anthropometrics and their computer workstation configuration" investigated the possibility that musculoskeletal symptoms (MSS) are related to worker anthropometrics and workstation setup. This paper discovered three different significant associations between worker posture and MSS, as well as three significant associations between worker/workstation discrepancies and MSS. The author concludes that further research needs to be conducted on the topic, and that there is a baseline relationship between posture and musculoskeletal symptoms.

Cardiovascular requirements are also an important aspect of a workstation design. Even though the users spend the majority of their time sitting, they can move around within their module. Proper blood flow is always a concern for the circulatory system. This can be achieved by reducing the amount of repetitive motions the user would have to perform and design the module so that no aspect of the system would apply pressure that would cut off the user's circulation. Reducing the amount of repetitive tasks allows the user to perform more dynamic work, which also reduces fatigue.

Aesthetic appeal also plays an important part in design. While the ergonomics and physical demand are necessary, there is a need for the desk to be appealing. The module is to be used for years to come within the firing room; hence, it should be appealing to the human eye. As the physical concepts were being incorporated into the design, aesthetic appeal was also focused within each design concept.

5. Result/Discussion

The desk module workstation designed for NASA's firing room fits all ergonomic guidelines and provides an innovative and aesthetic look. All of the technology selected is replaceable so that the newest models can be updated upon release. Also, the module is comprised of various manufacturing components that will allow for modifications to the desk if desired over time.

The total physical module (minus the triangular top) is 30" tall, 50" in length, and 28" in depth. The triangular top is 8.5" tall and slopes downward at 15 degrees. The touch monitor is embedded within the desktop (4" from the left-hand side and approximately 4.5" from the front edge). The height and angled top allows one to comfortably sit under the desk and also not have to reach for the touch monitor. The user will be able to see all of the information that is on the screen in front of them while also being able to have access to the virtual keyboard that is on the screen. The user will not have any unnecessary strain or have to extensively reach to use any of the areas of the touch monitor. Also, if the user chooses not to use the virtual keyboard, a pullout keyboard and mouse tray is placed conveniently under the desk. By allowing for both options, the user can select his or her preferred method of use. In reference to the [2] Computer/Electronic Accommodations Program (CAP), all of these dimensions fit within the ergonomic guidelines of a workplace computer station. The guidelines for a minimum of a 19" depth, 25-34" height, and 35-degree viewing angle for the curved monitor have been met.

We recommend that NASA buy the Herman Miller Aeron Chair for the workstation. This specific chair provides all of the necessary ergonomic factors, and by doing so, it allows employees to sit at their workstations comfortably for long periods of time. The lumbar

support relaxes the stress load that could be placed on the lower back while also placing the user in the correct posture. The waterfall edge provides circulation to the lower part of the human body and does not cut into the user's thighs. The armrest gives the user the option to relax their arms while working. A tilted seat pan also helps to foster correct posture. Due to the fact that each person is of a different height and body structure, adjustability allows one to properly adjust his or her chair so that it is most comfortable for their individual needs. An image of the Aeron chair can be seen in Figure 2.

An attachable headrest to the Aeron chair has also been recommended. This provides neck and head support for when sitting within the chair. Also, a foot rest has been recommended as well. The foot rest would be located under the desk module and provide support for when working for long durations.

On the left and right hand side of the module, a pullout drawer is located within arm's reach. These drawers have a solid top that can then be lifted up when completely pulled out. The solid top allows for the user to place a notepad on top due to it being 9" in length and 8" in depth. If one desires to use the drawer, then the solid top can then be directly lifted up for access to the drawer. The location of the drawers is placed properly so that one would not have to write in an uncomfortable situation and can switch from writing to using technological devices easily. Also, by placing the same drawers on both sides of the desk, it is not limited to just right handed or left handed individuals.

Located under the desk drawers is a 10" offset from the base of the module to the edge in which the user sits at. The purpose of the cut out is to allow the user to move freely under the desk. It also provides the user the ability to travel to other desk modules with ease. This aspect promotes collaboration within the firing room while also allowing the user to achieve dynamic movement. Allowing the body to achieve dynamic movement provides blood flow to the necessary muscles and can reduce fatigue. Quick dynamic movement helps negate long-term static risks that can be caused from sitting in the same position for a long period of time.

A personal storage area is located on the left hand side of the desk and is within reach of the module. This area is designed for personal storage due to long periods of time spent at the workstation. Being that the door is within arm's reach, one does not have to extend far or bend too far down in order to obtain access to this area. This prevents any back issues that could occur from constantly having to reach and bend down to use this area. Back issues that could occur would affect the lower vertebra (lumbar lordosis), and when sitting for a long period of time, this could also irritate the lower back even more if not considered within the design.

On the back of the module (located at the edge of the top) is a solid transparent extension. This back piece rises above the 4K monitor and provides privacy for the individual. The user can derive a sense of individualism module due to the panel, even if the firing room is at full capacity. The user will be able to focus specifically on his or her work and have limited distractions. The back panel is made of a transparent but dark material that allows light to shine through. The panel allows for less user distractions, bust still allows others to see through the material it is made of.

At the edge of the triangular desktop is an armrest cushion. This provides both support and an area for one to relax the user's wrists while working. Edged surfaces can cut off blood circulation, which can cause discomfort and potentially harm the user. By placing this cushion at the edge, the user does not have to worry about these risks and can use the touch monitor with ease. The cushion also allows for items to be placed on top without falling off. The 15-degree angle is steep enough for items, such as paper, to begin to slide off. However, the cushion strip prevents this and allows the user to place desired items on the desktop.

The technology that is used within the desk module has been specifically chosen for its ergonomic benefits. The 34" curved monitor provides the most visual area within a comfortable peripheral view. While looking into

the center of the monitor, one is able to view both the left and right side edges of the screen without any strain or unnecessary head movement. Also, with the touch screen and the curved monitor being aligned with each other, one does not have to make any obscure movements in order to move from one viewing angle to the other. Due to the monitor arm mount's free range of motion, the user will be able to properly place the monitor in front of them so that a 35-degree viewing angle is achieved, as well.

One article the team reviewed is titled "Identification of the preferential gaze position through evaluation of visual fatigue in a selected group of VDU operators." The objectives of this research paper were to obtain evidence of visual fatigue and to determine a preferred gazing position. The article identifies these goals by carrying out a test in which the subjects view a monitor at 35° below the primary gazing plane. The authors of this paper could not conclusively determine that visual fatigue was reduced as a result of this angle, but that there was a good chance that the two factors were correlated. They did observe less muscle fatigue at 35° than any other angle above or below the viewing plane.

A 4K 24" monitor has also been added to the desk module. This monitor attaches to the other adjustable arm mount when turned vertically. By providing this monitor, the user has more room for reviewing data and calculations. The arm mount allows the user to adjust the monitor so that it is comfortable to physically view.

A port replicator has also been attached to the desk module on the right hand side under the writing top at a 45-degree angle toward the user. This kit plugs into the computer and monitors. It includes two USB ports, three HDMI ports (one to each monitor), a headset port, and two outlet sources. This replicator will be within reach of users so that they will have easy access to it. A key aspect of the firing room is communication. During a shuttle launch, it is highly important that management can talk to everybody within the room, and with an accessible headset port, it allows for one to simply plug in his or her headset in order to communicate with everybody. Also, this port allows the user to bring in their personal laptop, tablet, or phone and obtain power or connection to the computer with the replicator.

Finally, with all of the design decisions made and the technology selected, a 3D rendering of the module was created. Each design concept was created and placed within the simulation so as to form one complete design. This approach ensured that all dimensions were correct and all consumer needs were incorporated. It also provided a method in which the module could be ergonomically assessed before fabrication.

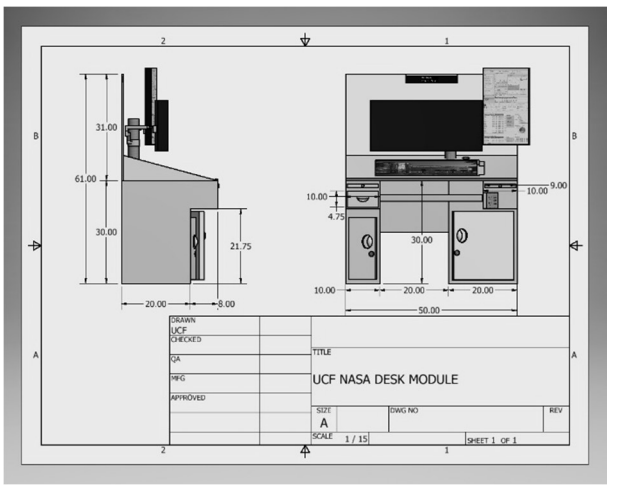

Figure 1. UCF NASA desk module dimensions

6. Conclusion

Cognitive, cardiovascular, and musculoskeletal demands are all highly important factors that require attention when designing a properly designed ergonomic workstation. The n workstation described within this article meets and exceeds all of the requirements associated from these demands. The module is in accordance with all ergonomic guidelines, provides a unique design, and meets all of NASA's individual requests. Designing a work module for NASA's firing room requires more attention to long-term duration usage than typical workstations. It also requires more

attention to size due to the constraint of having to fit as many modules as possible within one room while still simulating a sense of privacy. However, when the modules are all together in the facility layout, a collaborative environment is created.

Two designs were under consideration. Both designs had similar features and benefits; however, the module base was different. One of the designs had a solid base with no cut underneath the desk drawers while the other had an offset base. The solid base was designed for stability throughout the desk and as a single unit for the user. The offset base provides a communal aspect to the individual modules. It allows users to move around their own modules and travel to other modules with ease.

Three-dimensional renderings were created with exact design dimensions. These elements allowed for a visual comparison of the two designs. The team was able to view the designs and assess the ergonomic benefits of each. Since each design provided different benefits, it was vital to properly select the design that best satisfied NASA's requirements. The design with the offset base that allows the user to freely move under the module was selected.

The rendering expressed the possibility for this type of desk to be manufactured while ensuring that all of the selected pieces technology could be attached successfully. It also provided a method in which the design concepts could be easily explained in detail to the subject matter experts, NASA officials, and also the manufacturer for fabrication. A dimensional description and visualization of the selected workstation module can be seen in Figure 1.

The desk module is aesthetically and technologically innovative. Current technology and software has been incorporated within the design with the ability for change as future products are always being developed. The technology also provides ergonomic benefits, as well as a futuristic look. To make the module appear more visually appealing, the team has reached out to experienced fabrication companies to gather their inputs.

Overall, the desk module provides NASA employees with a fully innovative ergonomic module. The user will be able to work for long durations with ease and with minimal risks. All requirements have been met from an ergonomic standpoint to satisfy NASA's needs. The module is designed to last and be able to adapt to changes in the future.

Any additional future research on this subject would include studies of one's behavior while working at a workstation for a long duration. Physical observance would provide insight into true behavior within a work environment, which could lead to adaptations to the module that would benefit the design. These adaptations would reflect the user's true nature while he or she utilizes the new workstation, which, in return, would allow the team to consider further module redesigns.

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Human Error Perspectives in Flight Monitoring Envelope Monitoring

Alyssa D. Marcoux[1]
Kyle J. Levin[2]
Deborah S. Carstens, Ph.D., PMP [3]
[1,2,3]*Florida Institute of Technology*
Amarcoux2013@my.fit.edu; klevin2011@my.fit.edu; carstens@fit.edu

Abstract

The research proposes the development of a Flight Envelope Monitoring electronic device as a method to check calculations made by pilots prior to take-off. The proposed device would calculate the weight and balance calculations so it would no longer be necessary to input any data by the pilot since the data would automatically be in the FEM device from the weight sensors. This would potentially mitigate human error as the human would be removed from this task eliminating human miscalculations. The main concern of the researchers is that incorrect calculations of an aircraft's flight envelope can result in system failures. A survey was conducted to obtain flight students and pilots' perceived usefulness of utilizing the proposed device. The results of the survey are discussed along with the research implications and future research areas.

1. Introduction

The research proposes the development of a Flight Envelope Monitoring (FEM) electronic device as a method to check calculations made by pilots prior to take-off. Pilots and aircraft technicians are presented with many documents that are meant to teach them about weight and balance but can be a challenge for flight students and pilots. The proposed device would calculate the weight and balance calculations so it would no longer be necessary to input any data by the pilot since the data would automatically be in the device from the weight sensors. This would potentially mitigate human error as the human would be removed from this task eliminating human miscalculations. The main concern of the researchers is that incorrect calculations of an aircraft's flight envelope can result in system failures. A survey was conducted to obtain flight students and pilots' perceived usefulness of utilizing the proposed FEM device. The results of the survey are discussed along with the research implications and future research areas.

1. Literature Review

The Transportation Safety Board (TSB) has identified aircraft performance safety issues due to risks associated with incomplete weight and balance calculations (2012). Specifically, the TRB suggests that if the weight and balance are not properly calculated, it can result with an attempted take-off with the center of gravity outside of the prescribed limit for the aircraft resulting in increasing the risk of control difficulties.

The Aircraft Weight and Balance Handbook is a document to inform Aviation Maintenance Technicians on how to calculate the weight and center of gravity of an aircraft, and to teach flight crew how to load and operate an aircraft to verify the weight and center of gravity are both within allowable ranges (FAA, 1999). The

document discusses three main methods for assisted weight and balance calculations. The most sophisticated method is using a Dedicated Electronic Flight Computer. These computers are programmed to solve many flight problems, including weight and balance. All flight computers handle the problem a little differently but are all programmed to prompt the pilot to input the required data including the weights and arms. The benefit of the computer is that memorizations of formulas are not required. The next method is using an E6-B Flight Computer, which is a special kind of slide rule. It cannot be used for addition or subtraction, and its accuracy is limited, but it is sufficiently accurate for most weight and balance problems. The last method presented for assisted weight and balance calculations is simply to use an electronic calculator.

The proposed FEM device is most similar to the Dedicated Electronic Flight Computer, however the key differences are that its sole purpose would be to handle the weight and balance calculations and it would no longer be necessary to input any data as that would be coming directly from the weight sensors and therefore more accurate because miscalculations in the input data could not be caused by human error.

There are existing patents for tools dedicated to calculating the weight and balance of an aircraft dating as far back as 1939 (U.S. Patent No. 2179822, 1939). There are more recent patents as well, one such patent filed in 2003, states the need for a more accurate system to calculate the weight and balance for aircrafts specifically those that carry ten to nineteen passenger. Currently, the system in place for calculating the total weight is based off of estimates. The FAA standard calculation average for a passenger and they're carry-on luggage was 180lbs, for the summer, and 185lbs, for the winter, as of 2003. As national weight averages shift throughout the country these averages have to be configured and reconfigured (U.S. Patent No. 6923375, 2003). Crane Aerospace & Electronics (2007) has been awarded a contract from Naval Air Systems Command (NAVAIR) to provide the military with their AirWeighs Real Time Weight & Balance System. This system would be utilized on the US Navy's C-130 Hercules Airlifter as it is designed to provide significant improvements in flight safety. Safety of flight operations would be enhanced through giving aircrews the ability to accurately measure aircraft weight and balance using an accurate and real-time on-board measurement tool. A patent by inventors Long and Gouette (2013) was issued in December 2012 for a weight and balance system. The device is a system carried aboard an aircraft which provides instantaneous weight and balance system. The device is a system carried aboard an aircraft which provides instantaneous weight and balance of the aircraft. It provides the aircraft's total weight and the location of its center of gravity in a fast and reliable manner to enhance safety critical factors affecting flight safety.

As shown through previous patents and devices, such as the one proposed, have been considered a possible solution to the existing problem of miscalculation of the weight and balance of aircrafts. However as O'Brien (1984) suggests, one of the biggest flaws in a device such as the one proposed is the testing requirements that would be involved. Rigorous testing of all the sensors would be required for "temperature, shock, humidity, and vibration extremes, along with operational considerations, dictate high reliability, survivability, and maintainability designs" (O'Brien, 1984, p. 12). If passenger planes that currently use estimates to calculate weight and balance switched to a device such as the one proposed, then the device would have to be at least as accurate as the estimations and ideally more accurate. Depending on the durability, it would be required to recalibrate or replace the sensors frequently to guarantee accuracy and reliability (O'Brien, 1984). These calculations become even harder to work with on cargo planes due to the type of cargo carried as suggested by Souffriau, Demeester, Berghe, and Causmaecker (2008). Cargo crafts require extra calculations in order to insure the aircraft is"loaded with containers in such a way that its

center of gravity approaches an optimal point, while at the same time maximizing the total cargo weight (Souffrian, 2008, pg. 1)."

2. Methodology

The focus of the study was to assess interest by pilots in the use of a proposed FEM electronic device as a method to check calculations made by pilots prior to take-off. The research team performed a literature review followed by development of a ten-question survey to obtain aviation profile information, difficulty of the weight and balance calculation, perceived usefulness of the proposed device from a learning and safety perspective and willingness to use the proposed device. The survey was developed and distributed using Survey Monkey. Once the Institutional Review Board approval was provided, the sixty-five survey respondents were recruited through email targeting flight students and pilots. The survey data was analyzed and survey findings are discussed.

3. Results

The survey findings consisted of aviation profile information, difficulty of the weight and balance calculation, perceived usefulness of the proposed FEM device from a learning and safety perspective and willingness to use the proposed device.

4.1 Aviation Profile Information

The survey questions began with five questions relating to aviation profile information. The first aviation profile question pertained to the academic level of the sixty-five survey respondents. Of the sixty-five survey respondents, 20% of the survey respondents were freshman, 12.31% were sophomores, 18.46% were juniors, and 13.85% were seniors pursuing an undergraduate degree. Of the sixty-five survey respondents, 18.46% were graduate students. Of the sixty-five survey respondents, 16.92% responded other as these could be flight instructors or individuals outside of the university working on their pilot license. Of the sixty-five survey respondents, sixty-two survey respondents responded to the question regarding the hours of simulator time have been logged by the survey respondents. Of thee sixty-two survey respondents, 17.74% survey respondents logged under five-hours, 4.84% logged 6-10 hours, 1.61% logged 11-15 hours, 12.90% logged 16-25 hours, 14.52% logged 26-35 hours, 16.13% logged 36-45 hours and 32.26% logged 50+ hours. Of the sixty-five survey respondents, sixty-three survey respondents responded to the question on the number of hours of flight time logged. Of the sixty-three survey respondents, 7.94% of the survey respondents logged 25 hours or under, 3.17% logged 26-50 hours, 0% logged 51-75 survey respondents, 4.76% logged 76-100 hours, 17.46% logged 101-150 hours, 4.76% logged 151-200 hours, 33.33% logged 200 or more hours and 28.57% logged 500 or more hours.

Of the sixty-five survey respondents, sixty three survey respondents responded to the question on the types of certificates and ratings held by the survey respondents. Of the sixty-three survey respondents, 12.70% survey respondents are flight students, 39.68% are private pilots, 33.33% are flight instructors (CFI), 50.79% are commercial pilots, 61.90% hold their instrument rating and 26.98% are in an "Other" category. Of the sixty-five survey respondents, sixty four survey respondents responded to the question on the types of planes. Of the sixty-four survey respondents that responded to this question, 43.75% fly Skyhawk, 89.06% fly Warrior, 53.13% fly Archer, 42.19% fly Arrow, 48.44% fly Seminole and 20.31% fly other types of planes.

4.2 Weight and Balance Calculation

This section is on the one question regarding the difficulty of the weight and balance calculation. Of the sixty-five survey respondents, sixty-three responded to the question on the number of flights it took respondents before they consistently got the weight and balance calculations correct on the first attempt. Of the sixty-three survey respondents that responded to this question,

44.44% took up to two flights to get the calculation correct, 36.51% took three to five flights, 9.52% took six to ten flights, 7.94% took eleven to fifteen flights and 1.59% took between fifteen to twenty flights. Survey respondents on this particular question also provided a multitude of comments with the majority suggesting that the calculation is extremely easy with the minority suggesting that the calculation is confusing to perform.

4.3 Flight Envelope Monitoring Device

Of the sixty-five survey respondents, fifty-six of the survey respondents responded to the question regarding whether the FEM device would assist in the learning process of the weight and balance calculation. A five-point scale was used with 1 being poor and 5 being excellent in assisting with learning with 37.50% responding a 1 which is poor, 23.31% responding a 2, 17.86% responding a 3 which is neutral, 12.50% responding a 4 and 8.93% responding a five which is excellent. Of the sixty-five survey respondents, fifty-six of the survey respondents responded to the question regarding whether the FEM device could improve safety. A five-point scale was used with 1 being poor and 5 being excellent in the FEM device assisting with safety with 23.21% answering a 1 which is poor, 16.07% answering a 2, 14.29% answering a 3 which is neutral, 19.64% answering a 4 and 26.79% answering a 5 which is excellent.

Of the sixty-five survey respondents, fifty-four respondents responded to the question on which flights do you believe this issue is most relevant. Of the fifty-four respondents that answered this question, 44.44% responded large commercial flight, 57.41% responded small commercial flight, 44.44% responded recreational flight and 18.52% responded in the other flight category. Of the sixty-five survey respondents, fifty-four respondents responded to the question on whether the respondent would utilize this tool in flight. A five-point scale was used with 1 being never and 5 being frequent with 31.48% answering never, 22.22% answering a 2, 16.67% answering a 3 which is neutral, 20.37% answering a 4 and 9.26% answering frequent.

4. Discussion

The survey gave the options for comments to also be provided by survey respondents. An interesting theme that appeared is that the majority of pilots don't like the idea of the FEM device yet saw the potential merits in its increased safety. The survey respondents that agreed with the FEM device concept voiced concerns about the system being leaned on too much as a crutch but with proper designing it could be mitigated. Of the survey respondents that disagreed with the FEM device concept, provided different comments. Some of the survey respondents seemed to believe that this system was being put into place over a distrust in pilots and pilot training. Others commented that the device was not needed since the weight and balance calculation is basic math. Some of the comments also expressed the expense of the tool as a potential problem. Therefore, researchers identified a cost breakdown for the device resulting in it being $7,233 per device. Table 1 displays a cost breakdown.

Table 1. Cost Breakdown

Item	Quantity	Price/Item
NI cDAQ-9174 (Mounting Kit and Power Supply Included)	1	$1,051
NI 9127 (R350) Module (with adaptors and cable)	2	$1,551
Transducer Techniques THA-250-P/Q	6	$515
Asus Transformer Tablet	1	$269
TOTAL	X	$7,512

Additional comments from survey respondents included the need for cultural changes if the devices were installed on planes. For example, bags may not always be placed in ballast compartments or on seats so this would need to become part of the culture. Comments also suggested that pilots believe weight and balance to not be a huge issue in private planes.

According to FAA crash records (2016), 12.5% of the crashes researched were caused by weight balance in a private plane; however about 25% of the crashes researched were agricultural plane crashes, all of which were caused by weight balance issues. This suggests that this technology could also be helpful in seeding and fertilizing aircraft used by farms.

5. Conclusion

Incorrectly calculating the weight and balance of a plane by hand has been a cause of accidents (FAA crash reports, 2016). The proposed system which uses weight sensors and a tablet interface would not eliminate the need to calculate these numbers by hand, but would give a back-up system to mitigate errors. Along with mitigating these potential errors it could also be used as a teaching tool in flight schools for new pilots learning to do the weight and balance calculations.

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Proposed Techniques for Capacitated Vehicle Routing Problem Considering Environmental Loads

Yutaka SHIRAI [1]
Wataru FURIHATA [1]
Hiroyuki ONO [1]
[1]*Chiba Institute of Technology*
Corresponding E-mail: yutaka.shirai@it-chiba.ac.jp

Abstract

Reducing CO_2 emissions to protect the environment and reducing costs of cargo transportation are crucially important issues confronted recently by private enterprises. As described herein, we propose techniques for the Capacitated Vehicle Routing Problem (CVRP) considering environmental loads. Our technique for route search, proposed here, provides a method to find a route that incorporates different CO_2 emissions for different loading capacity limits of delivery vehicles. Furthermore, the method uses sweep and optimal partitioning methods for partitioning delivery points. The Max-Min Ant System (MMAS) uses CO_2 emissions as an evaluation standard and uses the improved ton-kilometer method to calculate the CO_2 emissions for loading different capacity limits. Finally, we performed numerical experiments to solve benchmark problems and thereby evaluated the effectiveness of our technique, which incorporates different CO_2 emissions for different capacity limits.

1. Introduction

Recently, the environment of logistics-related businesses has changed in various ways along with increasingly diverse customer needs. Finding proper routes for smooth and efficient delivery plans is indispensable to accommodate complex material flows. Increasingly, freight enterprises particularly ask logistics firms not only to cut costs but also to reduce environmental loads such as CO_2 emissions. In fact, urgent issues for these enterprises are cutting material flow costs for parts and products of freight customers, which are mainly manufacturing businesses, and reduction of environmental load substances to protect the environment. Moreover, the influences of wildly fluctuating oil prices and exacting requirements for environmental protection are becoming stricter these days. Overall, a movement to radical review of transportation systems, mainly of delivery vehicles, is strengthening among logistics firms and freight operators.

Many conventional studies of the Capacitated Vehicle Routing Problem (CVRP) (Toth and Vigo, 2002; Ralphs, Kopman, Pulleyblank and Trotter, 2003; Baldacci, Hadjiconstantinou and Mingozzi, 2004) have used minimization of the total circuit distance as an evaluation standard. According to the improved ton-kilometer method promulgated by Japan's Ministry of Economy, Trade and Industry (METI, 2006) for the calculation of CO_2 emissions, the CO_2 emissions per distance of transportation increase concomitantly with increased loading ratios of delivery vehicles. Using that method along with the conventional CVRP method, which considers only the total circuit distance, firms might be unable to cope with CO_2 emissions reduction.

A CVRP is divided roughly into two problems: determination of the partitioned delivery point allocations; and route search of the allocated partitioned delivery points, to which each vehicle must travel. Therefore, one must optimize the environmental load of CO_2 emissions in terms of partitioning delivery points and of route searching.

Although similar studies (Cinar, Gakis, and Pardalos, 2015; Jabir, Panicker, and Sridharan, 2015; Juana, Faulinb, Bernabeuc, and Jozefowiez, 2014; Ubeda, Faulin, Serrano, and Arcelus, 2014; Wygonik and Goodchild, 2011) incorporate CO_2 emissions, they include CO_2 emissions merely for the total circuit distance. Therefore, few studies have included consideration of CO_2 emissions for different loading capacity limits.

Herein, the authors propose techniques for CVRP considering different environmental loads for different capacity limits. The environmental load criterion addressed here is CO_2 emissions, the main greenhouse exhaust gas emitted by delivery vehicles. This technique for route search uses the "sweep method" (Goodrich, Ghouse, and Bright, 1996; Augugliaro, Dusonchet, Favuzza, Ippolito, and Sanseverino, 2010) and "optimal partitioning method" (Fisher and Kedia, 1990; Bompard, Carpaneto, Chicco, and Napoli, 2000) for partitioning delivery points and applies the "Max-Min Ant System (MMAS)" (Stützle and Hoos, 2000; Dorigo and Stutzle, 2004; Wang, Zhou, Zhao, and Xia, 2012) using CO_2 emissions as an evaluation standard. Therefore, we can perform a route search while considering the CO_2 emissions for different loading capacity limits. Our evaluation standard based on CO_2 emissions for different capacity limits might reduce the environmental load. Furthermore, the technique is useful to evaluate environmental load reduction. To evaluate the effectiveness of our proposed techniques, we used numerical experiments to solve benchmark problems for CVRP published in TSPLIB.

2. Problem Setting

2.1 Capacitated Vehicle Problem Routing

The basic CVRP is designed to ascertain the efficient delivery routes of vehicles leaving a delivery depot or factory and returning there, while minimizing the total circuit distance, delivery costs, and the vehicle load capacity. A CVRP includes two problems. One is to ascertain the allocated partitioned delivery points of a vehicle for a vehicle within its limit of capacity. Another is to perform an optimal route search among the delivery points to which each vehicle must travel.

Three constraints are relevant when seeking an optimal route. The first is the truck load capacity, which dictates the requirement of "adherence to vehicle capacity restrictions." The second is that each delivery point must be visited by a vehicle, or a "mandatory vehicle visit to every delivery point." As the third, vehicles leaving a delivery depot for any number of points must return to the original depot, thereby "making a circuit departure and return to the original depot: i.e. a circulation route restriction."

Being subject to the three constraints above simultaneously, CVRP presents difficulties because of the practical degree of complexity it entails. Finding a truly optimal solution requires an overly long computation time. For that reason, an approximate solution obtained using approximate methods in practical machine time is usually used instead of the optimal solution.

2.2. Formulation of CVRP

The fundamental CVRP is shown below.

$$\min \quad Z_d = \sum_{i=0}^{n} \sum_{j=0}^{n} d_{ij} \sum_{k=1}^{m} x_{ijk} \tag{1}$$

$$\text{Subject to} \quad \sum_{k=1}^{m} y_{ik} = \begin{cases} 1 & (i = 1, 2, \cdots, n) \\ m & (i = 0) \end{cases} \tag{2}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} w_i x_{ijk} \le C_k \quad (k = 1, 2, \cdots, m) \tag{3}$$

$$\sum_{j=0}^{n} x_{ijk} = \sum_{j=0}^{n} x_{jik} = y_{ik} \quad \begin{matrix} (i = 0, 1, 2, \cdots, n) \\ (k = 0, 1, 2, \cdots, m) \end{matrix} \tag{4}$$

$$\sum_{i\in s}\sum_{j\in N\setminus S} x_{ijk} \geq 1 \quad (5)$$

$$\forall S \subset N\ (S \neq \phi, S \neq N)\ (k = 1, 2, \cdots, m)$$

$$x_{ijk} \in \{0,1\} \quad y_{ik} \in \{0,1\} \quad \forall i \in N, \forall k \in K \quad (6)$$

Those equations use the following variables.

Z_d: Total circuit distance

n: Number of delivery points

m: Number of vehicles

d_{ij}: Distance between delivery points i and j (i, j = 0 shows a delivery depot.)

x_{ijk} = 1, if vehicle k visits delivery point j after visiting delivery point i;

= 0, otherwise.

y_{ik} = 1, if vehicle k visit delivery point I;

= 0, otherwise.

w_i: Demand for good at delivery point i

C_k: Loading capacity for vehicle k

N: Set of delivery points = {1, 2, …, n}

K: Set of vehicles = {1, 2, …, m}

S: Subset of N (not equal to null set or N)

Equation (1) expresses minimization of the total circuit distance Z_d. Equation (2) shows that each delivery point must be visited by any vehicle, with a mandatory visit of the vehicle to every delivery point: the assignment constraint. Equation (3) includes the loading capacity, which is the amount of goods a truck can carry in one trip: the loading capacity restriction. Equation (4) shows that vehicles leaving a delivery depot for any number of points must come back to the original depot, "making a circuit departure and return to the original depot: i.e., a circulation route restriction." Equation (5) shows prohibition of sub-tours.

2.3. Formulation of CVRP Considering Environmental Loading

As described in Chapter 1, CO_2 emissions are incorporated into CVRP considering the environmental load as an index of the load for evaluation of the reduced load. We formulate CVRP considering the environmental load as presented below.

$$\min \quad Z_c = \sum_{i=0}^{n}\sum_{j=0}^{n} CO_{2\,ij} \sum_{k=1}^{m} x_{ijk} \quad (7)$$

Z_c: Total CO_2 emissions

$CO_{2\,ij}$: CO_2 emissions during travel between delivery points i and j (i, j = 0 shows delivery depot.)

Equation (7) expresses the minimization of Z_c, total CO_2 emissions. Constraints shown in section 2.2 apply here as well.

3. Method Used

3.1. Max-Min Ant System (MMAS)

Ant colony optimization (ACO; Stützle and Hoos, 2000; Dorigo and Stutzle, 2004; Wang et al., 2012) simulates ant behavior. Actually, MMAS (Stützle and Hoos, 2000) was developed as an ACO method to solve the traveling salesman problem (TSP; Lin and Kernighan, 1973) with revised pheromone intensity.

In the fundamental ant system (AS), ants seek a route while traversing an area of ground. Pheromones having different intensities are applied to each route connecting two points of their visit. An ant visits the next destination by selecting, with high probability, the route with high pheromone intensity. After making a circuit route, ants intensify pheromones on the route depending on its total distance movement. Ants increase the pheromone intensity of such routes that introduce short circuit routes, and vice versa.

Because the generated circuit route depends on the associated probability, one cannot ascertain the quality of a circuit route among many candidate routes. Moreover, the pheromone intensity of an ant is rather uncertain. In contrast, the pheromone intensity produced by many ants after many route searches is presumably a good information source to locate a good circuit route. In the AS algorithm, many artificial ants use the pheromone intensity yielded by many ants to make a collective search under the influence of

their mutual interaction. Figure 1 depicts the concept of route search by artificial ants in AS. As shown there, while they proceed from the nest to the prey field, they select shorter routes along with the progression of search experience. Therefore, the pheromone intensity of shorter routes increases with the search progress. Such routes become prone to be selected.

MMAS uses a revised algorithm of AS that introduces a mechanism of setting upper and lower bounds of pheromone intensity to make the search behavior more proper, avoiding overly strong concentration and decentering of a search. This adjustment of the pheromone intensity circumvents difficulties arising from overly high intensity (concentration of search) or overly low intensity close to zero (hardly selected) and therefore removes the defect of AS in updating pheromone intensity. We present the MMAS algorithm below.

[Step 1] Set unity for the number of search trials t; (t = 1), the maximum number of search trials, the upper and lower bounds of pheromone intensity and the initial pheromone intensity for the route between i, j visiting points τ_{ij}.

[Step 2] Deploy artificial ants at the initial visiting point.

[Step 3] Each artificial ant repeats selection of visiting points until finding a circuit route depending on the following equation.

$$P_{ij}^{k}(t)=\begin{cases}\left([\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}]^{\beta}\right)\Big/\left(\sum_{i\in J_i^k}[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}]^{\beta}\right) & \text{if} \quad j\in J_i^k \\ 0 & \text{otherwise}\end{cases} \tag{8}$$

P_{ijk}: the probability that artificial ant k selects the route between visiting points i and j.

J_{ik}: set of visiting points not visited yet when artificial ant k is at visiting point i.

η_{ij}: reciprocal of the distance between two visiting points i and j.

α and β: parameters to adjust the influences of pheromone intensity and distance.

[Step 4] Examine the circuit route and total circuit distance of each artificial ant. Update the pheromone intensity between visiting points. Adjust the pheromone intensity at the upper and lower bounds.

$$\tau_{ij}(t)\leftarrow(1-\rho)\cdot\tau_{ij}(t)+\Delta\tau_{ij}(t) \tag{9}$$

$$\Delta\tau_{ij}(t)=\sum_{k=1}^{h}\begin{cases}1/L^{k}(t) & \text{if } (i,j)\in T^{k}(t)\\ 0 & \text{otherwise}\end{cases} \tag{10}$$

ρ: coefficient of evaporation.

$\Delta\tau_{ij}$: increment of pheromone intensity between visiting points i and j.

h: number of artificial ants.

T_k and L_k: circuit route and total circuit distance of artificial ant k.

[Step 5] If the search trials are fewer than the maximum number, then go to [Step 2] after adding one to t; (t = t + 1).

[Step 6] Output the best circuit route among all obtained routes and halt operations.

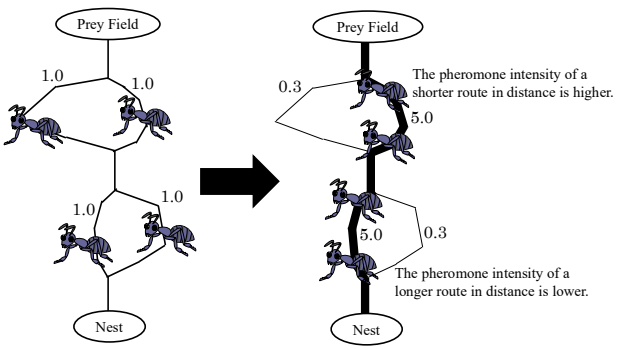

Figure 1. Concept of route search by artificial ants in MMAS.

3.2. Improved ton-kilometer method

Because the weight of a vehicle load changes as it unloads goods, one must re-

calculate CO_2 emissions according to the change. Our study found CO_2 emissions using the improved ton-kilometer method (ton-km; METI, 2006). Emissions were calculated using the following equation with the loading ratio, heating value of fuel, and transported weights of load of each vehicle with different maximum loading capacity.

CO_2 emission (t-CO_2)
= {weight of load transported (t)
× travel distance (km)}
× specific fuel consumption (l/t・km)
× 1 / 1000 (kl/ l)
× heating value (GJ/kl)
× emission coefficient (t-C/GJ)
×44 / 12 (t-CO_2/t-C) (11)

That equation shows t-CO_2, including CO_2 emitted and other emitted, absorbed, and stored greenhouse gases. The latter were converted to the weight of equivalent CO_2.

3.3. Proposed CVRP

The CVRP technique comprises two methods: determining the "partitioning delivery points of a vehicle" and determining "route search in the allocated partitioned delivery points," where each vehicle must travel. For the basic CVRP, minimizing the total circuit distance has been the evaluation standard. However, merely minimizing the total circuit distance, as done in a conventional routine, is insufficient as an evaluation standard if one wishes to conduct evaluation based on the minimization of CO_2 emissions. Here, we propose a new CVRP technique using CO_2 emissions minimization as the evaluation standard.

(1) MMAS-CO_2 Method Considering CO_2 Emissions

In conventional MMAS methods, an artificial ant that found the shortest circuit distance obtains the best evaluation. We make that ant emit pheromones. Furthermore, in MMAS methods considering CO_2 emissions, an artificial ant with minimized CO_2 emissions obtains the best evaluation. We make that ant emit pheromones to help us select a circuit minimizing CO_2 emissions.

Our study evaluated artificial ants in terms of the CO_2 emissions instead of the total circuit distance and made the ants move in search of route-minimizing CO_2 emissions. Using the improved ton-km method described in section 3.2, this study calculated CO_2 emissions. This idea was applied to route search of "Sweep + MMAS-CO_2" and "Optimal Partitioning + MMAS-CO_2" as explained below.

(2) Sweep + MMAS-CO_2 Method

The sweep method that uses the total circuit distance as the evaluation standard first creates patterns of clusters as much as the number of delivery points, then finds routes using the method of searching them. Finally, it determines the pattern of minimum circuit distance, in all patterns examined, as the best answer. However, CVRP using CO_2 emissions as an evaluation standard must select the solution of minimum CO_2 emissions as the best one. For that purpose, we propose a technique of "Sweep + MMAS-CO_2" using CO_2 emissions as the evaluation standard. The relevant algorithm is presented below. Figure 2 depicts the sweep method concept.

[Step 1] Set the delivery depot as the rotation center and select a delivery point as the start point of rotation. The map of delivery points rotates about that center in later steps.

[Step 2] Rotate the map about the center to cover all delivery points. Put all delivery points in ascending order of angle of rotation from the start point of rotation.

[Step 3] With the angle of rotation, the load weight increases. Increase the angle of rotation until the weight of the load on the vehicle attains the capacity limit. All

the delivery points involved in that angle of rotation make partitioned delivery points. Repeat the above until all delivery points are in partitions.

[Step 4] For each partition, to generate a circuit route, apply MMAS-CO_2 method considering CO_2 emissions.

[Step 5] Select a new start point of rotation and repeat [Step 2] through [Step 4] above.

[Step 6] Cease repetition when all delivery points except the delivery depot have functioned as the rotation center. Then calculate CO_2 emissions for all the circuit routes and select the solution with minimum CO_2 emission. Stop operations after saving that best solution.

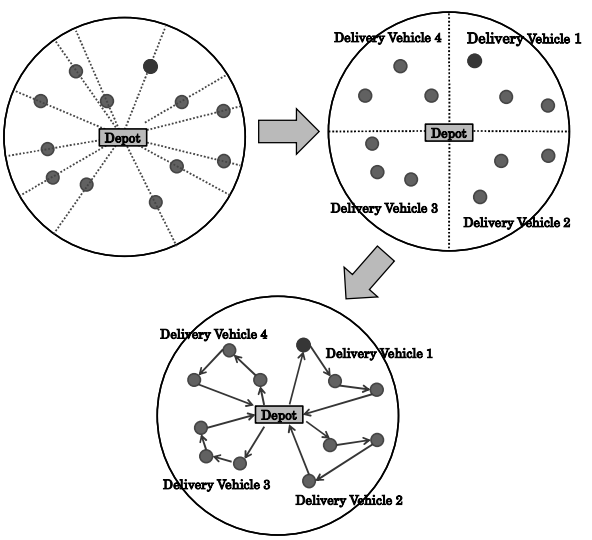

Figure 2. Concept of Sweep method

(3) Optimal Partitioning + MMAS-CO2 Method

For optimal partitioning with the evaluation standard of the total circuit distance, one first creates as many patterns of clusters as the number of delivery points for each route that is visited. Each route must include all the delivery points, except for the delivery depot. Then routes are determined by route search. Finally, the route with the minimum total circuit distance is selected as the best solution. However, CVRP using CO_2 emissions as the evaluation standard must select the solution with the minimum CO_2 emissions as the best solution. For that purpose, we propose a technique of "Optimal Partitioning + MMAS-CO_2" using CO_2 emissions as the evaluation standard. The algorithm is presented below. Figure 3 shows the optimal partitioning concept.

[Step 1] Find a route visiting all delivery points except the delivery depot, making use of a self-organizing map (SOM; Angeniol, Vaubois and Texier, 1988; Kohonen, 2001).

[Step 2] [Step 1] Allocate delivery points from the starting point given by [Step 1] to the point immediately before that at which the weight of a load exceeds the delivery vehicle capacity limit.

[Step 3] Connect the starting point and the last point in [Step 2] to the delivery depot to define a circuit. The next starting point is the point which is next to the last point in [Step 2].

[Step 4] Repeat [Step 2] and [Step 3] until all the points are allocated to a vehicle.

[Step 5] After completion of the allocation above, start formation of another circuit using MMAS-CO_2 method considering CO_2 emissions.

[Step 6] Change the starting point set at [Step 1] above (to the next delivery point) and execute from [Step 2] to [Step 5] again.

[Step 7] Finish the repetitions above when all the delivery points have worked as the starting point. Stop operations after saving the solution with minimum CO_2 emissions.

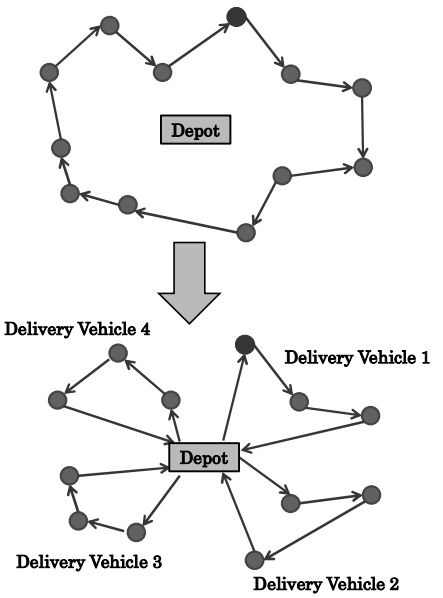

Figure 3. Optimal partitioning concept.

4. Numerical Experiments

As numerical experiments, we solved eil51, eila76, eilb76, eilc76, eila101, and eilb101, published by TSPLIB as benchmark tests of CVRP, using our proposed techniques of "Sweep + MMAS-CO_2" and "Optimal Partitioning + MMAS-CO_2" and using the conventional techniques of "Sweep + MMAS" and "Optimal Partitioning + MMAS." By assessing the relative performance of these methods using these four tests, we evaluated the effectiveness of our techniques. Parameters of "MMAS" were the following: 1000 maximum number of search trials, 100 artificial ants, 1.0 initial pheromone intensity, 0.1 coefficient of evaporation, α 2.0, and β 5.0. The improved ton-km method used kerosene fuel, a heating value of 38.2 GJ/kl, and a 0.0187 t-C/GJ emission coefficient. Trials were conducted 100 times using each parameter set.

Each table lists the total number of dispatched vehicles for 100 trials, total circuit distance, average of CO_2 emissions, and priority of total circuit distance or CO_2 emissions.

4.1. Performance Evaluation of Conventional Techniques (Evaluation standard of Total Circuit Distance)

For the analyses presented in this section, we conducted a performance evaluation of "Sweep + MMAS" and "Optimal Partitioning + MMAS" using the total circuit distance as the evaluation standard to find the partitioning method features. Here, no consideration was devoted to CO_2 emissions. Table 1 provides results of "Sweep + MMAS." Table 2 presents those of "Optimal Partitioning + MMAS."

Tables 1 and 2 show the apparent superiority of "Optimal Partitioning + MMAS" in terms of the total circuit distance in many benchmark problems. The total circuit distance entails shortcomings of instability, showing large variation. In contrast, "Sweep + MMAS" seems stable, showing small variation of the total circuit distance. Each method has a number of delivery vehicles. They do not mutually differ to any great degree.

These results suggest that a shorter total circuit distance does not necessarily mean smaller CO_2 emissions. Therefore, we must seek a route of small CO_2 emissions considering the loading capacity of vehicles, e.g., by unloading heavy goods earlier.

4.2. Evaluation of Proposed Techniques (The CO_2 Emissions Evaluation Standard)

We used the evaluation standard of CO_2 emissions to compare the performances of the proposed "Sweep + MMAS-CO_2" and "Optimal Partitioning + MMAS-CO_2." Here, no consideration was given to the total circuit distance. Table 3 presents results of "Sweep + MMAS-CO_2." Table 4 presents those of "Optimal Partitioning + MMAS-CO_2."

These two tables show better performance of "Sweep + MMAS-CO_2" for five benchmark problems in six problems.

Table 1. Results obtained using "Sweep + MMAS"

Benchmark Problem		Number of Delivery Vehicles	Total Circuit Distance		CO_2 Emission (t-CO_2)
			km	Ratio of Optimum Solution	
eil51	Average	5.0	531.90	102.09%	0.2150
	Distance Priority	5.0	531.90	102.09%	0.2143
	CO_2 Priority	5.0	531.90	102.09%	0.2129
eila76	Average	11.0	902.36	106.54%	0.3251
	Distance Priority	11.0	902.36	106.54%	0.3222
	CO_2 Priority	11.0	902.36	106.54%	0.3193
eilb76	Average	16.0	1137.50	107.51%	0.3418
	Distance Priority	16.0	1137.50	107.51%	0.3393
	CO_2 Priority	16.0	1137.50	107.51%	0.3313
eilc76	Average	8.0	771.24	103.52%	0.3161
	Distance Priority	8.0	771.24	103.52%	0.3174
	CO_2 Priority	8.0	771.24	103.52%	0.3094
eila101	Average	8.0	847.88	102.77%	0.3602
	Distance Priority	8.0	847.88	102.77%	0.3615
	CO_2 Priority	8.0	847.88	102.77%	0.3560
eilb101	Average	14.0	1189.61	106.79%	0.3868
	Distance Priority	14.0	1189.61	106.79%	0.3892
	CO_2 Priority	14.0	1189.61	106.79%	0.3835

Table 2. Results obtained using "Optimal Partitioning + MMAS"

Benchmark Problem		Number of Delivery Vehicles	Total Circuit Distance		CO_2 Emission (t-CO_2)
			km	Ratio of Optimum Solution	
eil51	Average	5.4	563.93	108.24%	0.2196
	Distance Priority	5.0	524.93	100.75%	0.2091
	CO_2 Priority	5.0	553.43	106.23%	0.2084
eila76	Average	11.0	899.24	106.17%	0.3188
	Distance Priority	11.0	869.16	102.62%	0.3118
	CO_2 Priority	11.0	895.63	105.74%	0.3056
eilb76	Average	15.1	1093.89	103.39%	0.3332
	Distance Priority	15.0	1069.42	101.08%	0.3267
	CO_2 Priority	15.0	1074.01	101.51%	0.3217
eilc76	Average	8.0	788.98	105.90%	0.3143
	Distance Priority	8.0	760.92	102.14%	0.3012
	CO_2 Priority	8.0	760.92	102.14%	0.3012
eila101	Average	8.0	877.61	106.38%	0.3646
	Distance Priority	8.0	856.11	103.77%	0.3566
	CO_2 Priority	8.0	864.53	104.79%	0.3537
eilb101	Average	14.1	1163.87	104.48%	0.3770
	Distance Priority	14.0	1133.33	101.74%	0.3616
	CO_2 Priority	14.0	1133.33	101.74%	0.3616

Comparison of the two methods of "Sweep + MMAS Method" and "Optimal Partitioning + MMAS Method" used in section 4.1 under the evaluation standard of total circuit distance shows that the latter mostly provided better results. The former was better under the evaluation standard of CO_2 emissions.

For "Optimal Partitioning," where route reconfiguration was done after decoupling a route once it had been made, little redundancy was available. Reconfiguration of the route using MMAS method produced no noticeable change in the route compared to that before reconfiguration.

In contrast to the above, "Sweep Method" makes zone partitioning by examining the positional relation between a depot and delivery point to create better solution patterns. It might have accomplished route search through simple optimization of CO_2 emissions.

Comparison of the numbers of delivery vehicles used in these methods revealed little difference, as was true also in section 4.1.

A method with an evaluation standard of the total circuit distance provides a solution with a short total circuit distance. A method with an evaluation standard of the CO_2 emissions yields a solution with small CO_2 emissions. Because the circuit distance and CO_2 emissions are both important items, a technique must be developed to yield some compromised solutions considering the delivery vehicle loading capacity.

Figure 4 portrays the circuit route obtained by "Sweep + MMAS-CO_2" (priority, CO_2 emission) for benchmark problem eil51.

Table 3. Results obtained using "Sweep + MMAS-CO_2"

Benchmark Problem		Number of Delivery Vehicles	Total Circuit Distance		CO_2 Emission (t-CO_2)
			km	Ratio of Optimum Solution	
eil51	Average	5.0	547.26	105.04%	0.2056
	Distance Priority	5.0	536.56	102.99%	0.2061
	CO_2 Priority	5.0	549.88	105.54%	0.2052
eila76	Average	11.0	953.61	112.59%	0.2944
	Distance Priority	11.0	945.17	111.59%	0.2962
	CO_2 Priority	11.0	952.86	112.50%	0.2941
eilb76	Average	15.0	1168.70	110.46%	0.3173
	Distance Priority	15.0	1159.67	109.61%	0.3182
	CO_2 Priority	15.0	1163.06	109.93%	0.3146
eilc76	Average	8.0	810.14	108.74%	0.2911
	Distance Priority	8.0	792.12	106.32%	0.2941
	CO_2 Priority	8.0	805.79	108.16%	0.2900
eila101	Average	8.0	901.18	109.23%	0.3378
	Distance Priority	8.0	893.13	108.26%	0.3370
	CO_2 Priority	8.0	906.61	109.89%	0.3360
eilb101	Average	15.0	1239.80	111.29%	0.3586
	Distance Priority	14.0	1228.57	110.28%	0.3592
	CO_2 Priority	15.0	1230.46	110.45%	0.3564

Table 4. Results obtained using "Optimal Partitioning + MMAS-CO_2"

Benchmark Problem		Number of Delivery Vehicles	Total Circuit Distance		CO_2 Emission (t-CO_2)
			km	Ratio of Optimum Solution	
eil51	Average	5.6	580.03	111.33%	0.2123
	Distance Priority	5.0	538.82	103.42%	0.2073
	CO_2 Priority	6.0	540.59	103.76%	0.2067
eila76	Average	11.0	931.75	110.01%	0.3103
	Distance Priority	11.0	893.86	105.53%	0.3104
	CO_2 Priority	11.0	910.33	107.48%	0.3011
eilb76	Average	15.3	1123.98	106.24%	0.3250
	Distance Priority	15.0	1085.83	102.63%	0.3221
	CO_2 Priority	15.0	1112.65	105.17%	0.3156
eilc76	Average	8.2	818.40	109.85%	0.3070
	Distance Priority	8.0	769.62	103.30%	0.2967
	CO_2 Priority	8.0	789.98	106.04%	0.2958
eila101	Average	8.0	926.91	112.35%	0.3537
	Distance Priority	8.0	892.78	108.22%	0.3485
	CO_2 Priority	8.0	917.76	111.24%	0.3444
eilb101	Average	14.1	1202.24	107.92%	0.3659
	Distance Priority	14.0	1157.79	103.93%	0.3577
	CO_2 Priority	14.0	1160.45	104.17%	0.3531

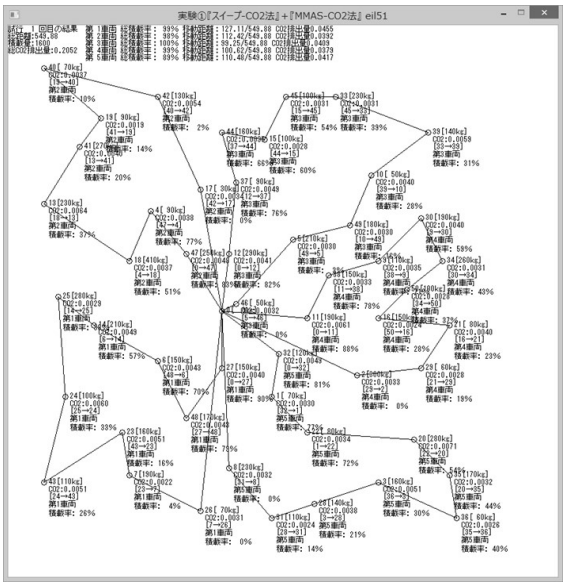

Figure 4. Circuit route generated using "Sweep + MMAS-CO_2" for eil51 Problem (priority, CO_2 emission; total circuit distance, 549.88 km; CO_2 emission, 0.2052 t- CO_2).

5. Conclusions

We proposed two techniques of "Sweep + MMAS-CO_2" and "Optimal Partitioning + MMAS-CO_2" for CVRP considering CO_2 emissions. Then we evaluated their performance using numerical experiments for benchmark problems to obtain better results by "Optimal Partitioning + MMAS" for the evaluation standard of total circuit distance and that by "Sweep + MMAS-CO_2" for the evaluation standard of CO_2 emissions. Regarding the number of delivery vehicles, these two experiments yielded similar results. Although they seem to have their own features, we recognized the effectiveness of our proposed techniques considering CO_2 emissions. Therefore, it is important to develop a technique that can optimize the total circuit distance and CO_2 emissions simultaneously.

6. Future Work

Our future challenges include proposing a technique that can elucidate clever methods of partition and route searching, examining types and numbers of delivery vehicles, and considering other environmental loads in addition to CO_2 emissions.

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Opportune Paradigm Shift: How an American Technology Image Had Been Tarnished

John Wang[1]
Qiyang Chen[2]
Sylvain Jaume[3]
[1, 2] *Montclair State University*
[3] *Saint Peter's University*
wangj@mail.montclair.edu, cheng@mail.montclair.edu, sylvain@csail.mit.edu

Abstract

We track The Eastman Kodak Company's glory history, its dominant position in the photographic film industry in the 20th century, as well as its dramatic collapse. How had an American technology image been tarnished? What can we learn from its paradigm shift locus classicus? A combination of external factors (Declining economy, Digital revolution, Deep-rooted competition, Disruptive technologies) and internal factors (Disconnected leadership, Deteriorated decisions, Discounted assets, Diversification of products) has played a big role.

1. Executive summary

The Eastman Kodak Company, universally known as Kodak, is an American imaging, and photographic equipment, materials, and service company, headquartered out of Rochester, New York. After being founded by George Eastman, Kodak rose to a dominant position in the photographic film industry in the 20th century. Kodak began to decline in the late 1990s in correlation to the decline in sales of photographic film. Kodak made strides to conform to the technological changing world, but to no avail. In a time where more pictures were being taken than ever before, Kodak filed for bankruptcy protection. A culmination of external and internal events saw the company plunge from its position at the top to another file in bankruptcy court. This paper will check these factors that led to this historic company's downfall.

2. Organization background

The Eastman Kodak Company is widely known for creating products to enhance photography. The name Kodak was born in 1888 with the slogan "You press the button – we do the rest". Kodak gained global brand recognition which lead to it becoming an international corporation. George Eastman, the founder of the company, wanted to make photograph "as convenient as a pencil". In 1892, the company was officially called the Eastman Kodak Company of New York. Four principles have made Kodak a big success: mass production at low cost, international distribution, extensive advertising, and a focus on the customer. Eastman built the company through the policies that promoted growth and development through continuous research. He believed in treating workers in a respectable way in order to build and expand the business (Tremaine, 2016; Diamandis, 2015).

In 1881 George quit his job as a bank clerk in

order to work full time on his experimental business known then as the Eastman Dry Plate Co. In less than two years, his firm moved into a four-story building on the lot that still exists today as the headquarters in Rochester, New York. In 1884 The Eastman Dry Plate and Film Co. was formed as a $200,000 corporation with 14 shareholders (Utterback, 1995). When the Brownie camera was introduced in 1900, it sold for $1 and used rolls of film that cost 15 cents each. This created a massive market for photography which became dominated by Kodak. In 1907 Kodak's employment surpassed 5,000, and in 1914 the headquarters was expanded to a 16-story building. When George Eastman died in 1932, he left his entire estate to the University of Rochester. In 1935 Kodachrome film was introduced which became the first commercially successful amateur color film. In 1946 Kodak employment exceeded 60,000 and in 1959 the company's shareholders topped 100,000. For the first time, Kodak's domestic sales exceeded $1 billion in 1962, and by 1966, worldwide sales reached $4 billion. The company would continue to expand and by 1981 total sales surpassed $10 billion. In 1988 global employment peaked at 145,300. Since then, things have been on the downslide with dwindling employment and sales regardless of the introduction of new products and services. In 1997 Kodak began to sell off its divisions to various industries (Dickinson, 2013).

On January 19, 2012, the company filed for bankruptcy protection under Chapter 11 in New York. After the filing, Kodak had about $5.1 billion in assets and approximately $6.8 billion in debts. Kodak owes the bondholders represented by the Bank of New York Mellon over $670 million (Creswell, 2013). The 11.4 billion linear feet of film Kodak manufactured as late as 2007, enough to circle the earth about 88 times, has shrunk 96 percent. Kodak reappeared on the public markets in September 2013. Currently, they focus on a legacy of innovation in the photography business and see if its remaining talent in optics and chemistry can be turned into new money in other industries with corporate partners. They are studying nanoparticle wonder inks, cheap sensors that can be embedded in packaging to indicate whether meats or medicines have spoiled, and touch screens that could make smartphones cheaper (Hardy, 2015).

3. Case description

Since its creation the Eastman Kodak company was the brand that was synonymous with taking pictures. It was an industry leader for its quality and innovations in photography. It combined a high quality product with consumer needs, making Kodak a household name. The ironic part of Kodak being overshadowed by the Digital Age is that Kodak had patents in digital technology already. They felt that the digital products were inferior, because the image quality was secondary to film, and digital storage had minimal capacities. Digital technology would advance faster than Kodak predicted. Management believed the digital age was decades away when in reality it was right around the corner. Kodak felt it had the global prestige to dominate and dictate the market, but as this case will discover, the company faced many shortcomings. After peaking around 1988, things seriously changed for Kodak. The factors at play will be examined for what is to blame for this business failure.

4. External factors

4.1. Declining economy

In 2008 Kodak blamed the global economic slowdown for ruining the company. CEO Antonio Perez pointed out the drop overall in the tradition film industry. Being desperate over losses, Kodak sued Apple and HTC for infringing some of its patents. Once Kodak started to produce digital products, the economy started to slow down as well. Perez was certainly in a critical position. Although the economy was certainly a factor, its rival company Fujifilm has thrived (The Economist, 2012).

4.2. Digital revolution

While there are many reasons that a business such as Kodak could fail, there are key elements that are common to such business failures. The inability to innovate and also to stay ahead of the times by forward thinking is a classic external factor for a loss of market share leading to a decline of a business. Kodak was the holder of many patents and had even developed a digital camera; however, they missed being a part of what became the digital revolution because they viewed it as crude and inefficient. As Williams (2012) pointed out, "No adjustment to the market place or competitor's technology along with living off past successes, yesterday's wins" (p.2) contributed to Kodak's downfall. As early as 1981, following Steven Sasson's invention of the first digital camera, Vince Barabba studied for Kodak core technologies that included the use of silver halide film versus digital photography (Mui, 2012). The results of the study indicated that Kodak's film would be replaced by digital photography in ten years. Because of the costs of the peripherals including equipment and prints, Kodak thought that the impact of the digital revolution was far off and would not harm them. The new age came sooner than any of their experts ever predicted. Perhaps one of the most overlooked additions was the camera phone, almost forcing consumers to convert to the digital technology.

4.3. Deep-rooted competition

For decades Kodak operated with little, to no, formidable competition. They enjoyed a long lived opportunity to operate using a *quasi-broad differentiation* business strategy. Kodak's mindset - when a company dominates a field such as the film business why bother to change their problem - was "Institutional Arrogance" (Mendez, 2011). They had no prior experience of surviving in a marketplace with high competition and small margins. The culture at Kodak was that they were, and would always be, the leader in the market. During those years almost all of Kodak's business markets evolved, and revolved, around film. The *razor and blade* strategy which sold inexpensive cameras and making large margins from film, chemicals, and paper was generating the bulk of the revenue for Eastman. The popularity of Kodak spread rapidly throughout the world. In 1976 Kodak owned the American photography market with 90% of film sales and 85% of all camera sales (Economist, 2012).

Over the last two decades competition has emerged from foreign competitors employing a *best-cost provider* strategy (Koen & Bertels, 2011). Sony, Nikon, and Samsung have satisfied consumers' desires of better value for the money, more appealing features, dependability, and a perceived higher quality product (Dickinson, 2012). There are glaring similarities to General Motors who also faced similar early market dominance and then stiff competition from foreign manufacturers forcing them to bankruptcy.

By 1993, Kodak's strategy was confused and its photo business was losing ground as other competitors were striving in the digital photo business. For instance, Fujifilm and Kodak were rivals that are very similar to one another. Both companies faced the same problem, the fact that digital technology was coming in and their products would no longer be of use. The difference between the two companies here was the adaption process. While its competitors flourished and adapted, Kodak remained behind. Fujifilm did a much better job at modifying their company. First they were able to steal sales and profits away from Kodak, which at the time was pretty much a monopoly. Fujifilm did this by sponsoring the Olympics, getting great publicity, and attracting consumers with their lower prices. "Another reason why Kodak was slow to change was that ... the Kodak bosses seldom heard much criticism of the firm… because it was working in a one-company town" (Economist, 2012, p.63).

Fujifilm basically diversified its company more successfully than Kodak. As Kodak attempted and failed with some pharmaceutical operations, Fujifilm came out with a line of

cosmetics, which was successful in Asia and Europe. Fujifilm also made optical films for LCD flat-panel screens, where they enjoyed a 100% market share, making that a good move by the company. Kodak did not invest enough time and effort into its transition to a digital company. Xerox, Kodak's third competitor, has also expanded its products and services to include document management, finance and administration services, product lifecycle services and consulting services (Datamonitor, 2011). Kodak has failed to create a diverse line of products and services, leaving them vulnerable as well as unable to remain profitable and on top. Too long did they try to hold on to the old business model and the use for film and print. Being attacked by ever-changing technology and the fact that their competition was moving with the flow of things, creating new products and diversifying their companies, Kodak struggled to stay afloat eventually leading to its bankruptcy.

4.4. Disruptive technologies

While Kodak invented and developed many of the components used in digital technology they have been unable to profit from it. Actually, it has had a negative impact on the company. The reason this happened was explained by Christensen's theory. Christensen noted that senior management does not take notice of disruptive technologies because they do not conform to the existing customer base and that the initial consumer attraction occurs with the least profitable consumer group in the market (Assink, 2006). Since the demand does not come from the markets most profitable customer base, most disruptive technologies are absorbed in middle management and the technology never makes its way to the top. Most companies miss the opportunity to profit from a technology that is initially perceived as disruptive is because the company "is practicing good management" (Lucas & Goh, 2009). For a company to profit from a disruptive technology it is up to senior management to have middle managers transform the organization from their level down. Inherent throughout the layers of management is the corporate culture to protect and preserve the current business model at all costs. Christensen's theory was exacerbated by the fact the Kodak's management had developed a culture of complacency driven by monopolistically forged egos (Economist, 2012).

Kodak fell prey to the "incumbent's curse". According to Vijay Govindarajan the curse is "when a company becomes successful, it develops a dominant logic. When the world went digital, Kodak's strengths became weaknesses. It could not overcome its dominant logic and build a new logic" (Newman, 2012).

Although Kodak had sufficient information, they chose to ignore it. In hindsight it is easy to understand the digital frenzy. Personal computers were being produced within the consumers' budget making it the most popular home item since the television. Digital cameras and computers required a one-time cost. Once the consumer had both of these, they could capture as many photographs as possible and store them on their computer without having to pay any cost per photograph. Consumers began to be more interested in purchasing more storage capabilities than film or image production. It was a matter of time before Kodak lost its loyal customers over to the competing digital companies. For Kodak to adapt to the digital technology it would have required a revolution of the company and cutting ties with an industry that had been so profitable in the past. Kodak's internal decision to underestimate and dismiss the digital age as critical external factor, would prove devastating to the company.

5. Internal factors

5.1. Disconnected leadership

Proper leadership is very critical for the overall success of a company. It can either build, or ruin a company. Kodak, like many other huge companies, became captive to its core business, that it could barely risk other ways of doing business to succeed. In many cases, when companies become successful, they tend to develop a dominant logic. And as most of the

world went digital, it was obvious that Kodak became its own worst enemy and played a big role in its imminent death. The Kodak management had failed to foresee digital photography as a disruptive technology because they envisioned its traditional business rendered obsolete.

Kodak's leadership failed to have proper forecasting because they failed to read other emerging markets correctly and had continued to hope that its largest market in China would be attracted to buying lots of film; however, many potential customers jumped from no cameras straight to digital cameras, smart phones, tablets and other electronic devices. It was obvious that the film business premise was no longer relevant in a world where people didn't even need films anymore because cell phones and smart phones became today's cameras, with virtually unlimited shooting capacity and at virtually no cost. Kodak's management did not realize that in the imaging business they had to focus on fundamental changes that included evolving their way of doing business simultaneously with the rapidly changing times.

The senior executives wavered on strategic decisions that would help evolve Kodak's way of doing business which led to Kodak's inability to evolve and grow as it should have in order to satisfy its customers. Clearly, due to improper leadership, Kodak failed to see its unending opportunities and took a plunge. Kodak was living off past successes; it needed to look beyond the present and be ready with forward planning for the future.

The unwillingness to change leadership, as well as having too many changes in leadership, can threaten the stability of a company. Where and how management is selected can be a problem itself. If promotions are from within, there may be no new perspectives or "fresh eyes" (Williams, 2012). This means that it is business as usual; things are done the way that they have always been done with no motivations. This results in the business stagnating. The other choice was to hire new leaders. However, they may have their own agendas and priorities and establish new goals for the company. Kodak has had four CEO's since 1990 (Pangarkar, 2012). One way to look ahead is to examine management and its philosophies. Kodak remained in denial of the importance of digital photos from as early as 1975 through 2012. Each new CEO would cite the failure to transform to digital by the previous leader and then also fail to accomplish this transformation (Mui, 2012). New CEO's bring a period of restructuring which can impede any company's progress.

Kodak laid off 10,000 employees in the late 1990's, devastating an entire town. Also, so many changes in leadership could indicate an inability to retain the best and the brightest; Kodak and any other company have to create opportunities to retain these upper management employees in order to ensure the continued success of its business. Kodak was once a leader with great potential; they had thousands of patents and information about digital imaging. However, failure was due to its strongly inward focus (Pangarkar, 2012). The key factors in lack of leadership, inconsistent philosophies, no sustainability, and unwillingness to adapt to markets all played off each other negatively.

5.2. Deteriorated decisions

When George Eastman funded the company in 1881, it eventually became an iconic giant of the industry for more than a century. The downfall began in the late 1990's when Kodak had to lay off 10,000 of its employees who were based at its headquarters in Rochester, New York. At the time, Kodak was the largest employer in Rochester. George was a philanthropist; he endowed the University of Rochester with the Eastman School of Music, which was well known throughout the world (Pangarkar, 2012). What other factors caused this company to diminish from its social prestige?

The internal factors of Kodak's failure to remain a sustainable business model really highlight the source of the collapse. Kodak made several major corporate decision blunders. The

innovation of digital photography was something that Kodak should have anticipated. Ironically, as early as 1975, one of Kodak's engineers, Sasson, invented the first digital camera called the megapixel digital camera. This embryonic device was bulky, required sixteen batteries, and took several seconds to record an image since it used a cassette tape (Mui, 2012). Its brand of little yellow film was highly recognizable. Kodak also had invested heavily in film and chemically treated paper. A consumer's first purchase was the camera, but he had to continually purchase film cartridges and also pay for the cost of developing and printing. This gave Kodak a never-ending revenue stream, which Kodak was unwilling to lose. "Filmless photography" would be disastrous (Mui, 2012, p. 1).

In fact, Kodak's founder, Eastman, had twice before made two changes that saved his business. The first of these changes was when he switched from dry plate to film, and the second was the implication of color film, which was inferior to black and white in which Kodak dominated. Also, Kodak had more than a ten-year period, in fact decades, (if one goes back to Sasson's work in 1975) to prepare for the transition. Because the transition would take some time, Kodak did not recognize the technology as a threat. In addition to ignoring the advances in technology, Kodak suffered from poor management all around.

Kodak's business model has been hit hard by the decline in the number of people who print photos. In the autumn of 2011 Kodak ran a TV commercial trumpeting their Kodak Hero series of printers to attempt to entice more customers to buy Kodak digital cameras and print their photos. In reality, this was how they sold film by promoting cameras. The competition seems to be more in touch with what drives the consumer digital market than Kodak. Kodak should restructure and market its camera portfolio and cross-sell their printer and frames. Kodak needs to be more vocal with the market and inspire new consumers with innovative communications about future technology to enhance its market presence (Ellis, 2011).

Kodak changed its business strategy in the printer market. Competitors in the market today sell printers on a very small margin but make it up with huge margins on repeat ink sales. Kodak was betting everything that their strategy of selling the printer at a higher up front cost that their competitors and then selling the ink at a large discount would make them the market leader. The concept was to pay more up front and save more in the years to follow sounds like a very difficult sell.

5.3. Discounted assets

Poor decisions will hurt any business, but the mishandling of assets and investments drained Kodak of billions of dollars. When the company's board made a decision in 1988 to purchase Sterling Drug, a pharmaceutical company, for $5.1 billion (Mui, 2012), perhaps this was an attempt to diversify and to combine a chemical company with Kodak, it was not as related to photographic chemicals as Kodak thought and Sterling was sold at a great discount. It grew into $9.3 billion in debt by 1993. In addition, the board voted to sell Kodak's healthcare imaging business in 2007, which was a successful entity since the demand for healthcare was increasing. The board also failed to invest in its high-end Leaf photography unit and its image sensory technology. If investments backfire causing debt, it can distract the leaders focus as well as be a financial disaster.

Aside from just creating new products in the photography market, Kodak also attempted to enter new markets and take on new acquisitions. As a result of this, Kodak turned to pharmaceuticals, medical diagnostics, copiers, and computer hardware. However, none of these acquisitions became a large enough part of Kodak to allow them to remain a leader in their industry, but in 2005 Kodak did something that was supposed to assist them in their tough time (McCullough, 2012). One of Kodak's latest acquisitions was Creo. Kodak purchased Creo for $1.05 billion in cash, in hopes of improving their company (McCullough, 2012). Kodak's plan for this acquisition was for it to grow into something

more than the inventive company that it had been since 1983. Unfortunately for Kodak, as they began to falter, so did Creo. Kodak was forced to outsource a majority of the divisions for cheaper labor, causing financial stress for Creo as well as ruining the great reputation that this company once had. Creo has seen nothing but decline for its company since being bought by Kodak. This acquisition was not only a disappointment for Kodak, but this also caused a serious decline in a once great company.

5.4. Diversification of products

Over the years, Kodak's research leveraged its deep scientific understanding in materials science, imaging science and technology to improve the products that they offered to their customers. Kodak's research mainly focused on improvements in areas that dealt in: data organizations, capture technologies, digital workflow and output systems. Kodak's innovation boasted unimaginable brainpower, which existed in places many may not have realized. However, Kodak failed to translate its brilliant innovations into marketable products. Kodak always led the way with an abundance of new products and processes that set them apart from others in the same business.

Customers are constantly in search of multiple-functionality in products that help to make life easier, or faster. Kodak could no longer depend on the purchasing power of its core customers. These customers were being diverted by the multitude of products that were being marketed to a faster paced life. But Kodak was so caught up in perfecting its innovations that it failed to see or be aware of the possible dangers of not dealing promptly in products that would be marketable as times evolved. Kodak's strength in other products like organic chemistry and optics enabled them to carry out research and develop some excellent, high end products. More so the investments spent on innovations, made Kodak products more powerful, flexible and easy to use with each new generation and should have been very successful if released to the market in a timely manner.

Kodak's management believed that innovation was their best course and dwelt so much on the perfection of its products that it failed to explore other technologies and business tactics which, has inadvertently lead to its demise.

6. Epilogue & lessons learned

From 1888 to the 1980s, Kodak dominated the consumer photography market, as an innovative and admirable icon of American industry. Kodak made the hobby of photography accessible and affordable to the common man. Kodak went from a $25.05 billion market cap in 1996 to filing for chapter 11 bankruptcy protection on January 19th, 2012.

There are many ways for a company like Kodak to fail, but Kodak's downfall was a result of them being unable to innovate and keep up to date with current times. Poor decisions and misuse of assets drove them further into the hole they were in. The digital photography was a big concern for them and would affect the industry completely. If Kodak took the initiative to fix their problem by changing their practices they could have survived this change in consumer trends (see Table 1).

They were so focused on producing and selling film that they did not want to spend the capital investment in completely different technology. Eventually they would realize the effect of new technology on the industry. Kodak lacked decision making skills and forecasting ability at the time as they ignored information that could have helped them prosper in the industry.

Kodak had not taken a proactive approach to building an industry around a strengthening market. They chose to avoid the future that experts had predicted was on its way. They neglected to run a business that took into the consideration customer satisfaction and growth as its number one priority. Customer demand is the driving force of business. Kodak tried to maintain the customers it already had but it neglected to follow the demand of new

customers and in so doing provided new customers to other businesses.

For a company that was so well known for its innovativeness and creativeness, it's rather ironic that it was their inability, or unwillingness, to change that eventually led to the failure of the company. It is always dangerous for one to pride oneself only on past success.

How to warn businesses to avoid similar costly mistakes in the future? How applicable are the lessons to businesses in general or strategic thinking? In order to be a sustainable business model, changes must be made in response to the progressing market. Sometimes, knowledge needs courage to set counter-cultural action into motion. You can't outrun disruption and market. Do follow the curve; don't fight the wave.

7. Appendix

Table 1. SWOT analysis

Strengths
Strong focus on technology innovation
Global manufacturing and distribution network
Strong brand recognition
Weaknesses
Lack of product diversification
Opportunities
Robust growth in functional printing market
Increased focus on action cameras
Positive outlook for packaging industry
Threats
Competitive pressures
Rapid technological changes
High dependence on third party suppliers

(Cited from MarketLine, 2016)

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The Impacts of Wealth Distribution as a Result of State Funded Lotteries

Gordon W. Arbogast[1], Ph.D.
Barry Thornton[2]
David Szweda[3]
[1,2,3]Jacksonville University, FL

ABSTRACT

There are 44 states in the United States that have organized state lotteries in the last twenty years. A large majority of these states were well intentioned and declared that they intended to spend most of the monies derived from these lotteries toward education funding within their state. While these programs often had great potential at the onset, many seem to have failed to deliver on their promises. For many states only a small percentage of the money spent on lottery tickets actually appears to go toward the funding of social needs such as education. Secondly, it has been suggested that a greater percentage of the sources of lottery money may often be coming from disadvantaged individuals and go toward programs that benefit individuals in the middle and upper classes of society. Today, many of the states are facing program shortfalls in education funding. As to the lottery programs, many appear to not have actually contributed additional monies toward education, but instead at best have been supplementing tax dollars that were previously spent on education.

This paper reviews one such State that has adopted a lottery to fund educational needs. It investigates whether race and education levels are directly related to the spending on lottery tickets, and also whether the distribution of the money has been evenly distributed or if it is also impacted by income, race and education levels. Data was collected from South Carolina as it was readily available and has not been previously studied to the depth of some states like Georgia. It was noted that Georgia had undergone substantial changes to their lottery over the years. Such changes make it very difficult to evaluate data consistently across the time horizon. In contrast the South Carolina lottery has stayed consistent over its 12 years in existence. The final results of this study offer evidence that an individual's discretionary income in South Carolina may be being misused. Income that is being spent on the lottery appears to be flowing disproportionately from the more disadvantaged portions of society and redistributed to the less needy in the form of education funding.

1. BACKGROUND

There are a number of states that today have state funded lotteries. A number of these lotteries have been modeled after Georgia's HOPE (Helping Outstanding Pupils Educationally) Scholarship. The Georgia HOPE Scholarship was created in 1993 with the goal of providing scholarships to students funded entirely by revenue from the Georgia Lottery. It sponsors a merit-based scholarship for students attending in-state colleges and a grant for those entering technical schools. It increased freshman enrollment by 5.9% or roughly 3000 students per year. Four-year colleges accounted for most of the gain with both white and black enrollments increasing because of Hope (Cornwell, Mustard and Sridhar, 2006). The program was so successful that a number of states soon began to follow setting up similar programs (Cohen-Vogel, Ingle, Levine, and Spence, 2008).

One such state was South Carolina. The South Carolina Education Lottery (SCEL) was created on January 7, 2002. This Lottery intended that its profits were to be used solely for educational purposes. It is the General Assembly of South Carolina that allocates and determines the distribution of net funds generated by SCEL (Ghent, and Grant, 2015).

The breakdown of SCEL's gross proceeds, is listed in Table 1 in the Appendix (South Carolina Education Lottery Brochure- Programs and Information, 2015). It can be seen in Table 1 that 75.6% of the proceeds goes toward prizes, commissions and operating expenses. These elements are necessary to run the lottery. The remaining 25.4% are allocated back to specific education accounts as outlined by South Carolina statutes. None of the funds are allowed to be distributed to other special accounts or to the general fund to cover general legislative expenses. The Education Accounts have been setup to redistribute funds for specific purposes. The purposes are divided into three parts. 1) Funding for K-12 programs by county; 2) Funding for county libraries; and 3) Scholarships given to students who meet certain requirements. Since its inception the SCEL has distributed the following funds, shown in Table 2 (Ibid).

Table 1 – SCEL Proceeds

Category	Explanation	%
Prizes	Distribution of Winnings	65.5%
Retailer Commissions	Commissions paid to retailers that host Lottery machines	7.1%
Operating Expenses	Costs to operate the Lottery	3.0%
Education Accounts	Distribution to fund education	25.4%

Table 2 – SCEL Distributions (2002 – 2014)

Distribution Category	Amount
K-12	$585,018,132
County Library	$16,827,511
Scholarship Funds	$2,015,068,084

As can be seen by the distribution table, the vast majority of funds go toward Scholarship activities. The eligibility requirements for scholarship and grants are set by the South Carolina Legislature and are generally based on grades, residency and placement tests. In return these scholarships pay a significant portion of a student's tuition. There are four Scholarship programs and three grant programs available through the SCEL and they are distributed to students by county in South Carolina (SCEL Distribution by County, 2015).

A number of games are available through the South Carolina Education Lottery. Six games are based on drawings, where a set of random numbers is chosen. Therefore, on a given date a random mechanism chooses a series of numbers. Then individuals who chose numbers that match the random set of chosen numbers receive a prize. Seventy-one games are instant games. Instant games are obtained by purchasing a scratch card at a retail location. Scratching the card reveals winnings which can be received from the retail location or the lottery offices. One remaining game is an online game, where numbers are chosen through a special website. All games involve a consumer paying for the chance to win a prize. The prizes are based on statistical models that are skewed toward the state receiving more money than they need to pay out. Individuals are drawn to play these games through the opportunity of winning large prizes. Since the beginning of the lottery more than 76,406 prizes have been awarded (South Carolina Education Lottery Brochure- Programs and Information, 2015).

While the lottery is prohibited from marketing to specific individuals, demographic studies have shown that purchases of lottery tickets are skewed toward a certain demographic. Specifically, demographic studies (to be discussed later) have been conducted that show that spending on lottery tickets is disproportionally skewed toward certain segments of society, notably minorities, low income and less educated individuals. Annual surveys of player studies conducted on the

South Carolina Lottery by independent third parties, as required by state law, indicated a number of interesting trends. These studies are typically conducted via surveys and the populations are quite small (i.e. 500-600 individuals). While overall player participation of the lottery reflected the overall population distribution, the frequency of play was significantly higher among certain populations. It found that in general "frequent players" (those playing Lottery games more than once a week) tend to be skewed most heavily toward males, African Americans, and households with incomes under $30,000. It also found that individuals, who play scratch cards, tend to skew strongly toward younger players, households with income under $20,000, African Americans and men. "Pick 3" players are those that play a game where three separate single digits are chosen. These players are heavily skewed toward African Americans and households with incomes between $20,000 and $50,000 with only minimal differences based on age and gender. Those games associated with Powerball were more reflective of the overall demographic of the state (South Carolina Education Lottery Player Profile Study (2015).

One of the more interesting outcomes of the SCEL are some of the subsequent actions that occurred after the lottery was established. In the 2007 timeframe there was a study by Ghent and Grant to determine if the vote for the new South Carolina lottery was driven by latent demand for lottery products or whether it reflected other public finance considerations. The authors of this study determined that there were significant differences in individual's voting and buying behaviors in the state. Specifically, the lottery vote was higher in counties with underperforming schools and in counties along state's borders. Of great interest was the discovery that the creation of the South Carolina lottery drew substantial revenues from North Carolina shoppers and also stemmed an outflow of revenue to Georgia. Prior to the SCEL, the Georgia Hope lottery had been receiving significant revenues from South Carolina citizens (Ghent and Grant, 2007).

Because of these demographic studies conducted not only in South Carolina, but also across other states, there has been a clear indication across various news outlets and studies that lotteries in general tend to target minorities and low income individuals. The http://www.stoppredatorygambling.com website and others have questioned the value of these lotteries and the effect they are having on certain communities (Bloomberg Business, 2012). While these sites and studies have highlighted the individuals who play the lottery based on either surveys or anecdotal evidence, none have looked at the information on not only player spending habits, but also which lotteries give back to the communities and families of those who spend. As a result, no one has clearly outlined the redistribution of wealth from those individuals who play the lottery to those individuals who receive the benefits from the lottery. Since data is not readily available, and also because the spending of the money is clearly controlled by the state legislatures, education based lotteries appeared to be the preferred types of lotteries to study. Lotteries of one kind or another have been around almost as long as mankind has lived in settlements, and scholarly work on lotteries has been around for nearly as long as lotteries themselves. In more modern United States history, works continue to be produced that takes critical looks at the practice. G. Robert Blakey took a look at the history of lotteries in America and their continued failure to fulfill promises (Blakey, 1979). C.T. Clotfelter and P.J. Cook in a seminal work looked at lotteries and described them to be consumer commodities, as well as government ventures and businesses (Clotfelter, Charles and Cook P.J., 1991). Both works are very indicative of most research in the area. They paint a broad brush of the varied history of lotteries in the United States, and tell a revealing story of how the promise of lottery wealth has been a part of the fabric of the country from the start and how those promises have failed to materialize for most Americans. In an earlier work C.T. Clotfelter and P.J. Cook showed how the lottery could be

construed to be an implied tax imposed by the state on its citizens (Clotfelter, Charles and Cook P.J., 1987).

As works on the lottery have proliferated since their inception, articles outlining lotteries as taxation have also blossomed. The most prevailing argument is that state and government lotteries act as a substitute for tax revenue. Charles Clotfelter and Philip Cook set the bar in 1987 when they examined lottery finance and the extraction of the profits for state revenue (Clotfelter and Cook, 1987).

Many of the scholarly works produced in the last 30 years have focused on lotteries as a regressive tax. A regressive tax is a tax imposed in such a manner that the tax rate decreases as the amount subject to taxation increases. In doing so, it general hits lower income individuals harder as they have: (1) higher tax rates; and (2) less disposable income. Kathryn Combs, Jaebeom Kim, and John Spry examined the implicit taxation in Minnesota's lottery and the possibility of an inherent regressive effect between some products as compared to others offered in Minnesota (Combs, Jaebeom and Spry, 2005). In a similar vein, Andrew Weinbach and Rodney Paul have related government payments to welfare recipients to a rise in lottery sales of specific games that target higher probability games (Weinbach, Andrew and Paul, Rodney J., 2008). Finally, some aspects of race have been examined in a tangential role. Kasey Hendricks has examined the use of lotteries to offset state tax revenue and its effects on race. Heller and Marin at Harvard have questioned the fairness of lotteries such as the Georgia Hope Scholarship in providing equal access of revenues to all sectors of society and especially to minorities (Heller and Marin, 2004).

2. PROBLEM STATEMENT

This research paper seeks to establish a potential relationship between the amount of money an average individual spends on lottery purchases and an individual's race, education and income level. Also, the research paper seeks to establish a potential relationship between the amount of lottery funds individuals receive from lottery distribution and an individual's race, education and income level. This will be examined by looking at two different multiple regressions.

The relationship between the amount of money an average individual spends and its independent variables is shown in the following formula:

$$Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

The relationship between the amount of money distributed to an individual and its independent variables is shown in the following formula:

$$Y_2 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

Where

Y_1 = Amount spent on lottery tickets per person in dollars for a given county

Y_2 = Amount of money distributed per 10 people in Scholarship funds in dollars for a given county

X_1 = Median Income per household in dollars for a given county

X_2 = % of population for a given county that is classified as a minority race

X_3 = % of population for a given county that has obtained a bachelor's degree or higher

B_i = Coefficients

ε = Random error

The following explains the details of the independent variable (X_1) and expresses the expected relationship of the amount spent on lottery purchases (Y_1) and the amount distributed to each county per 10 people in Scholarship funds (Y_2).

Median Income - There have been a number of studies conducted that show that income may be a factor on lottery purchases. All of these studies have relied on surveys conducted upon random sampling of the population. To understand player demographics, the State of South Carolina performs periodic player profile studies. No clear study has been done tracking the real numbers associated with Median Income. The team collected the median income, by using information from the US Census Bureau for each county. The median income was chosen because it divides the households evenly in the

middle with half of all households earning more than the median income and half of all households earning less than the median income. It provides a much less biased view of income and removes the impacts of a few extremely high numbers that may exist. The Census Bureau recommends this number be used when evaluating the income levels and provides a more accurate representation. Race - This is the percent of individuals who are not identified as a single race or are classified as white only, according to the US Census Bureau classification categories. This number was taken from subtracting the percent of individuals who are reported as white and classify themselves as only one race from 100%. The US Census Bureau classifies the race term "white" as a person having origins in any of the original peoples of Europe, the Middle East, or North Africa. It includes people who indicate their race as "white" or report entries such as Irish, German, Italian, Lebanese, Arab, Moroccan, or Caucasian. This means that the races used for this analysis include those individuals who are classified as two or more races, or by those individuals who are classified as Black/African American, American Indian, Alaska Native, Asian, Native Hawaiian or other Pacific Islander. In general, the predominate non-white race in South Carolina is classified as Black/African American, where the other non-white races are typically between 0.3% and 4% of the population for the given county. We chose all non-white race individuals in this study because of the ease and accuracy of the data.

Education - This is the percent of individuals who hold a bachelor's degree or higher in a given county of those individuals 25 years old or higher. A bachelor's degree or higher includes those individuals who have received a bachelor's degree from a college or university, or a master's, professional, or doctorate degree as defined by the ACS guidelines entitled "Educational Attainment", as defined by the Census Bureaus, these data include only persons 25 years old and over. The percentages are obtained by dividing the counts of graduates by the total number of persons 25 years or older. Choosing this data does not indicate that 25 years old or a bachelor's degree is the key dividing line for determination, but that this is the most readily available and accurate data to indicate education attainment for a given county.

3. HYPOTHESES

Two models were developed. The first deals with the expenditures by individuals on lotteries and the second deals with the distribution of funds to individuals by lotteries.

Model #1

Null Hypothesis (H_0) - "In the State of South Carolina, there is no relationship between lottery purchases and the independent variables identified as income, race and education i.e. low income, minorities or less educated individuals are not disproportionately taxed through lottery purchases."

$$H_0: \beta_1 = \beta_2 = \beta_3 = 0$$

Alternative Hypothesis (H_1) – "In the State of South Carolina, there may well be a relationship between lottery purchases and the independent variables identified as income, race and education, i.e. low income, minorities or less educated individuals may well be disproportionately taxed through lottery purchases"

$$H_1: \text{At least on } \beta_i \neq 0, i = 1, \dots, 3$$

Model #2

Null Hypothesis (H_0) – "In the State of South Carolina, there is no relationship between lottery distributions for scholarships and the independent variables identified as income, race and education, i.e. low income, minorities or less educated individuals are not disproportionately targeted in the distribution of lottery income for scholarships.".

$$H_0: \beta_1 = \beta_2 = \beta_3 = 0$$

Alternative Hypothesis (H_1) – "In the State of South Carolina, there may well be a relationship between lottery distributions for scholarships and the independent variables identified as

income, race and education, i.e. low income individuals are disproportionately targeted in the distribution of lottery income for scholarships.

H_1: At least on $\beta_i \neq 0, i = 1, \ldots, 3$

Independent Variables - The null hypothesis and the alternative hypothesis for each independent variable are: (the independent variables with the set are)

- Median Income (in dollars)
- % Non-white (Race)
- % College Degree (% with a bachelor's degree or higher)

4. RESEARCH DESIGN AND METHODOLOGY

Data – To test the hypothesis, data for each of the measures was needed. The following data was collected:

Names of Each County – was collected through public information found on Wikipedia.

Distribution of Education Funds – was collected from the South Carolina Education Lottery Website. While all distributions for education funds were collected per county, the figure that is of interest to this study are the funds distributed associated with all Scholarships. The funds distributed to Scholarships represent over 99% of all education funds distributed.

Median Income –collected through the US Census Bureau's (http://factfinder.census.gov), website and reflects the most current up to date information available from the Census Bureau, the 2010 US Census.

% Non-white–collected through the US Census Bureau's website (http://factfinder.census.gov), and reflects the most current up to date information available from the Census Bureau, the 2010 US Census.

% College Degree - collected through the US Census Bureau's (http://factfinder.census.gov) website and reflects the most current up to date information available from the Census Bureau, the 2010 US Census.

Amount each county collects for the South Carolina Education Lottery – was collected through a request from the SCEL through a Freedom of Information Act. It was received on March 11, 2015. The data covers the money collected from March 1, 2014 to February 28, 2015. This represents one full year of the latest data available from SCEL.

The population for each county was obtained using the latest census data collected through the US Census Bureau's (http://factfinder.census.gov) website.

The amount of tickets purchased per person was calculated by taking the amount of revenue collected by each county (as indicated above) and divided by the population of the county. This allowed the normalization of the value per resident, while also isolating trends for that county.

Scholarships per person - was calculated by taking the amount of money distributed by the lottery per county (which was a total number over the last 12 full years) and divided that by 12 (to annualize the value) and divided by the population of the county. This allowed the normalization of the value per resident, while also isolating trends for that county. The final number was multiplied by 10 (per 10 people) in order to bring the number closer in relation to the amount of tickets purchased per person, and to provide graphs that made more sense. Since the multiplication factor was evenly applied it will have no effect on the number.

Significance Level – A significance level of $\alpha = 0.05$ (5%) was used. A lower significance level makes it harder to reject the null hypothesis (H_0). It results in a better outcome if in fact the null hypothesis is rejected in favor of the alternative hypothesis (i.e. if the test of significance gives a p-value lower than the significance level α).

Regression Models - Two multiple regressions will be conducted. The first will determine the relationship between the three independent variables of Median Income, Percent Non-white, and Percent College Degree

with Per Capita Lottery Purchases (Expenditures). A second regression will be conducted to determine the relationship between the three independent variables of Median Income, Percent Non-white and Percent College Degree with Per Capita Lottery Distributions (Receipts).

If a significant relationship is identified in either regression the null hypothesis will be rejected for that variable. It will then be concluded for the variable that there is a change in either (or both) the purchasing of lottery tickets and the distribution of scholarship funds per county. The coefficient of determination or R^2 will show the variation in our data set that is accounted for by the regression model.

5. RESULTS

Multi-collinearity/Correlation Tests

If multi-collinearity exists, it can create a problem for the analysis. The multi-collinearity test indicated that income, in combination with race and education may be a problem. In this regard Minitab was used to calculate the 'Variance Inflation Factors' (VIFs) for each of the independent variables. A Variance Inflation Factor that is greater than one indicates that the predictors are correlated. A Variance Inflation Factor that is greater than 5 indicates that the predictors are strongly correlated and will lead to poor estimates due to multicollinearity. As all VIFs were less than 5 it was determined that the analysis could proceed as planned using multiple regression (see Table 5).

Table 5 – Variance Inflation Factors

Term	Coeff	SEC	T-Val	P-Value	VIF
Const	140.9	99.51	1.42	0.164	
X1 Income	0.005	0.003	0.17	0.865	4.61
X2 Race	399.20	84.15	4.74	<0.001	1.72
X3 Educa-tion	-12.2	255.4	-0.05	0.962	3.47

Regression Test #1

The first of the Regression Models was then exercised and the results are shown in Table 5. The only variable that is significantly related to Per Capita Lottery Expenditures is the Percent Non-White in the county. It is seen in the Table that it has a strong P-value (0.000) and T-Statistic indicating that there is a strong relationship between the Percent Non-White and Per Capita Lottery Expenditures. For each one percent increase in this variable, it is estimated that Per Capita Lottery Expenditures will increase by $3.97. Also noteworthy is the Adjusted R-Squared value of .4204 indicating that the model with the three independent variables explains 42.04 percent of the variation in the dependent variable (Per Capita Lottery Expenditures). A strong F-Statistic (11.88) also is significant, indicating that this model has a moderate degree of predictive power.

There are 46 counties in South Carolina. Pickens County has the lowest Percent Non-White at 11.3%. Allendale County has the highest Percent Non-White at 76.3%. This is a difference of 65% in percent non-white persons. The estimated difference in per capita lottery expenditures between these two counties is $258.05. This is a huge difference, since it is an expenditure per person and presumably every person in the county doesn't buy lottery tickets.

The presumed relationship between Median Income ($1000s) and Percent College Degree is not supported by the results of the analysis. However, it is recognized that the high degree of correlation with the other variables could be having an impact on these variables due to multi-collinearity. This is common in research using socioeconomic and demographic variables, which may be confounding the results. However, there appears to be strong statistical evidence that there is a relationship between the Percent Non-White and Per Capita Lottery Expenditures.

Regression Test #2

The second of the Regression Models was then exercised. The model (that is, the three independent variables used in both regressions) does a considerably worse job explaining the variation in Per Capita Lottery Receipts (as measured by lottery based scholarship dollars per capita) than it does for Per Capita Lottery Expenditures. While the expenditures model explains about 42% of the variation in the dependent variable, the receipt model only explains about 8%. Furthermore, the F-statistic is much lower (2.35 for receipts, as compared to 11.88 for expenditures). While the expenditure model's F-statistic has a corresponding p-value of 0.000, the p-value associated with the F-statistic for the receipts model is 0.086. So, the receipt model isn't even significant at the 5% level, the usual standard, but is significant at the 10% level.

Once again, the only significant independent variable in the model is Percent Non-White, but the impact of this variable on Per Capita Lottery Receipts is much smaller, shown in Table 6. For every one percent increase in the percent non-white in a county, lottery receipts are expected to fall by about $0.14. It is noteworthy that the sign on the estimated coefficient is negative, suggesting that non-whites receive less benefits from the lottery than whites. But the estimated coefficient of $0.14 can be interpreted that the reduction in lottery receipts between the county with the highest percent non-white and the county with the lowest percent non-white is $9.10. Still, when you factor in that not every person in the county goes to college, it's not an insubstantial amount, just not as extreme as the impact of race on lottery expenditures.

Table 6 – Multiple Regression Results for Per Capita Lottery Expenditures

Variable	Estimated Coeff	Stand Error	T- Stat	P-Value
Constant	139	100	1.39	0.17
Median Income ($1000s)	0.66	2.73	0.24	0.81
Percent Non-White	3.971	0.846	4.69	0.00
Percent College Degree	-0.39	2.58	-0.15	0.88
Adjusted R^2 = 42.04%		F-Statistic = 11.88		P-Value = 0.000

Further Regression Testing

In an effort to determine more information on the relationships, simple linear regressions were run on all three variables. The results are shown in Table 7. The regression analysis table shows the regression equation for Expenditures (Purchases) with Median Income and Percent Non-White as being significant (p-value is < 0.05). Since the p-value is less than α, we reject the null hypothesis for median income and for Non-White. Thus, it can be concluded that sufficient statistical evidence exists in this analysis to provide evidence that there may well be a relationship between the Percent Non-White as well as Median Income with regard to Per Capita Lottery Expenditures. No such relationship was found to exist in the simple regression involving Education (Percent College Degree) and Expenditures.

Concerning the simple linear regressions run with the three variables and Receipts, only Non-White was found to be significant. Thus, it was concluded that sufficient statistical evidence exists in this analysis to indicate that Non-White may well have a relationship with Receipts. The other two independent variables were not significant.

Table 7- Multiple Regression Results for Per Capita Lottery Receipts

Variable	Estimated Coefff	Standard Error	T-Statistic	P-Value
Constant	40.5	9.35	4.33	0.000
Median Income ($1000s)	-0.125	0.255	-0.49	0.627
Percent Non-White	-0.1383	0.079	-1.75	0.087
Percent College Degree	0.229	0.241	0.95	0.347
Adjusted R^2 = 8.25%		F-Statistic = 2.35		P-Value = 0.086

6. Final Thoughts on the Analysis

The model was limited to the fact that data was collected at the county level. Data could have been collected at a lower level, but the effort needed to do this would have far exceeded the effort and timeframe for this paper. In addition, a number of the results had a value that significantly skewed the results, and because of the small population of counties, we believe it had an impact on the results. Aggregated results were graphed to provide a more consolidated view of the data:

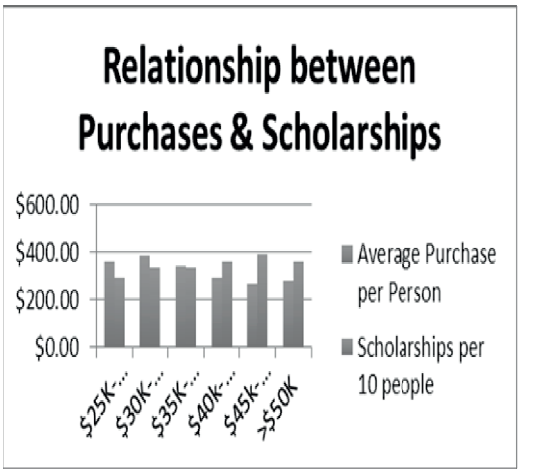
Lastly, a table was constructed to show the relationship between expenditures and receipts by income level (See Table 8). The data that was available for receipts actually was listed as scholarships granted using the lottery funds in the various counties of South Carolina. It is assumed in this table that scholarships are a surrogate for receipts. In this table it can be seen that there is evidence that supports the findings in this study. Specifically, as income levels rise the average purchases per person falls. Conversely, the higher rate of scholarships is being rewarded to those in the higher income bracket. This data would tend to confirm the notion that Non-Whites are expending more per person on lottery tickets and gaining less benefit from Receipts and Scholarships from the lottery system in South Carolina. However, although the graph shown in Table 9 anecdotally does show that there appears to be some relationship between Race and Income levels on the purchases of Lottery Tickets and the receiving of Scholarships, and that these are disproportionate across the disadvantaged or across racial lines, statistically this could still be questioned.

Table 8 – Simple Linear Regression Results

Regression Test	F_{stat}	$F_{critical}$	Model Acceptable (Y/N)
Purchases vs. Income	8.90	4.07	Y
Purchases vs Non-White	38.10	4.07	Y
Purchases vs. College Degree	4.02	4.07	N
Scholarships vs. Income	3.47	4.07	N
Purchases vs Non-White	6.07	4.07	Y
Purchases vs. College Degree	3.35	4.07	N

- If $|F_{stat}| > F_{critical}$ => *model is acceptable*

Table 9– Relationship between Expenditures and Receipts by Income Level



7. CONCLUSIONS

The model around race was of great interest. Both the Expenditures and the Receipts received do indicate that a direct relationship exists between money spent and received by Non-Whites. One element that is not highlighted in the numbers is that despite the amount purchased, the citizen is only receiving 26% of the benefits. This by itself shows that this is probably a poor means of taxation. While it is voluntary, it plays on the desire of many who may be disadvantaged to "gamble" on a large payout, when in reality the vast majority of individuals who play the lottery will never see a winning. The funds take money from where it is really needed, and distributes it to those who 1) do not play as often, and 2) who are more advantaged**.**

When presented at the 2016 IEMS conference in Cocoa Beach in March 2016, there was much discussion as to why Non-Whites appear to be so eager to expend in many cases their meager funds to play the lottery. Several present argued that the lottery may well be a form of entertainment to those in the lower social classes. The analogy of the gladiator games in ancient Rome was conjured up by one person. Irrespective of the motivation, it is apparent that the phenomena of the lottery are here to stay and that states need to spend more time and effort studying how it can be run more efficiently and fairly in the future.

8. APPENDICES

Table 3 – Player Frequency by Ethnicity

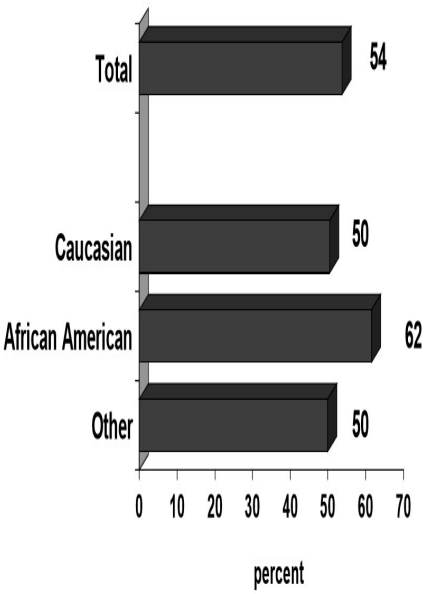
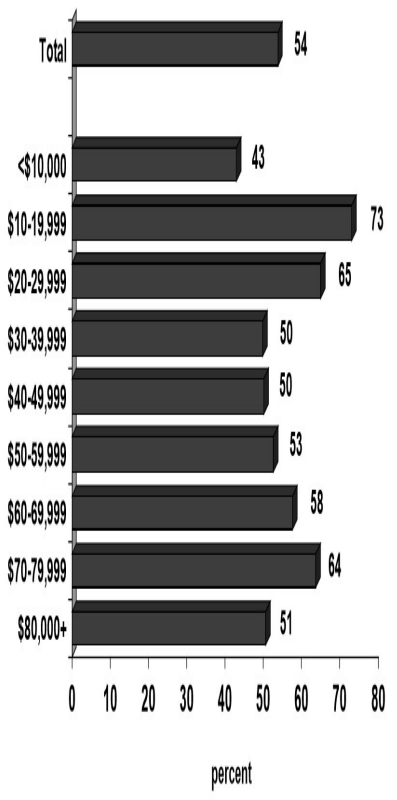


Table 4 –Player Frequency by Income



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How Players Respond to Monetary Incentives in Online Poker Promotions

Scott D. Swain[1]
B. Andrew Cudmore[2]
[1]*Clemson University*
[2]*Florida Institute of Technology*
sdswain@clemson.edu; acudmore@fit.edu

Abstract

Online casinos have begun to embrace the use of direct marketing and promotional offers to attract offline players. However, empirical evidence regarding the effectiveness of such tactics is limited. To examine this issue, we visited multiple Texas Hold 'em tournaments and conducted an experiment in which offline-only poker players viewed promotional invitations to join an online casino website to play poker. The invitations varied with respect to two monetary incentive cues that are frequently and prominently featured in the marketplace: the rake rate (the amount the house skims from the pot) and the matching bonus (the amount of a players' initial deposit that is matched by the casino). Through the use of mixture regression modeling, we identify two distinct segments of offline poker. Whereas one segment responds to matching bonuses regardless of the rake rate, the other segment only responds to bonuses at lower rake rates. Using binomial logistic regression, we assess linkages between player characteristics and segment membership. We find that segment membership is well-predicted by offline players' perceptions of online casino safety as well as their general responsiveness to incentive offers. These results are broadly consistent with self-determination theory: whereas some players appear to view monetary incentives as empowering (i.e., as facilitating autonomy and competence), others appear to view monetary incentives as a tool used by online casinos to control player behavior.

1. Introduction

The reach and popularity of poker is exemplified by the multiple, high profile, televised poker tournaments held each year around the globe (Eichenwald, 2006; Fiedler & Wilcke, 2012; Sandomir, 2005). Recently, states in the US as well other countries have legalized – or are considering legalizing – online poker (Kelly, 2015; Tselnik, 2007). Traction for this trend comes from growing acceptance of the notion that poker is distinct from gambling (and thus not subject to gambling regulations) since it is a game in which elements of skill predominate over chance. A variety of empirical and analytical studies support this perspective, including archival analyses of actual play in high stakes tournaments (e.g., Levitt & Miles, 2014), mathematical simulations (Hannum & Cabot, 2009), game-theoretic analyses (Bowling, Burch, Johanson, & Tammelin, 2015), and repeated-play experiments (Dedonno & Detterman, 2008).

Legalization of online poker has resulted in a new marketplace characterized by competition among online casinos to attract and retain new players. Accordingly, individual casinos have begun to explore the potential of direct marketing (e.g., email offers) for promoting their online poker services.

While previous research has catalogued a number of factors that may impact players' responses to online casinos (e.g., visual and designs, sponsorships, celebrities, and learning resources), there is little or no empirical evidence as to the effects of such promotions (McMullan & Kervin, 2012). This is somewhat surprising, as online casinos frequently offer novel incentives with the specific intent to acquire new players. We address this gap in the

literature by examining offline players' responses to two monetary incentive cues that commonly appear in promotions for online poker yet are rarely, if ever, featured in offline poker contexts: lower rake rates (the percent of the pot skimmed by the casino) and matching bonuses (the extent to which a players' initial deposit is matched by the casino).

2. Monetary incentive cues in online poker promotions: different things to different players

Several studies have examined poker behaviors through the lens of Deci & Ryan's (1985) self-determination theory (SDT), which posits that people have a need for self-determination (autonomy), competence, and relatedness in their interactions with the environment (e.g., Back, Lee, & Stinchfield 2011; Chantal, Vallerand, & Vallieres 1995; Mitrovic & Brown 2009). SDT defines different types of motivation, with the most basic distinction being intrinsic versus extrinsic (Ryan and Deci, 2000). Intrinsic motivation refers to engaging in an activity for its inherent satisfactions (e.g., playing poker because it is challenging, exciting, or fun) whereas extrinsic motivation refers to engaging in an activity to reach a separable outcome (e.g., winning money, escaping from daily stress, or meeting new people). In general, behaviors that reflect intrinsic motivation are more closely associated with feelings of self-determination.

In the present research, we contend that monetary incentive cues in promotions for online poker can be, and likely are, interpreted in different ways by different players such that feelings of self-determination can be enhanced for some but diminished for others. These differences should be reflected in differences in the players' willingness to visit or join an online casino's website.

For some players, monetary incentive cues can be empowering. For example, a new online player may view matching bonuses as an immediate, "house money" buffer on top of their initial deposit. This buffer can facilitate perceptions of lower financial risk and encourage greater feelings of freedom. Additionally, a matching bonus conveys the opportunity for extended, "free" play (an option that does not exist in offline poker), thus providing an opportunity to develop more skill and acquire more experience as well as achieve greater certainty in judgments about the experience. Thus, matching bonuses can enhance feelings that an online casino allows for both greater autonomy and greater competence. Similarly, lower rake rates represent a significant reduction in the costs of entry over time. Knowing that the cost is lower, a player can not only consider playing longer but also playing multiple, parallel hands. Additionally, players may feel that the long term benefit of lower rake rates is, in essence, a rebate for playing online rather than offline. This may help players feel like they are "smart shoppers" who are "beating the system" (Schindler, 1998).

In contrast, some players may view monetary incentive cues as a threat to self-determination.

This can occur when players believe that their decision to consider playing online poker is contingent on the presence of (external) monetary inducements. Such a belief would tend to diminish perceptions of self-determination. Instead of seeing a matching bonus as a simple windfall, players may see it as a control tactic in which online casinos offer a short-term reward in exchange for prescribed behavior. This framing prevents players from viewing their choices as intrinsically motivated (Kivetz, 2005). Similarly, players may view lower rake rates as an incentive that is contingent on entering a long-term relationship, leading to reduced perceptions of self-determination. This notion is consistent with empirical studies on consumer reactions to incentives associated with customer loyalty and relationship management programs (Dholakia, 2006; Melancon, Noble, & Noble, 2011).

To empirically examine offline poker players' responses to monetary incentive cues in online poker promotions, we conducted an experiment in which we systematically varied rake rates and matching bonuses and gauged players' willingness

to join an online casino website. Because we expect that there are distinct segments of offline poker players, we adopt an exploratory analytical strategy. Specifically, we analyze the experimental data using mixture regression models, a methodology designed to detect the presence of subpopulations with respect to a functional relationship between predictors and dependent variables. Thus, in contrast to the traditional analytical approach in which heterogeneity in responses to a treatment is viewed as noise, mixture regression views heterogeneity as potential evidence of unobserved groups.

3. Participants

We recruited 81 participants in-person at several Texas Hold 'em tournaments in the southeast US. Consistent with recent, large-scale cohort studies (e.g., LaPlante, Kleschinsky, LaBrie, Nelson, & Shaffer 2009; Smith, 2012), the sample was predominantly male (84%) and early adult (56.8% aged 21-30).

In order to qualify for the study, participants had to be bought-in at the tournament and had to answer "yes" when asked "Have you ever played poker before?" This ensured that participants had sufficient knowledge about the game and would be able to understand the concepts associated with online casino offers. Since this research focuses on how offline players perceive inducements to play online, participants also had to answer "no" when asked, "Have you ever gambled online?" and when asked, "Have you ever played online poker before?" To maintain participant anonymity, consent forms were torn off in front of the participants and placed in a separate folder.

4. Design, procedure, and measures

Qualifying participants were shown one of four written scenarios. The scenarios comprised a 2 (rake rate: low, high) × 2 (matching bonus: low, high) between-subjects, fully-crossed experimental design. All scenario stimuli included the same stock photo picture (two cards and a pair of dice) and the same introductory statement:

"*Imagine you receive an e-mail inviting you to join an online poker site. The image shown above accompanies this e-mail and you start to consider checking out this specific online poker site. You click the link and arrive at the poker site. The directions to play for real money are clear and easy to understand. You click on a link and arrive at a page stating the rules and the rake rate (the percentage the house takes from the pot).*"

The next sentence contained the rake rate manipulations:

- Low rake rate: "*The rake rate presented is 1% (as opposed to the 10% rake presented at casinos).*"
- High rake rate: "*The rake rate presented is 10% (like the 10% rake regularly presented at casinos).*"

The final sentence contained the matching bonus manipulations:

- Low matching bonus: "*You notice that this site also offers a matching bonus percentage (the percentage of your initial deposit rewarded to you after you play there for a certain amount of time) of 25% (e.g., you deposit $100 and they put in $25 extra money on top of that giving you $125).*"
- High matching bonus: "*You notice that this site also offers a matching bonus percentage (the percentage of your initial deposit rewarded to you after you play there for a certain amount of time) of 200% (e.g., you deposit $100 and they put in $200 extra money on top of that giving you $300).*"

After reading the scenarios, players indicated their willingness to visit the online casino by responding to three seven-point scale items: "Having read this scenario, I am now more ____ to join this site." [unwilling - willing; reluctant - eager; disinclined - inclined]. The scale exhibited high internal consistency (Cronbach's $\alpha = .93$) and thus the items were averaged to form an index.

Players then responded to two additional items, one to assess the manipulation of the rake rate ("The rake rate on this online poker site was..." 1 = Low, 7 = High) and the other to assess the manipulation of the matching bonus amount

("The matching bonus on this online poker site was..." 1 = Low, 7 = High). One-way ANOVAs indicated that the manipulations were successful (Rake rate: $M_{high} = 4.57 > M_{low} = 3.42$, $F(1,77) = 12.34$, $p = .001$; Bonus: $M_{high} = 5.41 > M_{low} = 4.02$, $F(1,77) = 13.44$, $p < .001$).

In the final section of the survey, we gathered measures of concomitant variables that may prove useful in predicting players' membership in latent response segments. We used seven-point scale items to measure participants' perceptions of the safety of online poker ("I feel that playing online poker is___" 1 = Unsafe, 7 = Safe), their general responsiveness to incentives ("My loyalty to a site can be affected by how many incentives they offer" 1 = Strongly Disagree, 7 = Strongly Agree), their perceptions of TV as a behavioral trigger ("Watching poker on TV encourages me to play poker more often" 1 = Strongly Disagree, 7 = Strongly Agree), and their belief in the importance of body language when playing poker ("Viewing players' body language during the game is important" 1 = Strongly Disagree, 7 = Strongly Agree).

5. Results

To explore the potential for subpopulations of players with respect to responses to rake rates and matching bonuses, we used mixture regression modeling. We commenced by fitting models that specified varying numbers of segments (one to four). Analysis of the resulting Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values indicated that a two-segment solution is most appropriate. To assess the stability of model parameters for the two-segment solution, we used a bootstrapping analysis. The bootstrapped parameter values did not substantively differ from those in the final model. Additionally, the pattern of significant and non-significant effects remained the same. The estimated model is presented in Table 1. Segment 1 comprises 75.3% of players while Segment 2 comprises the remaining 24.7%.

Table 1: Mixture Regression Results

	Segment 1		Segment 2	
	β	Sig.	β	Sig.
(Intercept)	4.64	<.001	2.37	<.001
Rake	-.61	<.001	-1.02	<.05
Bonus	1.30	<.001	1.61	<.01
*Rake*Bonus*	-.27	.36	-1.33	.04

Note: Coding for Rake and Bonus: 0 = Low, 1 = High

To aid with interpretation, we present visualizations of the rake rate and matching bonus effects for both Segment 1 (Figure 1) and Segment 2 (Figure 2).

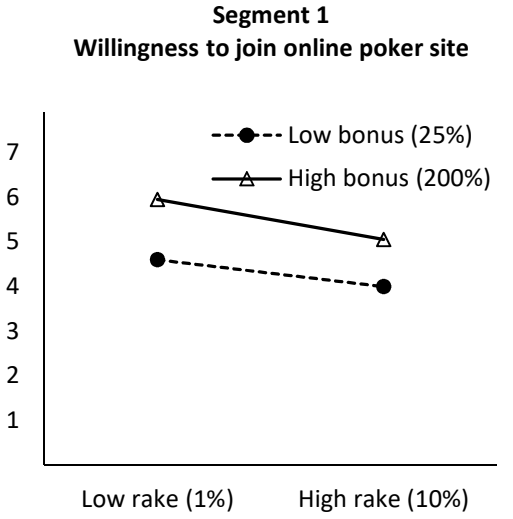

Figure 1

For Segment 1, willingness to join the online casino is relatively high overall (all means above the scale midpoint), with the rake rate and matching bonus cues demonstrating independent (additive) effects (interaction $\beta = -.27$, $p = .36$). Specifically, the 1% rake is associated with greater willingness to join the site than the 10% rake ($M = 5.24$ versus $M = 4.55$, $p < .01$), while the 200% matching bonus is associated with greater willingness to join the site than the 25% matching bonus ($M = 5.48$ versus $M = 4.37$, $p < .01$).

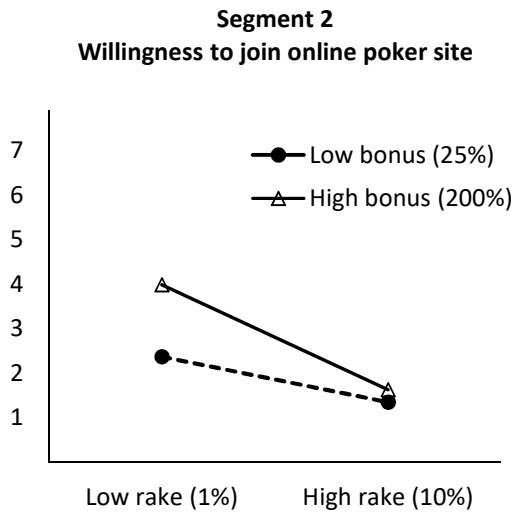

Figure 2

Segment 2 players exhibit lower overall willingness to join the site than Segment 1 players (all means below the scale midpoint). Similar to Segment 1, Segment 2 exhibits an interpretable negative main effect of rake rate ($\beta = -1.02$, $p < .05$). However, the effect of the matching bonus depends on the rake rate. With a low rake rate (1%), the 200% matching bonus is associated with greater willingness to join the site than the 25% matching bonus ($M_{200\%} = 3.98$ versus $M_{25\%} = 2.37$, $p < .01$). With a high rake rate, there is no effect of the matching bonus amount ($M_{200\%} = 1.63$ versus $M_{25\%} = 1.35$, $p = .47$).

Having identified two latent segments of offline poker players who respond differently to monetary cues in an online casino promotion, we next conducted a binomial logistic regression analysis to determine whether players' segment memberships are associated with other observed characteristics of the players. The dependent variable was coded so that the model predicts the log likelihood of membership in Segment 2. The independent variables are the measures of participants' perceptions of the safety of online poker (Safety), general responsiveness to incentives (Incentive prone), perceptions of TV as a behavioral trigger (TV activated), and belief in the importance of reading body language when playing poker (Body language).

The overall fit of the logistic regression model was significant, as indicated by a likelihood ratio test comparing the null model (no predictors included) to the hypothesized model (all four predictors included): $\chi2(4\ df) = 24.6$, $p < .001$. To assess model accuracy, we first generated the predicted probability of membership in Segment 2 for each participant. Participants with probabilities greater than .50 were predicted to reside in Segment 2 while the rest were predicted to reside in Segment 1. Cross-tabulation of the predicted and actual (mixture regression) segments revealed a classification accuracy of 82%.

Table 2: Binomial Logistic Regression Results

	β	Exp (β)	Sig.
(Intercept)	1.73	5.64	.14
Safety	-.78	.46	<.001
Incentive prone	-.56	.57	.01
TV activated	.11	1.11	.53
Body language	.34	1.41	.14

Notes: Dependent variable is the log likelihood of membership in Segment 2.

As shown in Table 2, players who view online poker as being more safe and who are generally receptive to online incentives have significantly lower odds of being in Segment 2 ($p < .001$ and $p = .01$, respectively). Specifically, the odds of being in Segment 2 decrease by 54% for each scale point increase in *Safety* (.46 - 1 = -.54). The odds also decrease by 43% for each scale point increase in *Incentive prone* (.57 - 1 = -.43). Perceptions of TV as a behavioral trigger (*TV activated*) and the importance of viewing body language when playing poker (*Body language*) had no significant effect.

6. Discussion

We have provided evidence that two monetary incentive cues frequently featured in online, but not offline, poker promotions (rake rate and matching bonus) influence offline gamblers' willingness to join an online casino. Further, our exploratory mixture regression models revealed two distinct segments.

Segment 1 is relatively willing to sign up for online poker and exhibits independent responses to the rake rate and matching bonus cues (higher willingness to join for lower rake rakes and higher matching bonuses). In contrast, Segment 2 is relatively unwilling to sign up for online poker but exhibits greater willingness when a higher matching bonus is combined with a low rake rate. Further analyses show that the distinction between Segment 1 and Segment 2 is associated with differences in the perceived safety of online poker and differences in responsiveness to marketing incentives in general.

Our results are broadly consistent with SDT and the notion that some players interpret monetary incentives as empowering while others view them as controlling. Players who value matching bonuses regardless of the rake rate (Segment 1) may frame such incentives as an exciting and "free" opportunity to have more fun and hone their skills (Brown, 2006). In contrast, players who only value a matching bonus at low rake rates may view monetary incentives as an attempt to control their behavior and may be skeptical about online casinos' motivations (Wood & Griffiths, 2008; Weathers, Swain, & Makienko, 2015).

7. Limitations and Future Research

While experimental designs allow for enhanced control over variables in a causal flow, as well as factors considered extraneous to this flow, they do have some natural limitations.

First, the respondents had to imagine being in the scenarios. The fact that we recruited active gamblers at poker tournaments somewhat assuages this concern. Nevertheless, the scenarios represented hypothetical rather than actual invitations to join an online casino to play poker.

Second, by being asked to consider the online casino, the notion of playing poker online may have become more salient than it would be otherwise. Of course, elevating salience in such a manner is actually one of the key objectives of email marketing promotions but we acknowledge that many such promotions are never opened by recipients in natural contexts.

Third, the relatively small sample size precluded discovery of smaller or niche segments of potential online poker players. Accordingly, we cannot rule out the possibility that some players respond to rake rates and matching bonuses in ways that are systematically different from the profiles of Segment 1 and Segment 2.

A promising avenue for future research would be to examine offline players' downstream responses to online casino promotions, including perceptions of website usability and interactivity. Such research may also examine players' patterns of technology appropriation and subsequent feelings of social identification or psychological ownership of the website (Kirk, Swain, & Gaskin, 2015).

We recommend testing alternative ways of presenting numerical cues in online casino offers. For example, prior research finds that consumers tend to perceive relative quantities (e.g., rates and percentages) "as if" they were absolute quantities (Weathers, Swain, & Carlson, 2012). It is possible that different framings of the same information could impact a players' sense of self-determination.

Finally, future research may consider different types of incentive programs such as "reload bonuses," which focus more on retention of existing players rather than the acquisition of new players. By combining behavioral and archival data with managerial judgments, researchers could estimate response functions for online poker incentives and determine the optimal allocation of a fixed budget across customer acquisition and

retention efforts to maximize overall customer lifetime value (Swain, Berger, and Weinberg, 2014).

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The Use of Taguchi Methods in Robust Design

J. S. Sutterfield[1]
Ashley N. Robinson[2]
[1]*Florida A&M University*
[2]*Florida A&M University*
pisces4914@earthlink.net

Abstract

Robust design is a concept that became current in the late 1980s in connection with minimizing the influence of variations in a manufacturing process upon the quality of the products that it produces. In this paper, we demonstrate the use of Taguchi's experimental method to select the optimal parameters for a manufacturing process that produces integrated circuit components.

1. Introduction

Design of experiments (DOE) is widely used in research to quantify cause-and-effect relationships between factors and results. DOE methods provide a vehicle in which exposes the interaction between factors, turning a standard design into a robust design. In identifying the effects of multiple factors simultaneously and its influence on yield, quality and productivity improvement in a product or process can be demonstrated through the use of variation reduction. This method is based on the technique of robust design developed by Professor Genichi Taguchi, a Japanese expert on quality (Shoemaker and Kackar, 1986). The use of Dr. Taguchi's approach through robust design serves as an effective quality tool for improving product and process quality at reduced costs. Robust design reduces variation by reducing the sensitivity of a design to the main sources of variation, without eliminating the effects of the variation. Taguchi realized that the best opportunity to eliminate variation is during design of a product and its manufacturing process (Hadjis, 2011). Because of this approach, the Taguchi Methods have been widely employed to improve industrial production, and the practical applications for these methods are almost limitless. Experimental methods may be applied to any process defined by a set of input parameters which can be adjusted to yield some output with characteristics dependent upon the input parameters. For the many instances of applicability see Taguchi (1988).

To define robust design more precisely, robust design involves the interaction of control factors and noise factors within a product or process. Control factors are variables with levels that are adjustable, whereas noise factors are variables with levels that are hard or impossible to control during normal conditions, such as environmental conditions and raw-material properties (Angelopoulos, Drosou and Koukouvinos, 2013). To investigate the quality of a process based on its control factors and noise factors, a design approach combining both types of factors within a matrix can be employed. This approach is known as orthogonal arrays. An example of an orthogonal array can be found in Table 1.

Table 1. Example orthogonal array - L_8 (2^3)

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

Orthogonal arrays have played a vital role in the development of the Taguchi Methods. The application of orthogonal arrays or otherwise interpreted as a mixed level array, is a highly fractional factorial design. The objective of orthogonal arrays is to examine the interactions of multiple factors in a combined technique. The composition of an orthogonal array is formed by the number of runs, factors, and levels. The rows of an orthogonal array represent the number of runs or the experiments to be performed, while the columns represent the different factors to be studied. The level in the orthogonal array is the number of levels set for each factor. The orthogonal array approach is an expansive approach, combining multiple factors at set levels in order to determine the resultant outcome of the combined interactions. Obviously, even with a moderate number of factors and a small number of levels for each factor, the number of possible level combinations for the factors increases rapidly (Hedayat, Sloane, Stufken, 1999).

It is difficult to overstate the significance of experimental methods in solving problems in which some critical property(ies) of a production item must be precisely and consistently reproduced in order that the item perform its function consistently. Experimental methods make it possible to identify those factors affecting such a critical property, and the ranges within which they must be controlled, in order to consistently produce items with optimal values of the critical property within narrow ranges. Thus, experimental methods make it possible to produce items that perform their intended function consistently, while maximizing production yield and minimizing cost.

This paper examines the use of Taguchi's methods in robust design through the application of orthogonal arrays. A detailed experiment is employed, analyzing a set of control factors against the uniformity of the thickness of a silicone layer in wafers used for optical filters. Taguchi's approach, viewed as nonconventional or a modified approach to DOE methods is compared to the classical approaches its foregoing pioneers. This paper further outlines both classical analysis and Taguchi's analysis and its application on experimental designs.

2. Literature Review

This literature review examines a few of the contributions made to the DOE field. With much research on the application of DOE methods, its originator and followers have helped shed insight on the emergence of DOE and its initial use to a more current modified approach used within industry today. These contributions have helped shaped the DOE field, providing answers to improving product and process quality and performance through input-output relationships.

Much contribution to the experimentation field is attributed to Sir Ronald A. Fisher. Fisher's principles of DOE have laid the foundation to statistical designs in experiments. He formed his research on the statistics of small samples, contending this approach was more viable than previous models made by his pioneers in this field. Fisher's objective was applying statistical experiments accurately to mathematical data, whereas earlier research made " … assumptions as to the distribution of the unknown population parameters" (Sutterfield and Lewis, 2010). This insight revolutionized the entire field of experimental analysis (Sutterfield and Lewis, 2010), leading Fisher's successors to extend research in this field and later to find a Japanese

scientist, known as Dr. Taguchi, to modify the DOE approach.

In the late 1940s and early 1950s, W. Edwards Deming, made much contribution to the quality movement. Deming's influence to the quality movement was pillared by a struggling Japanese economy after World War II. His ideas were adopted by the Japanese in order to shift the Japanese industrial production from its current despair into economic reform, by using quality and low cost metrics. His approach to rebuilding the Japanese economy was introduced by the concept of statistical methods, particularly statistical control quality. Deming popularized his quality-control concept during this period and in subsequent successes among the Japanese industry. This concept helped institutionalize a newly formed Japanese industrial base, by implementing quality measures early on in the manufacturing process as opposed to assessing quality during the final production phase.

Another approach to quality improvement was introduced by Dr. Taguchi. In the 1940s, Taguchi began to research with DOE and identified areas of development in its current application. His approach is a new experimental strategy in which he utilizes a modified and standardized form of DOE (Roy, 2001). In other words, the Taguchi approach is a form of DOE with special application principles (Roy, 2001). Taguchi found not only could DOE methods improve quality but, also resulted in cost savings. Taguchi's contributions to this field extend from Japan in the 1940s to the United States in the early 1980s and have served as an effective quality technique for diverse industries. Although many other Japanese scientists have made many substantial contributions to the field of experimental method, it is Taguchi, more than any other, who has advanced this area of science, and after whom the field has been named as "Taguchi Methods" (Sutterfield and Lewis, 2010).

Whether it is a product or process, classical DOE approaches or Taguchi Methods can be applied to an experiment. This literature study has shown that "By combining and blending strategies that work in unique situations, industry can do much better than by following only one approach" (Launsby, 1994). As demonstrated by Dr. Taguchi's modified approach to DOE, the application provides a design for determining factors and their interactions in order to obtain quality at a low cost. While DOE establishes the framework for Taguchi Methods, the orthogonal technique used by Taguchi, aids in the reduction of the number of experiments and lessens sensitivity in the factors involved. This approach helps to generate credible experimental data within the interactions between factors at their specified level. The application of Taguchi Methods has proven to be successful in industry, cutting costs and improving productivity. Taguchi Methods demonstrate that although there has been extensive research in the broader field of DOE, there remains a need for a flexible and adaptable approach that helps to optimize experiments and their resultant outcomes.

3. Methodology

Although the method employed for a specific experiment may differ from one application to another, the philosophy and approach of experimental methodology are the same no matter which application the analysis of experimental results might be applied. Thus, the experimental methodology is identical whether classical analysis or Taguchi analysis is used. Although the experimental method has been discussed in detail by its pioneers (Kempthorne, 1967; Box et al., 1978), as well as a previous work by one of the current authors (Sutterfield et al, 2005), it is herein repeated for the convenience of the reader.

1) A detailed but concise statement of some problem as determined by observing some phenomenon;
2) Formulation of a working hypothesis to explain the cause of the problem. This hypothesis must be capable of experimental verification or falsification

(Popper, 2002, and 2004) to explain the phenomenon;
3) Conceiving, designing and planning an experimental technique capable of verifying or falsifying the hypothesis from "2" above;
4) Examination of possible experimental outcomes with respect to the original purpose(s) for the experimental inquiry to ensure that the experiment will provide the desired information;
5) Consideration of the possible outcomes with regard to the statistical procedures used to obtain them to ensure that the necessary conditions for using these statistical procedures are satisfied;
6) Performance of the experiment;
7) Application of statistical analysis techniques to the experimental results;
8) Drawing conclusions as to the true values of estimated parameters, along with the reliability of the estimates, while giving careful consideration to the validity of conclusions for the population of objects or events to which the estimates may apply;
9) Confirmation or falsification of the original hypothesis; if a hypothesis is falsified, return to step "2" above for modification of or complete reformulation of the original hypothesis, and repetition of steps "3" thru "9;"
10) Evaluation of the present investigation with reference to other investigations of the same or similar problems.

It will thus be observed that the method outlined above is merely the scientific method adapted for statistical analysis. To expand just a bit upon steps "3," designing and planning an experiment involves identifying the entity of interest, that which is to be investigated, called the *response factor*. Further, it is necessary to identify all possible entities that may affect the response factor. These entities are called the *control factors*. The values of the control factors are systematically changed to determine the effect of each, with possible interactions, upon the response factor.

As part of the planning process for an experiment, an orthogonal array, as described above, is selected of sufficient size to accommodate all of the possible control factors, as well as their interactions. This array literally provides a template for systematic variation. We say a template because each control factor, or interaction of control factors, is assigned to a column of the orthogonal array. Further, this array will have a certain number of rows, which are equal to the number of individual runs that must be conducted in order to isolate the effect of each individual control factor, and the effects of its interactions with other control factors. Further, each row of the orthogonal array contains a number indicating the level at which the control factor is to be set for a particular run, the run number being indicated by the number of the row. Before the experiment is conducted, the row numbers are randomized to eliminate any systematic effects that might develop during execution of the experiment. Control factor effects are measured as variances of the response factor, and the experiment is aimed at accounting for all experimental variation.

Once the experiment has been completed, the experimental results are arranged in an analysis of variance table. Then each control factor variation is determined either to be significant or insignificant as to its effect upon the response factor. Significance, or lack thereof, is determined using an *F-test* for the desired level of confidence, usually 95% ($p = 0.05$). Finally, it is typical of Taguchi that the percentage of the response factor effect attributable to each control factor is computed and entered into the table.

4. Application of Methodology

For the instant experiment, the following factors were believed to be relevant to a uniform thickness of the silicone layer on the optical wafer, and were therefore selected as control factors. These are shown in Table 2.

Table 2. Control factors with settings

Identifier	Control factor	Reference setting	Initial test setting:1	Second test setting:2
A	Susceptor rotation method	Oscillating	Continuous	Oscillating
B	Wafer identifier	-----	Type I	Type II
C	Deposition temperature (^{0}C)	1,215	1,210	1,220
D	Deposition time	Low	High	Low
E	Arsenic flow rate (%)	57%	55%	59%
F	Hydrochloric acid etch temperature (^{0}C)	1,200	1,180	1,215
G	Hydrochloric acid flow rate (%)	12%	10%	14%
H	Nozzle position	4	2	6

In choosing an array when a number of control factors are to be tested, it is sometimes necessary to make some trade-offs between the amount of information obtained and the size of the experiment. Consequently, it is often necessary to omit those interactions of higher order than first so that the complexity and size of an experiment are manageable. When this is necessary, an experimental design is often used called the Fractional Factorial, or as Dr. Taguchi terms it, Interactions Partially Omitted. When a fractional factorial is used, the higher order interactions, usually above the first order, are in effect combined with the error term. Thus, information in the higher order terms is surrendered in order to make the size of the experiment manageable. For example, in the present case with 8 control factors, to obtain all principal effects, along with all possible interactions and the experimental error, an orthogonal array with 256 columns would be required. In practice, this is usually quite satisfactory because interactions higher than first order are usually inconsequential (Taguchi, 1988, Vol. 1). Should a particular experiment violate this heuristic, the analysis of results would disclose it and it would then be possible to recast the results in an orthogonal array with more columns. Thus, the higher order interactions could be recovered to the extent necessary to obtain reliable results. For this reason, a fractional factorial design was chosen for the instant experiment.

For reference purposes, an initial run was performed at the reference settings shown in the table. The initial and second test settings were then chosen to be approximately equidistant to either side of the reference settings. These control factors were then assigned to the orthogonal array as shown in Table 3 below.

Table 3. Orthogonal array with column assignments for control factors

No.	Run number	1 A	2 B	3 AxB	4 C	5 AxC	6 BxC	7 D	8 E	9 AxE	10 BxE	11 F	12 CxE	13 G	14 H	15 e	Layer thickness (μ-meters)	Coded data
1	13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14.821	-0.321
2	8	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	14.888	-0.388
3	12	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	14.037	0.463
4	9	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	13.880	0.620
5	4	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	14.165	0.335
6	15	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1	13.860	0.640
7	16	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1	14.757	-0.257
8	3	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2	14.921	-0.421
9	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	13.972	0.528
10	14	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	14.032	0.468
11	5	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	14.843	-0.343
12	10	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	14.415	0.085
13	11	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	14.878	-0.378
14	2	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2	14.932	-0.432
15	7	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2	13.907	0.593
16	6	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1	13.914	0.586

It is to be noted that an L_{16} array, such as that in Table 3, can be extended to only 15 orthogonal columns to take into account first order and higher order interactions among control factors. Thus, an L_{16} array is adequate to accommodate 15 control factors at two levels, with no columns remaining for higher order interactions or experimental error. At the other extreme, an L_{16} array can accommodate only four control factors with all possible interactions, again with no column remaining to capture experimental error. In the initial design of this experiment, however, it was believed that no interactions higher than first order would be significant. Consequently, the L_{16} was adapted to 8 control factors and their first order interactions only, and allocating column 15 to capture experimental error. It should be noted that the last column, that of "Coded data," was obtained by deducting a working mean of 14.5 from each

of the values in the column titled "Layer thickness." This was done to obtain more precision in the calculations. Using the information in this orthogonal array, the calculations in the next section were performed.

5. Results

First, we calculate the *correction factor* for the response variables. This is simply the square of the sum of the response variables divided by 16, the total number of response variables. This calculation is performed as follows …

$$CF = \frac{(\sum_{i=1}^{16} X_i)^2}{16} = \frac{(0.321 + 0.388 + \ldots - 0.593 - 0.586)^2}{16} = 0.198$$

The total variation is obtained by summing the squares of the coded values in each of the two columns labeled "RV," and deducting the square of the sum of these divided by 16, the number of coded values. This is illustrated in the following calculation:

$$S_T = X_1^2 + X_2^2 + X_3^2 + \ldots + X_n^2 - CF$$

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

$$S_T = (0.321)^2 + (0.388)^2 + (-0.463)^2 + \ldots + (0.432)^2 + (-0.593)^2 + (-0.586)^2 - 0.198$$

$$S_T = 3.262 \qquad (f = 15)$$

The effect for a given control variable is obtained by summing the values of the response factor for the "2s" in a given column, summing the values of the response factor for the "1s" in the column. Next, these sums are added and then squared. The result is then divided by 16. The result of the calculation for an effect is known as the variation for a particular control variable. For an L_{16} (2^8) orthogonal array with repetitions such as ours, the variation for any control variable may be written as …

$$S_{CV} = \frac{[(\Sigma RV_2) - (\Sigma RV_1)]^2}{16}$$

where …

RV_1 – the value of the response variable at the low level of the control factor in question

RV_2 – the value of the response variable at the intermediate level of the control factor in question.

This computation is illustrated for control factor A, the *Susceptor Rotation Method*, as follows:

Σcoded values corresponding with "2s" in column for A) = -0.671

Σcoded values corresponding with "1s" in column for A) = -1.107

$$S_A = \frac{[(-0.671) - (-1.107)]^2}{16} = 0.012$$

The variations for the remaining control factors and their interactions were calculated similarly. The error term was calculated in the manner just outlined. The experimental error calculated by deducting the sum of the control factor variations, along with their interactions, from the total variation, S_T. This approach is shown by the following equation:

$$S_e = S_T - S_A - S_B - \ldots - S_H - S_{AxB} - S_{AxC} - \ldots - S_{CxE}$$

It should be noted higher order interactions involving 3, 4 and 5 factors are possible. As noted in "Application of Methodology," It was believed at the onset that such interactions would prove negligible, and so no provision was made in the experiment to examine these. Subsequent results proved this assumption to be correct. When these higher order interactions are negligible, as is the case in this experiment, their combined effect will end up in the error term, as previously explained. The results of these calculations are shown in Table 4.

Table 4. Analysis of variance for wafer production process

Source	*f*	*S*	*V*	$F_0(95\%)$	*S'*	*ρ*
A	1	0.012	0.012	-----	-----	-----
B	1	0.012	0.012	-----	-----	-----
AxB	1	0.005	0.005	-----	-----	-----
C	1	0.048	0.048	-----	-----	-----
AxC	1	0.022	0.022	-----	-----	-----
BxC	1	0.003	0.003	-----	-----	-----
D	1	2.796	2.796	190.11	2.781	0.91
E	1	0.018	0.018	-----	-----	-----
AxE	1	0.000	0.000	-----	-----	-----
BxE	1	0.009	0.009	-----	-----	-----
F	1	0.014	0.014	-----	-----	-----
CxE	1	0.005	0.005	-----	-----	-----
G	1	0.038	0.038	-----	-----	-----
H	1	0.080	0.080	5.47	0.066	0.02
e	1	0.004	0.004	-----	-----	-----
(e)	13	0.191	0.015	-----	0.221	0.07
Total	15	3.067			3.067	100.00%

Now, consulting a table of *F* values (Taguchi, 1988) for a 95% confidence level with 1 degrees-of-freedom for the numerator and 16 for the denominator, yields a critical value of 4.49. Thus, control factor D, *deposition time,* and control factor H, *nozzle position,* prove to be the only significant control factors at the 95% level. Further, it will be seen that there are no significant interactions between any of the pairs of control factors. As a matter of good practice in experimental method, once the significant sources of variation are identified, The ANOVA table is condensed to include only the significant sources of variation. Consequently, Table 4 has been modified as shown in Table 5.

Table 5. Modified analysis of variance for wafer production process

Source	*f*	*S*	*V*	$F_0(95\%)$	*S'*	*r*
D	1	2.796	2.796	190.11	2.781	0.91
H	1	0.080	0.080	5.47	0.066	0.02
(e)	13	0.191	0.015	-----	0.221	0.07
Total	15	3.067			3.067	100.00%

It will be seen that the *deposition time* is significant at almost the 100% level, and accounts for 91% of the total variation. The *nozzle position* at well above the 95% level, and accounts for 2% of the total variation. Error variation accounts for the remaining 7% of the total variation. Further, there is no interaction between these two control factors. Thus, it is only these two control factors that will require optimization in the robust design process. Further, since these two control factors are independent of each other, as well as the other control factors, they may be optimized separately to arrive at the robust manufacturing conditions.

Ideally, sufficient data would be available to construct a plot of deposition thickness versus deposition time. However, since only two levels for the control factor D, *deposition time* were obtained, it is necessary to perform a linear interpolation within the deposition time interval used for the experiment. In general, such interpolations are not preferred, but in this case only two points are available, and the interval is narrow. Thus, the results should yield a relatively correct estimate of the true value. If the average response to the first deposition time is calculated, it will be found to be 14.807 □-meters; and for the second deposition time an average response of 13.971 □-meters. A linear interpolation within this interval will show 14.5 □-meters, the desired deposition thickness, to be at approximately 36.7% of the interval between the first deposition time and the second. Although no actual deposition times are given in the original data, this result would indicate that the first deposition time would have to be decreased by approximately 36.7% of the interval between the first and second deposition times. This adjustment would move the average thickness response from a current value of 14.389 □-meters to the desired optimal thickness of 14.5 □-meters. With this new deposition time setting the response for deposition thickness (DT) 95% of the time will be …

$$\boldsymbol{DT = 14.5 \pm \sqrt{F_{13}^{1}(0.05) * \frac{V_e}{n_e}}}$$

$$\boldsymbol{DT = 14.5 \pm \sqrt{4.67 * \frac{0,191}{16}}}$$

DT = 14.5 ± 0.24 μ-meters

The data for *nozzle inclination* indicate that increasing nozzle inclination increases deposition thickness. The average deposition thickness for the first nozzle setting, an inclination of 2° from the vertical, results in a deposition thickness of 14.318 μ-meters, while that for the second nozzle setting, 6°, results in a deposition thickness of 14.460 μ-meters. It will thus be seen that the optimal thickness of 14.5 μ-meters lies outside the interval between the first and second nozzle settings, and a small extrapolation will be required to compute the optimal nozzle setting. This extrapolation will show that 14.5 μ-meters is approximately 128.2% of the interval between the first and second nozzle settings. This in turn indicates that for an optimal deposition thickness of 14.5 μ-meters that the nozzle setting should be approximately 7.1°. With this new deposition time setting the response for deposition thickness 95% of the time will be …

$$\boldsymbol{DT = 14.5 \pm \sqrt{F_{13}^{1}(0.05) * \frac{V_e}{n_e}}}$$

$$\boldsymbol{DT = 14.5 \pm \sqrt{4.67 * \frac{0,191}{16}}}$$

DT = 14.5 ± 0.24 μ-meters

When both the new *deposition time* and *nozzle inclination* settings are implemented, the response for deposition thickness 95% of the time will be …

$$\boldsymbol{WT = 14.5 \pm \sqrt{(0.24)^2 + (0.24)^2}}$$

WT = 14.5 ± 0.34 μ-meters

Thus, with these new control variable settings, the response variable of deposition thickness will range between 14.16 μ-meters and 14.84 μ-meters 95% of the time.

6. Conclusions

The foregoing analysis has analyzed a set of eight control factors thought to affect the uniformity of the thickness of the silicone layer in wafers used for optical filters. It was determined that only two of these control factors had any significant effect upon the response factor, uniformity of the thickness of this silicone layer. These two factors, *deposition time* and *nozzle inclination,* were found to affect the uniformity off thickness: Both were found to be significant above the 96% level. Further, no interaction was found between these two control factors. This was an important result because it meant that these two factors might be optimized independently, without a change in one affecting the value of the other.

Then, in keeping with robust design principles, values were independently determined for these two control factors to re-center them so that the mean of each process was 14.5 μ-meters. With the new control factor settings, the mean thickness of the silicon layer was determined to be 14.5 ± 0.24 μ-meters. This means that 95% of optical wafers manufactured would have thicknesses between 14.16 and 14.84 μ-meters.

In order to verify these new control factor settings, another brief experiment would be necessary with each of these significant control factors varied over a minimum of three levels, and preferably four, to confirm that the new settings are correct. This could be done using an L_9 (3^2) or L_{16} (4^2) orthogonal array. The results could then be analyzed using orthogonal polynomials to isolate the components of variance. Such an approach would allow plots to be made for the response factor as a function of each of the two control factors. In this way, the new settings for each of the control factors can be verified as optimal.

Finally, it might prove necessary to adopt 6-σ processes to produce these optical wafers. It is true in general that the greater the process capability, in relation to the product specifications, the more robust the process.

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A Lean Six Sigma Project on Writing a Lean Six Sigma Textbook

Wei Zhan[1]
[1]*Department of Engineering Technology, Texas A&M University, College Station, TX 77843.*
wei.zhan@tamu.edu

Abstract

The Electronic System Engineering Technology (ESET) program started offering ESET 329, Six Sigma and Applied Statistics, at Texas A&M University in the Fall semester of 2012. Students in the class are required to complete a Lean Six Sigma project in the course. In 2014, the instructor planned to write a textbook for this course. Students enrolled in ESET 329 in the Spring semester of 2015 chose to work on the improvement of the textbook. They followed the DMAIC process to come up with suggestions for improvements on the textbook contents and the process. The project goals were defined with specific metrics developed to measure the quality of the textbook. Voice of customer collected through survey and brainstorming sessions was analyzed. The draft of the manuscript was thoroughly studied by the student teams with several statistical measures taken during the process. Problems with the draft manuscript were analyzed, which led to suggestions for improvement. The performance metrics were compared for before and after the implementation of improvement suggestions. This project provided students with first-hand experience in Lean Six Sigma, it also made the textbook a much better one.

1. Introduction

Six Sigma is a popular tool used in industries for process improvement (Harry and Schroeder, 2000; Pande and Holpp, 2002). Lean manufacturing was introduced by Toyota to eliminate waste in a process (Womack *et al*, 1990). The combination of Lean and Six Sigma proposed by George (2002) brought tremendously successful applications to industry, health care, service sectors, government agencies, and other areas. Lean Six Sigma is a structured, data-driven, quality control methodology that uses statistical analysis to improve processes (Nonthaleerak and Hendry, 2006; Snee, 2004; George, 2002).

There have been increasing needs to educate the workforce with knowledge in Lean Six Sigma. Driven by the demand, many higher educational institutions started to look into the possibility of offering Lean Six Sigma courses in their curricula (Coowar *et al*, 2006; Furterer, 2007; Gore, 2004; Ho *et al*, 2006; Rao and Rao, 2007; Scachitti *et al*, 2008).

These curricular modifications were typically made by industrial engineering, manufacturing engineering, or corresponding engineering technology departments (Furterer, 2007; Scachitti *et al*, 2008). However, in recent years, the demands from industry are also driving other engineering technology (ET) programs to offer courses in Lean Six Sigma (Zhan and Porter, 2010; Zhan *et al*, 2009).

Statistics is a critical component in Six Sigma. As a part of the Lean Six Sigma process, the use of statistics in engineering design, testing, and problem-solving is becoming increasingly important for companies to stay competitive in the global market. The enhancement of the education on statistics has been discussed over the last three decades (Bart *et al*, 1998; Bryce, 1993; Fernández de Carrera, 2006; Godfrey, 1986; Hogg, 1991; Hogg, et al, 1985; Mills, 2002; Romeu, 1986; and Standridge and Marvel,

2002). In particular, how to effectively teach engineering students statistics has been a major research topic (Snee, 1993).

Incorporating statistics and Lean Six Sigma into the curricula has been a challenge for the ET community. There have been many such attempts (Furterer, 2007; Gore, 2004; Scachitti *et al*, 2008). The increase in number of publications in the ASEE annual conferences in the relevant areas from 22 in 1998 to 174 in 2007 (Scachitti *et al*, 2008) clearly indicates the research interests in this area. It is also reflected in the readers' interest in statistics: A paper published in the American Journal of Engineering Education on teaching statistics to ET students has remained in the top of most frequently downloaded papers list over the past six years (Zhan *et al*, 2010).

For programs such as industrial engineering technology and manufacturing engineering technology, there is more flexibility to accommodate Lean Six Sigma in the curriculum. Scachitti *et al* presented their curriculum change effort to add Lean Six Sigma to the industrial ET program at Purdue University Calumet, Indiana University Purdue University Indianapolis, and Purdue University West Lafayette (Scachitti *et al*, 2008). They modified several courses and added new courses to incorporate the Lean Six Sigma contents into the curriculum. This required a significant amount of effort from the faculty. Through a $1.2M training grant, faculty worked with a local health care system and brought the real life project experience into the classroom to benefit their students. These successful stories motived the faculty of the Electronic Systems Engineering Technology (ESET) program to move forward with the curricular enhancement in the area of Lean Six Sigma.

Starting in 2007, the ESET program at TAMU experimented with different ways of teaching statistics and Six Sigma to ET students. First, Six Sigma was used in course projects in an instrumentation course (Zhan and Porter, 2010; Zhan *et al*, 2009). More efforts followed to incorporate similar content into other courses within the ESET program (Zhan et al, 2010). These were done within existing courses and the revisions to the curriculum were limited to two courses. There were no significant changes in the learning objectives in these courses. Therefore, no official course change requests were needed. The individual faculty members implemented these revisions to their courses. However, considering the importance of statistics and Lean Six Sigma to ESET students, these efforts are far from sufficient.

ESET students used to take a statistics course offered by the Statistics Department. However, the course was taught to all engineering students, therefore, it couldn't address the unique needs of ESET students. ET students have a unique learning style, they learn better when the knowledge is applied in practical design and analysis. Therefore, laboratory and course projects are critically important.

In the summer of 2012, ESET faculty had a retreat to discuss the program curriculum. It was decided at the retreat that ESET should shift its focus to product development (Porter *et al*, 2012). The need for teaching Lean Six Sigma was brought up because it was a key component in product development. Based on the findings in Zhan *et al* (Zhan *et al*, 2010), it was decided that the statistics course would be eliminated from the list of ESET required courses and a new course ESET 329, "Six Sigma and Applied Statistics," would be offered by ESET.

One of the issues related to the new course was the selection of a textbook. Devore's book was selected (Devore, 2015) for the course. It contains many practical examples that greatly help students understanding of the statistics material. However, Devore's book does not contain Lean Six Sigma contents. The instructor of the course decided to write a textbook for this course.

As a part of the curriculum, students in ESET 329 are required to complete a Lean Six Sigma project. Students enrolled in ESET 329 in the Spring semester of 2015 chose to work on their course project to improve the writing of the

textbook for the course. This paper presents the course project carried out by student teams.

2. DMAIC

The student teams followed the DMAIC process to conduct the course project. They learned the materials from the draft textbook.

Define

Define is the first step of the Lean Six Sigma process. Students used the affinity diagram and brainstorming to determine what aspects of the textbook improvement they should focus on. The majority of teams decided to set the objectives as correcting errors in the textbook and making recommendations for improved readability of the textbook. One team came up with a different objective, they wanted to improve the process of textbook improvement. In other words, they wanted to improve the efficiency of the textbook improvement process.

Specific metrics were defined for performance measurement. For the first group whose objectives were to improve the textbook, their metrics include number of errors corrected per chapter (with a goal of 10 corrected errors per page) and average time for a new reader to finish one page (with a goal of 15% reduction). The second group had an additional metric of editing time with a goal of 20% reduction.

Based on the information collected by the teams, the SIPOC diagrams were created. Fig. 1 shows the SIPOC diagram created by one of the student teams. The current process was captured in Fig. 2.

SIPOC

Suppliers	Inputs	Process	Outputs	Customers
Instructor	Cost info	Read and edit textbook!	Suggestions	ESET professor
Internet	Format Guideline		Corrections	Other pofessors
Library	Page limit		Clarifications	Publisher
Students	Student feedback		Revised manuscript	ESET students
Publisher	Instructor needs		Book contents	Other students
Practioners	Timeline req.			Practioners

Figure 1. SIPOC diagram

To understand the customer needs and what the team should do to improve the process, a CTQ tree was created, as illustrated in Fig. 3.

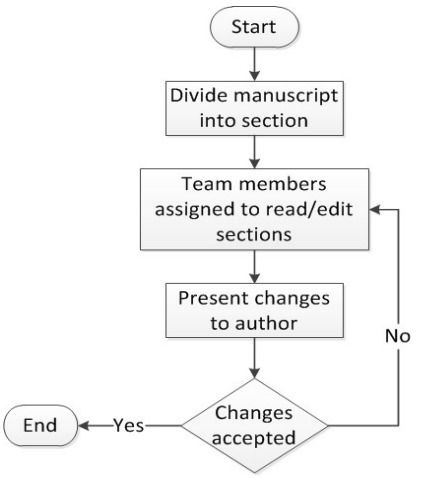

Figure 2. Current process

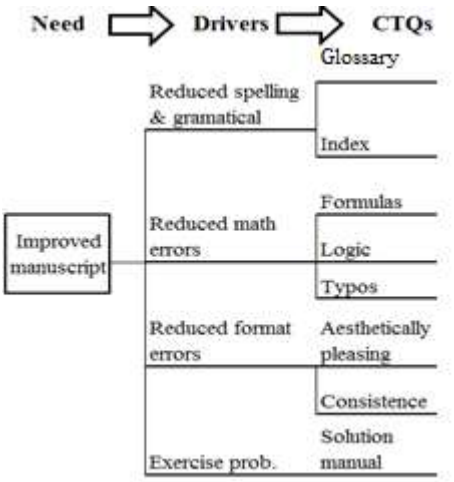

Figure 3. A CTQ tree

Measure

Student teams used one or two chapters of the manuscript to establish a baseline measure. All team members read the chapter(s) and recorded the time they spent, number of errors identified, and their suggestions for improvement. A sample measurement data set is shown in Fig. 4.

Type of errors	Student 1	Student 2	Student 3
Page number errors			
Problems			883,911
Grammaticals	142,151,162,987,1062, 1297,1975	812,853,856, 213,338	483,493,650,674,682 ,683,704,903,908
Sentence structure	141,142,151,152,196,1 96,197,999,1050,1238	815,861,330, 345	489,510,634,856,858 ,859,861,872,899
Technical writing	190,190,193,247,1075, 1112,1130,1171,1178	352	501,359,704,929
Graphics			920,932
Unclear ideas	259		828
Misc, typos, spacing	1664,1967,1972,1978	368,390,405, 449,458,473	518,531,591,618,798 ,853,867

Figure 4. Measurement data

Baseline metrics were calculated based on the raw measurement data, as shown in Fig. 5. This particular team focused on the time spent per page and errors found per page as the performance metrics.

Baseline Chapter 2	
Total time spent	645 minutes
Duplicated errors	
Total errors	42
Average time/error	15.36 minutes
Total pages	42
Average time spent/page	15.36 minutes
Average error found/page	1

Figure 5. Baseline metrics

Analyze

Cause-and-Effect diagrams were used by student teams to find the root causes of the problems with the current process. Fig. 6 illustrates a Cause-and-Effect diagram created by a student team.

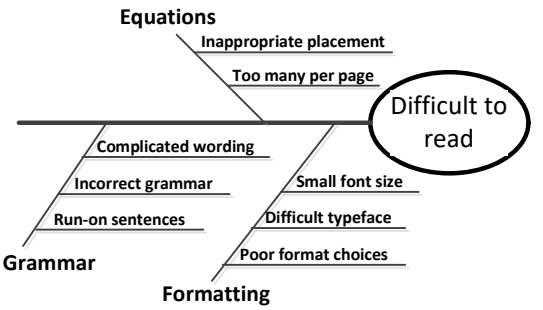

Figure 6. Cause-and-Effect diagram

One team divided the errors into different categories and evaluated each team member in these categories, as shown in Fig. 7.

Index	Error type	No. of errors identified			
		Student1	Student2	Student3	Student4
A	Page No. errors	0	0	0	0
B	Problems	2	0	2	0
C	Grammaticals	21	9	7	4
D	Setence structure	23	12	26	7
E	Techinical writing	14	1	5	1
F	Graphs	2	8	3	0
G	Unclear ideas	2	2	0	0
H	Spacing	17	14	4	10
Total		81	46	47	22

Figure 7. Strength of team members

Based on the measurement data they took in the Measure stage, the team analyzed the strengths of each member with regard to the error categories. They found that certain team members were more efficient in identifying certain type of errors. As one can see in Fig. 8, student 3 was very good in find error type D.

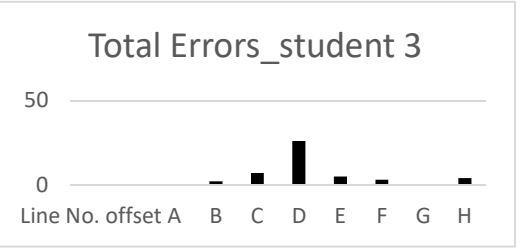

Figure 8. Strength of team members

Some teams tried to use as many tools as they learned in the course as possible. Some may not appear to be appropriate. For example, one team tried to conduct an FMEA analysis. Even though this particular Lean Six Sigma tool might not have helped them in the project execution, they did learn how to use the tool.

Improve

Once the root causes for the problems associated with the current process were identified in the Analyze stage, improvement ideas were proposed by each team.

Some teams proposed to modify the review process so that each member would focus on certain type of errors. One team identified the strengths of each member and then assigned

each member to work on the type of errors that were their strengths. All teams decided that they need to review each member's findings and make a team decision before submitting recommendations to the author.

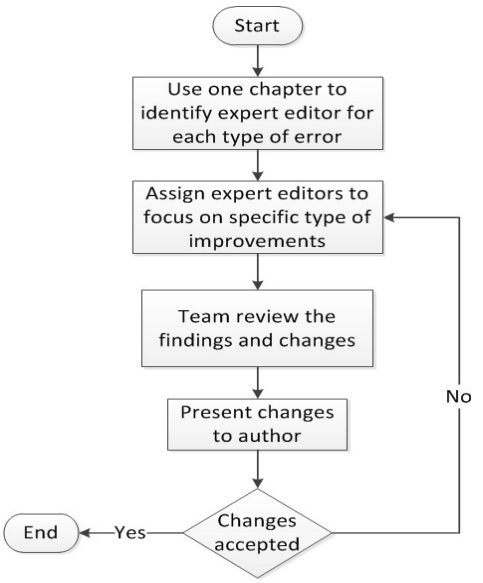

Figure 9. Improved process

The flowchart of one of the proposed improved processes is shown in Fig. 9. Common sense tells us that the new process should be more efficient than the old process. However, this claim must be validated by data.

Control

Each team completed the review of the entire manuscript using their proposed new process. Data such as the time spent per page, average time per error, and errors identified per page were recorded. These data were used to conduct the before-and-after analysis. For example, the baseline performance in Fig. 5 was compared to the performance following the new process, as illustrated in Fig. 10.

Improved process (Chapter 6)	
Total time elapsed	115 minutes
Duplicate errors	5
Total errors	38
Average time/error	3.03 minutes
Approximate pages	8
Average time spent/page	10.45 minutes
Average errors found/page	3.45

Figure 10. Performance of the new process

One team worked on the appearance of the contents. It was difficult to evaluate the improvement. The team relied on a survey from other students to show how much improvement was made. Fig. 11 shows the comparison for an example in the manuscript that was used in the survey.

Before:

Example 2. 14. Let X be a standard normal random variable. Find $P(0.15 < X < 0.63)$.

According to the relationship depicted in Figure 27,

$P(0.15 < X < 0.63) = P(X < 0.63) - P(X < 0.15)$

Using Table 2.1, we can find $P(X < 0.63) = 0.7357$ and $P(X < 0.15) = 0.5596$. Therefore,

$P(0.15 < X < 0.63) = 0.7357 - 0.5596 = 0.1761$.

After:

Example 2.14:
X = Standard Normal Random Variable
Find $P(0.15 < X < 0.63)$

According to *Figure 27:*
$P(0.15 < X < 0.63) = P(X < 0.63) - P(X < 0.15)$

Using Table 2.1 we find:
$P(X < 0.63) = 0.7357$, and
$P(X < 0.15) = 0.5596$, Therefore:
$P(0.15 < X < 0.63) = 0.7357 - 0.5596 = 0.1761$

Figure 11. Before-and-after comparison

Many recommendations were made by the student teams for continuous improvement:

- Future students re-read the textbook and suggest further improvements.
- Continue to collect data for improvement by creating a website for comments and feedback from readers.
- Enhance the book with additional resources such as exercise problems, answers to selected problems, solution manual for instructors, PowerPoint presentations, and glossary.
- Publish a 2nd edition of the book (using the improved process established in this project).

3. The outcome: A new textbook

After one semester's reviewing by the students in the ESET 329 class, a new textbook

was published (Zhan and Ding, 2015). The cover page is shown in Fig, 12.

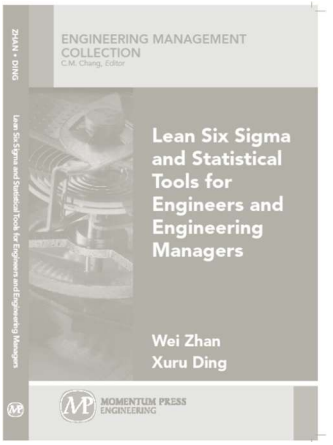

Figure 12. The new textbook

It should be pointed out that the co-author Dr. Xuru Ding, who is an engineer, trainer and Master Black Belt at the General Motors, made significant contributions to the textbook. Her expertise in Design for Six Sigma and case studies from the automotive industry made this book suitable for advanced training for Lean Six Sigma Black Belts.

The textbook contains eight chapters. Chapter 1 is the introduction, it provides a brief history and background information on Lean Six Sigma. The concept of optimal quality cost is introduced. Chapter 2 contains the probability and statistical background necessary for Lean Six Sigma. Chapter 3 discusses the DMAIC process, which is illustrated by a Lean Six Sigma project conducted by a student team. Chapter 4 introduces tools that are commonly used in Lean Six Sigma. Chapter 5 introduces the use of software packages for Lean Six Sigma analysis. Chapter 5 is intended to be used as laboratory materials. Chapter 6 addresses the high-level planning and project execution issues. Chapter 7 contains optional material, for more advanced students or those wanting to become a Lean Six Sigma Black Belt. Chapter 8 contains three case studies based on the authors' real-world design experiences in industry.

One unique aspect of the textbook is that it contains many examples with step-by-step instructions so that readers can easily learn the materials by themselves. This is particularly important for Chapter 5, where Minitab, Excel, MATLAB, and R are used to conduct statistical analysis.

4. Conclusions

This paper discusses a course project in a Lean Six Sigma course, where student teams worked on the improvement of a new textbook. Students followed the DMAIC process to first define the project, followed by data collection for current process performance measurement, analyzing the root causes of the inefficiency of the current process, proposed improved processes, implemented the new process, and did before-and-after analysis to verify that the process is indeed improved. As a result, a textbook was published. This book is currently being used in the same course.

During the course project, students not only learned the material in the manuscript, but also practiced the knowledge they learned to improve the book using the DMAIC process. They made many useful suggestions to make the book much better than the draft version.

Future work includes getting feedback from students using the book, revising the book in preparation for the second edition, creating homework problems and solutions for the instructor, using the book for a graduate course and for continuing education workshops offered to professionals in preparation for their Lean Six Sigma Green Belt certification (Pyzdek, 2003; Wortman *et al*, 2001).

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Process Improvement in the Financial Services Industry

Rachel George[1]
[1]Indiana Tech University
12georger@gmail.com

Abstract

The priority of the project was to eliminate extensive processing time by standardizing the Quality Control (QC) Deposit error report process. The process report included all of the affiliate banks' combined error reports. The process report measured the ranking of the affiliates among themselves by comparing the amount of errors and the error type. Results from the process report went to the Retail Deposit Operations Group showing them what areas need to be improved upon so they could begin training the associates for better results. Improving their systems included various lean tools, such as time studies and the Lean Six Sigma DMAIC method.

1. Introduction

ABC Bank is a community bank based out of Ohio. Their motto states, "We base our service on the simple promises of providing sincere attention, fast service, giving, trustworthy guidance, and being a reliable expert, partner and friend" ("About Us"). This is something ABC Bank strongly stands by. Unfortunately, the Account Services department cannot provide the internal guidance due to the fact that their error report is skewed and misleading.

Their process started when six quality controllers created error reports for each of the eleven affiliate banks. The error report for each affiliate was different because there is no standardization in the report document or bank. Therefore, when collected by the QC manager, not one error report was the same. The affiliates had the required information, but it was in no certain order. When the process report was created, it took several days to take each error report from the quality controllers and then incorporate it into one process report. Then, the QC manager created the process report by going through each error report and trying to copy and paste the sections into one Excel document. Next, they had to go through and try to fix the misspellings of the affiliates' names, error type, account opener, duplicate accounts and incorrect dates. Finally, the QC manager would then manually highlight the accounts that have been in the error report for 30, 60, or 90 days. When completed, the process report was distributed amongst the affiliates to review their comparative results. This shows them how they ranked amongst each other. This information took up to several days to compile. The final result is that the process report ended up being incorrect because the administrator might not catch a typo or incorrect date. This caused their ranking to be wrong, which caused the Bank to focus on the wrong type of error that would have helped train their future and current employees to handle.

The problem consisted of a lack of standardization in the error report and cycle time. The high cycle time was created by the time it took to compile, scrub and standardize the error reports into the ending process report. This meant that they were processing reports that may be skewed and reports that they have no way of validating what areas that needed improvements.

2. Literature Review

The case study shows the necessary steps needed to improve ABC Bank's high cycle time and standardizing their error report. The study is about improving the cycle time and using the Lean Six Sigma DMAIC method to execute.

Case Study: Improving Medical Bill Review Cycle Time

In this case study, one large insurance company executed a Lean Six Sigma project to review a medical bill process for personal injury protection (PIP) and medical payment (med pay) auto insurance coverage (Panigraphi, 2015). They used the DMAIC principles to help solve the company's problems (Panigraphi, 2015).

Defining the problem was their first step. They first identified that the medical bill review process was overloaded with repetitive and inefficient handoffs between the insurance company and its outsourcing partner. This then led to loss of money and time (Panigraphi, 2015). If the review process takes longer than 30 days, they can be hit with major fines due to the legal regulation put in place by that state (Panigraphi, 2015). The company set a goal to reduce the average PIP cycle time and the med pay bill review process from 28 days to 15 days (Panigraphi, 2015).

In the next step, they measured the review process. They did this by first identifying the upper and low control limits and the operational output metric (Panigraphi, 2015). They then created an "as-is map" of the review process (Panigraphi, 2015). This is a current state process map to show each step that the procedure takes. Knowing every step, they created a map that divided the process into two different categories and showed the average amount of time it takes to do each category (Panigraphi, 2015).

In the analyzing stage, they did several diagrams outlining the potential causes of the bill review cycle time related to machines, methodology, providers, measurements, partner operations and internal operations involved (Panigraphi, 2015). They also conducted hypothesis testing, which confirmed that the review response time requirement does impact the actual turnaround time (Panigraphi, 2015).

Improving the processes, the company conducted a process value analysis to identify the non-value-added activities contributing to delays in the bill review process (Panigraphi, 2015). They made a three-column table that gave the categories: Non-value added activities, solutions, and projected savings. After reviewing the improvements they could make, they took the original map from the measuring stage and color coded the steps that they plan to change (Panigraphi, 2015). The new map is called the "to-be" process (Panigraphi, 2015). Creating this aid helped them visualize what steps in the process they are changing to make sure it flows with the steps before and after it (Panigraphi, 2015). Next, they described how they changed it and the areas that will be affected (Panigraphi, 2015).

Lastly is the control stage. The company tested the new process with pilots in a few states initially, and then rolled out a detailed control plan to all states after the success of the pilot (Panigraphi, 2015). The bill review cycle time was reduced from 28 days to 15 days by controlling the items causing variation and delays (Panigraphi, 2015).

DMAIC is used to apply the principles of Six Sigma to existing business processes. Using DMAIC helps to break down the process into component parts (Pande, 2014). Using this Six Sigma model, you would start by defining the problems and project goals, measuring data relating to the current process and analyzing your findings to identify cause-and-effect relationships (Ward, 2006). The next step involves improving existing processes based on your data analysis. Finally, you need to implement controls to avoid variation in the process going forward (Pande, 2014).

There are multiple tools used in Six Sigma to help define what your problem or scope is. CTS' is a tool were basic elements can be used in driving process measurement, improvement, and control ("Handbook", 2004). They are

elements of a process that significantly affect the output of the process. (Green and Furterer, 2016). Another tool is SIPOC. Which explains the customer / supplier relationship in the process. Identifies where the process begins and where it ends, and the activities included within the scope of the process to be improved (Green and Furterer, 2016). Stakeholder Analysis identifies the internal and external customer roles and concerns to ensure their expectations are addressed. Customers and Stakeholders identify internal and external stakeholders involved in the process (Green and Furterer, 2016). Must include owners of the process, those responsible for performing the work, and anyone with a stake in the process (Green and Furterer, 2016). When it comes to analyzing the problem the Why-Why Diagram helps individuals achieve divergent thinking. The purpose of the Why-Why Diagram is to enable individuals and teams to creatively explore and consider numerous causes of a problem by asking why multiple times to get to the root cause (Why-Why). Process mapping helps to truly understand a process, identify challenges and make improvements, the details of the process must be clarified (Wiesenfelder, 2003). Only by creating a detailed process map based on input from those who perform it, and reaching agreement that it does in fact reflect reality rather than expectation, can leaders and project managers gain a full understanding of an existing process (Wiesenfelder, 2003). Often the mere act of creating a process map leads to increased awareness of inefficiencies and related problems (Wiesenfelder, 2003).

3. Model/ Theory Development/ Methodology

Using the information obtained from the cycle time case study, the DMAIC (Define, Measure, Analyze, Improve, Control) method helped minimize the review cycle time of retrieving and implementing the error report and process report. Using this method, the first step was defining the repetitive and inefficient waste time between the QC manager and the quality controller's error reports. A good understanding of their process helped identify the root of the problem. Shadowing several quality controllers and the QC manager were most beneficial. This helped to see how exactly they go about the error report and studying the communication between the two.

Next, the length of time it took to create the process report was measured by conducting a time study. The time study separated the information into sections to determine: how long it took to get the information, how long it took to decipher the information, and how long it took from receiving the information to processing the report. In this step, an "as-is" map was created to show how all factors were connected. Analyzing the potential causes of the high cycle time was next. To do this, a why-why diagram was created to see what the common problem was. These factors included lack of communication, training, and standardization of the error report.

Next, the information was analyzed. Identifying the waste gaps and making observations of the critical errors were crucial. Then, a meeting was scheduled with the QC manager, quality controllers, and affiliate banks to identify the non-value added activities contributing to the high cycle time.

The next step was to review improvements by making a "to-be" map that identified the stages that were changed; making sure that both parties' needs are satisfied in the new error report. The new error report had drop down boxes for each affiliate, operator, error type, and reviewer. The date column had a restriction where the affiliate, putting in the date no longer has the ability be able to enter a date before or after the year 2016. The rows were highlighted depending on the length of time they had been in the error report. When the administrator received the report and compiled them all together, a different tab had several pivot charts showing the variations of errors from the affiliates.

The control stage required conducting a test trial before going to a live environment that ensured everything was working properly. After the trial, a time study was conducted to

determine the efficiencies. Finally, developing a step-by-step procedure was formed to ensure proper training was implemented.

4. Application/ Findings/ Results

In the DMAIC method, the first step was to define the problem. The problem was that the Quality Deposit Account Services department's had eleven different error report spreadsheets that were not standardized and were inconsistently completed for all of the banks. This caused unreliable error percentages because the spreadsheets varied in content. The six quality controllers who made the error report completed their reviews to different levels of scrutiny. It had taken the QC manager 2.5 business days to consolidate the error reports down to one process report. After identifying the problem, setting a goal was key to staying on task, which in this case was: standardize the error reports for all quality controllers, improve data quality, and reduce the time it took to create the process report. Defining the critical to satisfactions (CTS), stakeholder analysis, SIPOC, and the customers and stakeholders were important for the overall project to visually represent what the target was.

in formatting. Some of the examples include the set order of the columns and the location of where they go; color coding was aged information and entered manually. Determining how long the mistake had been in the document was manually color coded and error types were lost in the comments which had to be properly organized.

More mistakes included spelling errors with each column and no ability to get elapsed process time. Due to the corrections the QC manager had to make to create the process report, a time study was conducted to measure the time it took for the overall process and the time it took the QC manager to create the process report from the error reports. A table showing the time values is presented in Table 1. This table shows the various steps in the process which includes two different types of jobs with the times indicating how long it took to do each step. This included eight steps, with a total time of 17.7 hours. Four of those steps were the QC manager and a total of ten hours. The QC manager gave an estimate of approximately four business days for this whole process to be completed. The critical to satisfactions (CTS) that were created in the previous step were put into a table to show how to go about measuring each of the three CTS. While conducting the time study, an "as-is" map was created to show

Table 1. Time of Tasks BEFORE Changes

Tasks	Time (Hours)
Account Specialist pulls up spreadsheet for affiliate bank being quality controlled	.1
Account Specialist completes quality control on account opening documents received	7
Account Specialist saves spreadsheet	.1
Each Account Specialist copies their data into a master spreadsheet	.5
Manager reviews data on master spreadsheet	1
Manager manually creates tables	3
Manager manually sends each affiliate their own numbers	1
Manager compiles metrics report for superiors	5
TOTAL	**17.7**

In the measuring step, studying the old error report was crucial to understand what improvements needed to be made. Examining the old report, one will find that all of the spreadsheets had no consistency

how all of the steps in the time study were connected. The "as-is" map is a visual representation of the process, which helps the employees identify how each step is interlocked with other steps. This step is highly

important so that future improvement ideas may stem from looking at the as-is map and

Figure 1. As-Is Map

seeing the flaws of their process. This is represented in Figure 1.

For the analyzing stage, a why-why diagram was put in place to break down the cause or solution into more explicit elements. This helps to identify root causes related to the employees. The question that was asked was, "Why do we have a lack of data integrity?" Branching off of the question, four sub answers were created. Continuing on asking the question why, this author found that the most common problem occurred was from the lack of training the associates had with the error report or the Microsoft Excel program itself. The other most common problem was that the bank does not enforce standardization. This effected the documents that were used throughout the affiliates and the amount of training for each department. A Why-Why Diagram is presented in Figure 2.

Three improvement ideas were created to ensure success of the new error report were: spreadsheet/report, metrics, and training. In the first category, spreadsheet/report, mistake proofing the error report was crucial. This included: decreased spelling errors, adding data validation to ensure date accuracy, implementing conditional formatting to color coordinate unresolved errors over certain time periods, highlighting duplicates, and including cell formatting to make sure the data was entered in the correct format. In the spreadsheet/report creating formulas to automatically calculate values would reduce data entry and lock all the cells that do not require data entry to eliminate manipulation. The second main category, metrics, was to enhance the metrics by providing review and process times. One could also provide a breakdown of error types by affiliates to help management train on

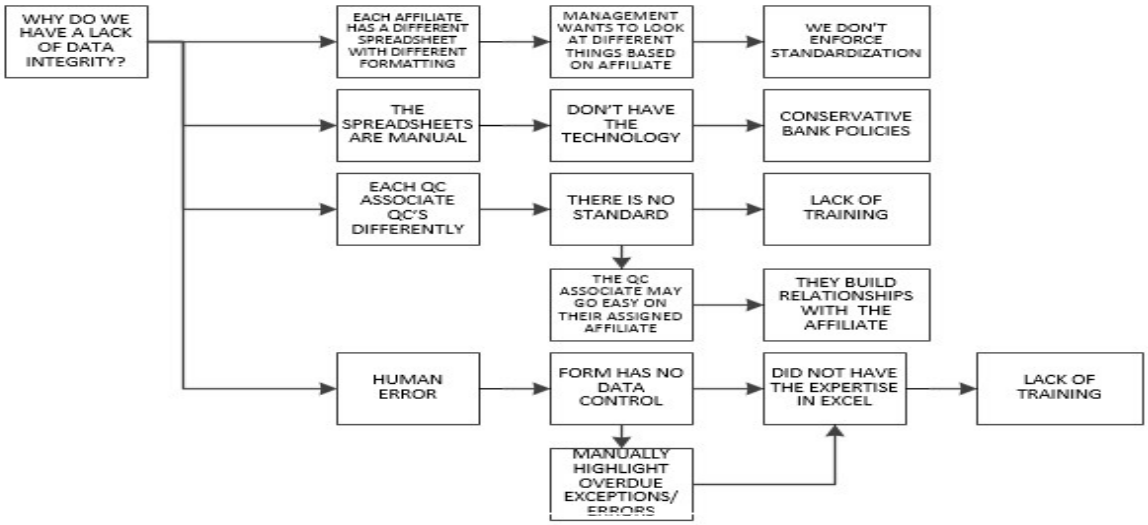

Figure 2. Why-Why Diagram

problem whereas and identify more improvement opportunities. The first and second categories were both provided in the new error report in the same Microsoft Excel document. The metrics consisted of eight different automated pivot tables that would populate with QC metrics which could be refreshed when new information was added to the error report. To accompany the pivot tables were visuals for the management to quickly view the branch error environment. The tables/ metrics were all password protected so that the affiliates can only view certain tabs. The last main category was training. A PowerPoint procedure was created to walk QC associates through the spreadsheet process and visual aid for by the QC manager. After the new error report was created, a "to-be" map was created to show the new step-by-step process. The "to-be" map was created through using the ideas that came from the "as-is" map. The steps in the "as-is" map that were determined to be wasteful steps were eliminated. Figure 3 shows the to-be map.

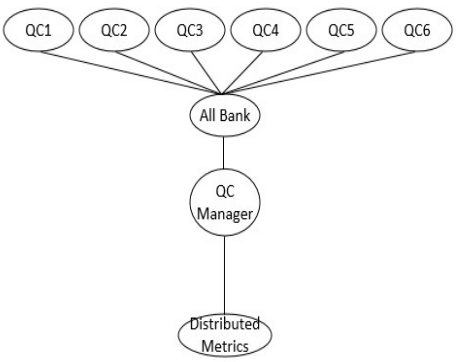

Figure 3. To-Be Map

The eleven affiliate banks no longer were involved and the QC manager doesn't have to waste time consolidating the error reports. Also, a new time study was conducted to see how much time was saved by implementing the new error report. A table showing the updated time values is presented in Table 2. Three steps were eliminated in total and two steps were redefined. Thus saved a total of approximately 9.9 hours of time in the total process. With the new process only being five steps, the total process only takes a total of 7.8 hours. This was a 44% improvement in the overall process time from the previous table to (compared??) Table 2. The QC Manager's process only takes approximately 0.5 days to complete. The QC manager no longer had to reformat all eleven different error reports from the quality controllers.

In the control phase two categories were created: Pilot and Monitoring. In the pilot stage, the QC manager had tested the form on the lead bank for one month and provided feedback for improvements. The spreadsheet was then rolled out to all QC associates, and metrics were provided, which asked for more break out metrics. In monitoring, the QC manager spent more time monitoring metrics than consolidating spreadsheets. Training was based on process times and error rates.

Table 2. Time of Tasks AFTER Changes

Tasks	Time (Hours)
Account Specialist pulls up spreadsheet for affiliate bank being quality controlled	.1
Account Specialist completes quality control on account opening documents received	7
Account Specialist saves spreadsheet	.1
Manager pulls up shared spreadsheets	.1
Manager manually sends out metrics to all recipients (all banks and superiors)	.5
TOTAL	**7.8**

5. Conclusions and Recommendations

An improvement made by the ABC National Bank in the Quality Deposit Account Services department was to combine the eleven different error reports into a universal, standardized error report. The error report document was originally not standardized and contained several human errors, which caused the QC manager to spend ten hours compiling, scrubbing and consolidating them each month. This new document was used across eleven affiliate bank processes which had directly saved the QC manager labor time as well as improved wait time. The new error report created, eliminated 9.9 hours of pure working time. This in turn saved 80% time for the QC manager and 44% for the overall process. This was done by the new standardized error report eliminated human error such as: color coding was not automatic based on identifying criteria, error type was in a drop down, process times can be calculated for review time and error resolution, metrics can be pulled directly from the error report, and all banks and their branches can be filtered. This project was successfully completed; this was clearly shown by the amount of time that was eliminated to do the same task.

Future recommendations would include having mandatory training for all associates who will be working with Microsoft or future software's concerning this worksheet. Since the main problem occurring in the trials were associates lack of knowledge with the basics of Microsoft Excel, this author would highly recommend training to eliminate even further human error and wasting time. Another recommendation this author suggested was to put the error report into an automated software system that will automatically calculate the process report and desired metrics. Since the company had software that the QC Deposit group can access, they should take full advantage of that opportunity. The last recommendation would be to have a solid base of communication with all branches associated with this report so everyone will be able to be on the same page. A solid base of communication was the key to successful results.

6. Acknowledgements

The author would like to thank Dr. Sandy Furterer and Jordan Green for their constant guidance and insight in process improvement.

7. Glossary of Terms:

Quality Deposit Account Services Department - A department that measure and monitor new accounts or existing accounts that have been changed

Error Report- A report that records any errors made when opening or the maintenance of a deposit account.

Process Report- End of the month report created from all error reports. This report shows areas that require additional training of personnel or deficiency in departmental processes.

Quality Controllers- In charge of creating error reports for the affiliate banks.

QC Manager- In charge of taking the error reports from each of the six quality controllers and consolidate into the process report.

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Application of Lean Six Sigma to Improve Inventory Management in an Emergency Department

Tettey, A. H. [1]
Gholston, S. E., Welch, P. [2]
Dyas, S. [3]
[1, 2, 3]*The University of Alabama in Huntsville*
[3]*Huntsville Hospital*
aht0005@uah.edu; gholsts@uah.edu

Abstract

This paper is the result of a continuous improvement effort and best practice approach for inventory management of the emergency department of a local Hospital using Six Sigma and Lean tools in the DMAIC process. The delicate nature of the healthcare operations require that items in inventory are available when needed. It is even more important to ensure that inventory items used are in the right conditions. Whilst ensuring that there are enough inventory items for the anticipated patients, the tradeoff is the temptation to keep more items in inventory than necessary, which eventually results in overinvestment in inventory. Each of the 5 stages of the DMAIC process and the relevant tools were applied and steps towards consistent and efficient process outcome are identified after familiarization with the inventory management system in place at the unit in the fall of 2014. The study concludes with a recommendation to redesign the cart storage system to reduce overstocking of inventory items. There is also the recommendation to change the storage system as a useful and simple approach to quantifying the daily usage of demand, the economic order quantities, and reducing the quantity of expired products.

1. Introduction

For Six Sigma purposes quality has been defined by Pyzdek and quoted in other articles as the value added by a productive endeavor (Kaila, 2005; Pyzdek, 1999; Pyzdek & Keller, 2014). Prior to Six Sigma, TQM was used extensively to improve the quality of processes within a business unit (Klefsjo, Bergquist, & Edgeman, 2006). In contrast to six sigma and lean however, no organization was the origin to the term TQM (Andersson, Eriksson, & Torstensson, 2006). Six Sigma which focuses on accomplishing minimum defects originated from Motorola whilst Lean which focuses on improving and reducing the variations in the process flow to eliminate waste originated from Toyota. In fact, Six Sigma discards a great deal of the complexity that characterized Total Quality Management (TQM) (Jensen, 2001) .

The DMAIC/ DMAVC process which is outlined in the following sections applies the relevant tools adopted from TQM, Six Sigma and Lean to increase profitability, effectiveness and efficiency of the operations in healthcare by improving on the inventory management of the emergency unit of the hospital. DMAIC is a simple performance improvement model used in six sigma projects. The breakdown of DMAIC as it relates to this project is explained below.

D - Define the goals of the improvement activity for the department.

M - Measure the existing inventory management system in place.

A - Analyze the system to identify ways to eliminate the gap between the current performance of the system or process and the desired goal.

I - Improve the inventory management

system.

C - Control the new system for sustainment.

Kwak et al have summarized six sigma as follows: Six sigma = Total Quality Management (TQM) or Continuous Quality Improvement (CQI)+ Stronger customer focus + additional data analysis tools + financial results + Project management (Kwak & Anbari, 2006).

In their book titled 'the six sigma handbook', Pyzdek et. al state that the Six Sigma standard of 3.4 problems per million opportunities is a response to the increasing expectations of customers and the increased complexity of modern products and processes (Pyzdek & Keller, 2003). It is interesting to note that General Electric estimated that the gap between three or four sigma and Six Sigma was costing them between $8 billion and $12 billion per year (Pyzdek, 1999).

The specific goal of this project is to achieve virtually an error free business performance with the inventory management system for the healthcare organization.

The study concludes with 2 main recommendations, one of which was immediately implemented by the hospital in January 2015

2. Overview of the existing inventory management system

The study was conducted at one of Alabama's largest emergency departments and trauma programs and the region's only state-designated level I trauma centre, with the capacity to treat nearly 100 patients at a time (Website, 2014). The hospital has about 69 emergency rooms and 6 supply rooms. Each of the emergency rooms has a cart that contains specified quantities of items often used on patients. There are established par levels for all items in drawers and this is the level to be maintained at the start of the shift. The par level for chloraprep swabs for example is five in number. It is the responsibility of the nurses to ensure that at the beginning of each day, between 6:30a.m and 7:30a.m, drawers have these inventory items at their predefined par levels.

The supply chain manager scans the barcode of all inventory items remaining in the storage rooms at the end of the day's shift and orders items from the hospital's logistic centre to bring the inventory items to a predefined quantity.

The application of six sigma concepts to the inventory management system was:

- Applying the concept to the demand side of the inventory (carts) system.
- Applying it the supply side, this entails restocking of inventory items from the logistic centre of the hospital.

3. The define phase

The define phase focuses on the definition of the project. This involves identifying the various systems, subsystems, the Key Input Variables (KIV), Key Output Variables (KOV). The main deliverable in the define phase is to come up with the project charter. The project charter states clearly the problem/goal statement, core team, business impact and tollgate review schedule. The project goals are mainly expressed as targets for the KOVS. For this reason it is very important to identify KOVs that can be quantified. Some tools that were applied to successfully define the project goals and determine the scope included developing the SIPOC map, the process map, the voice of the customer and the voice of the business. The proposed design improvements have to eliminate all processes labeled red in the process map.

As with any Six Sigma project, this phase is also accompanied by the appropriate literature review and the various problem solving methods like benchmarking against standards in the field and formal meetings with the hospital staff. At the end of the define phase, the following were the deliverables for each of the inventory areas under study.

3.1. Demand side of the inventory system

3.1.1. ***The problem statement*****:** The medical carts currently stationed in every room have an excess of $43.95 in inventory that is driving

annual cost upward by $1,040,000 and leading to over stocking of inventory storage rooms.

3.1.2. *The goal statement*: The goal here is to eliminate the overstocking of inventory stored in the medical charts so as to better maintain a lean process.

3.1.3. *The scope:* To prevent the overstocking of inventory in the 5 drawers which will reduce the amount of money locked up in inventory.

3.1.4. *The business impact:* The table below summarizes the financial gains if the drawers are not overstocked, this is money held up in inventory.

Table 1. The business impact of improving the cart

	One cart	All carts	Weekly '000'	Yearly '000'
Overstock	$44	$2856	$19	$1040

3.2. The Supply side of the inventory management

3.2.1. The problem statement: The ER inventory control process is currently operating with no quantifiable knowledge on actual demand or usage of supplies in inventory, leading to the inability to order in economic quantities and a lot of expired products. It is estimated that ordering chloraprep in economic order quantities (EOQ) translates into gains of $82,855 cash yearly for this item alone.

3.2.2. *The goal statement:* The goal of this project is to design an inventory control and data management system that will result in an ability to predict the demand with a 95% level of certainty by [11 NOV 14] and order supply items in EOQ.

3.2.3. *The scope:* The scope was to come up with a storage system to determine the actual daily usage of inventory.

3.2.4. *The financial and business impacts*: The study showed that there can be savings of approximately $213,000 yearly, gained on the reduction in expired products. There was also the cost avoidance of $82,855 yearly if supply of chloraprep can be ordered in EOQ. There will be much more gains if all items are considered. The cost savings were observed when simio simulation software was used to model the demand and supply of the selected item, making use of the KN procedure and 'opt quest' optimization techniques that come with the software.

Other benefits to the business entity that were not quantified include the easy identification of items in inventory for nursing staff and a smooth and successful transition of business when the supply manager is unavailable.

3.2.5. *Schedule and core team*: The schedule was the same for both areas of the study. It is shown below in table 2. The core team was made up of Anyama H. Tettey and Patrick Welch as students, Shiela Dyas as the project sponsor and Dr. Sampson Gholston as the instructor for the course.

Table 2. Tollgate schedule

Tollgate	**Scheduled**
Define:	10-Sep-14
Measure:	1-Oct-14
Explore:	22-Oct-14
Develop:	5-Nov-14
Improve:	19-Nov-14

4. The measure phase

The main objective in the measure phase is to evaluate the identified KOVs quantitatively against the KIVs. It is very important to do this thoroughly to ensure that the changes to be proposed will yield the anticipated outputs and not make things worse. In manufacturing systems there are efforts to ensure that the measuring systems in place are reliable. Some methods used are the gauge repeatability and reproducibility. Since this project is in the services industry, the measured phase quantified the input and output variables that had been defined whilst developing the SIPOC map. On the demand side all items in drawers were counted just after the drawers were supposed to have been restocked and the monitory value of the difference between the supply par level and the counted amount for each drawer was recorded. This was done over

a 4 weeks period, picking a total of about 20 treatment rooms at random and recording the medical supply items in each of the 5 drawers in the different emergency rooms.

For the supply side, there was no system in place to know the quantity of medical supplies used in a given period. The approach used to come up with some baseline data was to quantify 2 identified items: chloraprep and IVcathether, ordered from the logistic centre during different time frames. One source of data that was available to do this was a hardcopy (88 pages) of orders placed for all items in inventory during the previous 4 months. The document showed the barcode of items ordered, the par level of each item, the quantity ordered, and the date the order was made. The information in table 3 shows that from the 4th to the 6th of April, records from inventory showed an order amount of 4X400 units of the IV cathether, whilst the usage from the treatment/order (another source of information about inventory usage) shows a usage of only 167 units. Anomalies observed for the data sources in Table IV were alarming and it invoked the need for an inventory control and data management system in a more urgent tone. The explanation given for the inconsistency was that there's the possibility of some ordered quantities expiring or other treatments that required the use of this item not being captured in the column "usage from order".

Table 3. Supply data for IV cathether at the Huntsville Hospital in April 2014

Dates	Usage from inventory records (in 400 units)	Usage from order.
4th to 6th	4	167
6th to 9th	0	253
9th to 11th	2	166
11th to 16th	6	403
16th to 17th	4	78
17th to 23rd	4	520
23rd to 25th	4	166
25th to 27th	4	97

5. The analyze phase

During the analyze phase any cause and effect relationships between the system output and input must be identified and established. For this project the cause and effect diagram, the process map, data visualization and the simulation software are some of the useful tools that were used. Figure 1a shows that the most overstocked item is chloraprep swabs. The cost of this swab was $3.10 per unit, therefore a lot of the analysis focused on how to minimize the overstocking of chloraprep swabs. The box plot in figure 1b shows the variation in the observed quantities of chloraprep and betadine swabs for the observed counts over the 4 weeks period. The prioritized root causes/ effects showed that the lack of system in place to track what is being used on patients and the overstocked drawers are the two causes to concentrate most of the effort in improving the inventory system.

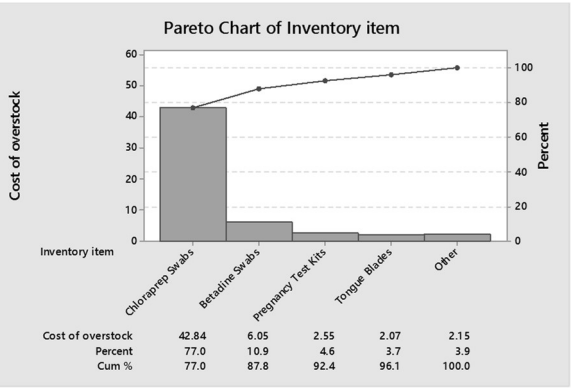

Figure 1a. Pareto chart of overstocked items

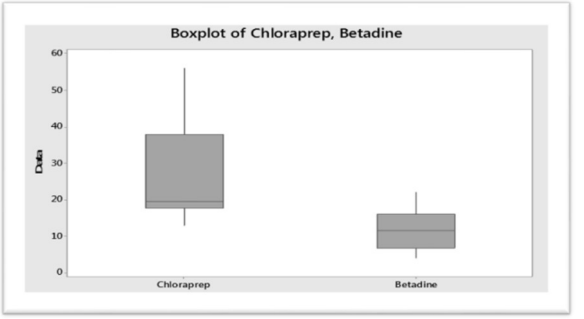

Figure 1b. Box plot of overstocked quantities of chloraprep and betadine swabs

6. The improve or design phase

For projects that already have existing systems in place, this stage will be referred to as the improvement phase. However when the task is to develop a new system it can be referred to as the design phase and hence the section heading. For the demand side, the idea is to reduce the overstocking of items on the cart, whilst a system had to be designed to track the usage of the supply items. This is necessary if a useful EOQ model for all items is to be developed. Figures 2 and 3 show the existing cart system and the storage system at the supply room respectively.

Figure 2. Current state of drawer 2

Figure 3. A snapshot of one of the 6 supply rooms

The proposal for the cart system was to divide each drawer into sections to be able to contain just about enough items required at the identified par level. Figures 4 and 5 show drawer 2 and the storage system; with the proposed improvements.

Figure 4. Drawer 2 after improvement

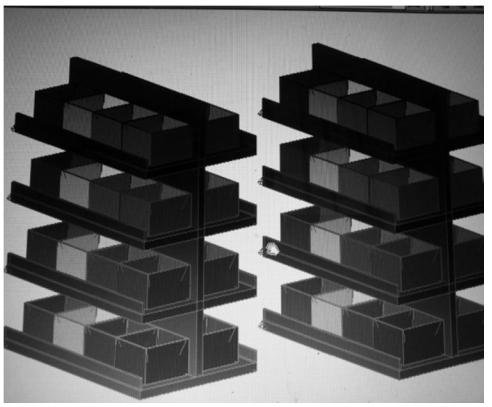

Figure 5. Proposed storage system

The proposed design at the supply side has color coded bins and wheels that is meant to slide down to the front once a bin in front has been emptied and removed from the stack. The color coding is meant to make for easy identification of the bins that have been used and also give an indication as to when items need to be restocked from the logistic centre. Isles are meant to be clearly labeled for easy identification of items in storage.

In addition to easily tracking the daily usage, the FIFO system can be practiced and thereby reduce the quantity of expired products.

Simulation of the inventory system in simio simulation software, using the KN procedure and opt quest optimization tools was used to model and identify the EOQ of the Chloraprep during each order that minimized cost.

The chloraprep swab was used for the analysis because the usage of chloreprep had been studied and quantified extensively in the demand side of the study.

Knowledge of the daily usage of inventory

items is very necessary to come up with good EOQ models. The results showed that ordering chloraprep in 6000 quantities instead of the current order amount of 4000 will result in a daily savings of 227USD, and this will translate into 82,855USD per year for this item alone. In the design of the storage and the improvement of the cart system one of the focus was to demonstrate the use of the 5s principle.

6.1. The 5s principle

- **SORTING** items in their bins as soon as the supply manager/nurses takes delivery of them
- **STRAIGHTENING** by placing the most active items near the input/output point.
- **STANDARDIZING** the location of items in rooms with clear labels on walls and door of each supply room
- **SWEEPING** and keeping the supply rooms and drawers clean and neat at all times.
- **SUSTAINING** the previous 4S with continual reminders, checks and the data entry of daily usage in a database. Reminders can also be incorporated when expiry dates are approaching. The known usage will help reduce the quantity of expired products because items will be ordered in appropriate quantities to avoid them expiring

6.2. The use of Poka-Yoke (Mistake Proofing)

For items that are highly overstocked like the chloraprep swabs and tourniquets, the packaging can be done to ensure that the quantity required in the cart is bundled together. For example the chloraprep and the betadine swabs can be torn into groups of 5 or the established par levels as shown in figure 5. Currently 5 swabs is the required par level.

Figure 6. Proposed storage quantity for chloraprep swabs

The following are more ways to avoid making mistakes:

- When sectioning the drawers the size of each section should be just enough to handle the required number of items during restocking
- Supply rooms will be well labeled and items will be labeled clearly at the appropriate locations.
- There will be color coding of bins to know when an item has to be reordered (before the stock level reaches zero in the supply room).
- Timers may also be programmed to alert the supply manager when the re- order level bins have only one bin in front of it.

7. The Control or implementation phase

The main objective of the control phase is to provide strong evidence that the project goals specified in the project charter have been met (Allen, 2010). During the review of the control phase it is possible to be asked to go back to the analyze phase if the recommended changes do not yield any improvement, the project may also be terminated if the proposed changes do not promise any gains for the business. For the demand side of the study, the project team, together with the hospital staff estimated how to section the bins to ensure that overstocking of drawers is brought to the barest minimum. This was done by specifying the sizing of each bin to take just about the quantity needed per shift. As a demonstration exercise different sizes of prototype boxes were arranged in each of the 5 sections in a drawer, and the estimated par

levels were just enough to contain the prototype bins. This is akin to how the cashiers' drawer in the various malls is sectioned. The bin meant to contain coins is designed to just contain coins and not paper notes. The demonstration exercise above was used to show how overstocking of drawers would be minimized.

Documentation of the results of the project to the hospital staff at this stage was necessary. The hospital staff readily decided to have a pilot to improve on the cart system during the final review and presentation.

8. Conclusion

This was a time intensive study that took 4 months to complete. A summary of some of the principles applied and the various deliverables at each of the DMAIC is shown in table 4

Table 2. A summary of tools used for the DMAIC process

Tool	D	M	A	I	C
SIPOC map	✓				
Process maps and flow charts	✓				
Some multivariate analysis		✓	✓		
Cause and effect diagrams		✓	✓	✓	
5s				✓	✓
Poka - yoke				✓	✓

Even though the recommended changes were quantified to reduce the cost of inventory to the emergency unit, it can be applied to medical supplies in any medical facility to yield similar results. Other benefits that were not quantified include easier and quicker identification of supply items which eventually reduces the service time by nurses and other health professionals. The redesign of the supply rooms also makes it very easy for new staff to get acclimatized to the routine. In the absence of the supply manager who presently has a good knowledge of where items are stored, the hospital's operations will not be affected. Our recommendation to the hospital authorities is to keep a record of the daily usage of all inventory items. The knowledge of this is very important in coming up with EOQ for all items and should be tackled with some urgency. A good knowledge of the daily usage of inventory will also be very beneficial in deciding on the re-order levels for all supply items that are used by the hospital.

9. Acknowledgements

We would like to express our appreciation to the hospital staff with whom we worked, especially Sheila Dyas, who sponsored the project

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Enhancing Performance Indices for Labor Intensive Assembly Lines Using ARENA and Factorial Experiments

Dr. Tamer A. Mohamed[1]
Ola N. Hamada[2]
[1] *Associate Professor, Mechanical Engineering Dept., The British University in Egypt, Cairo, Egypt*
[2] *Demonstrator, Mechanical Engineering Dept., The British University in Egypt, Cairo, Egypt*
Tamer.mohamed@bue.edu.eg
Ola.nagy@bue.edu.eg

Abstract

This paper proposes a framework that can be used to improve large assembly lines. The framework suggests setting certain performance indices, and creating a model that resembles the assembly line and presents all the factors affecting these indices. Hence, the model is to be simulated to present a thorough evaluation of the factors affecting these indices. Improvement hypotheses are to be made accordingly based on the output of the assigned performance indices. An experiment will then be designed to test these hypotheses. Provided the list of improvement alternatives that are found to have a significant effect on the performance indices, optimization techniques are used to determine the most beneficial combination of alternatives to be implemented. This framework was applied to a case study of an assembly line with many wastes. Three improvement indices were selected, namely number of units produced during the run time, the smoothness index and the worker utilization. When the line was simulated, six improvement hypotheses were suggested based on the authors' evaluation of the results yielded from the As-Is line. A 2^6 factorial design of experiments was used and the changes were implemented on the model and simulated. The results revealed that all the hypotheses had a significant effect on at least one of the response factors. An array of optimal hypotheses to be implemented was then portrayed, depending on the importance of each of the performance factors. The decision maker will have a choice of which improvement alternative to implement based on the required values of the performance indices.

1. Introduction

When it comes to large products with many elements, a revolutionary leap towards productivity was introduced in 1913 by Henry Ford as shown by Wilson and McKinlay (2010), as he replaced batch assembly with continuous flow assembly. The means of manufacturing was first linked to the businesses sustainability and ability to maximize profits by Hayes et al. (1979). The concept was developed as a progression of the process life cycle. Hayes et al. found that the manufacturing process strongly affects its sustainability. A manufacturing process may be classified into one of five categories namely Project; Job Shop; Batch; Line Flow; and Continuous Assembly depending on the flexibility and volume of production required. The higher the flow of the line, the lower the cost of an individual product. However, one has to compromise the customization of the product and the customer's involvement.

Trending towards line flow assembly,

however, arouses complications, one of which is assembly line balancing. Approaches to reduce losses caused by an unbalanced assembly line were done through several tools including optimization with given constraints (Pastor et al.,2003-2009), heuristic algorithms, experimental design and TOPSIS (Cortes et al., 2010; Roy 2001; Mozdgir et al., 2011; Nourmohammadi et al., 2009; Mozdgir et al., 2011;Yazgan et al., 2011).

Improving production line performance indices is everybody's target in industrial settings. Many tools can be used for this enhancement to make the absolute most of every resources available. These tools include Total Productive Maintenance; 5S system, Lean Manufacturing; Total Quality Management; Continuous Process Improvement and many more, each of which have been implemented on labor intensive production processes differently to improve the process parameters (Klieza et al., 2012; Lešková, 2013).

Using modelling to verify changes, make improvements or compare different scenarios is a common approach when the line parameters are easily measured. Though a good model may itself be an improvement tool (Digalwar et al. 2013), it is often used to validate implemented changes (Villarreal et al., 2011; Cortes et al, 2010).

This paper proposes an improvement framework that can be used to enhance the performance of an assembly line flow. The proposed model will be implemented on a real industrial assembly line at hand to prove its effectiveness.

In what follows, three sections are presented. Section 2 displays the proposed improvement framework, and elaborates its potential advantages. The framework is implemented on a real industrial assembly line as a case study in Section 3, and in Section 4, a conclusion is drawn.

2. The Proposed Framework

The author proposes the model presented in Figure 1 which consists of three main phases, namely simulation, evaluation and optimization. The concept was to use the current limitations on the assembly line as the basis upon which hypotheses of improvement are made.

After setting the performance parameters aimed to be improved by the model, the first phase involves creating a model of the “as-is” assembly line. This is modeling of the actual line before any improvement initiative can be implemented. Though most performance indices may be collected directly from the actual line, the model provides them easily, and enables the user to simulate the hypotheses and predicts their output. A robust model which produces accurate simulation results is essential to understand where there is an area for improvement. This can be achieved by firstly setting assumptions within which the model will be created. It must be ensured that these assumptions do not affect the pace of the line, compromising the model’s accuracy. Designing the model may be done via many programs, based on the user’s preferences. However, the aims being tested must be kept in mind while designing the model, to ensure that the results of the simulation are of use. Hence, a time study should be conducted in order to have the data that will be used as the inputs of the model.

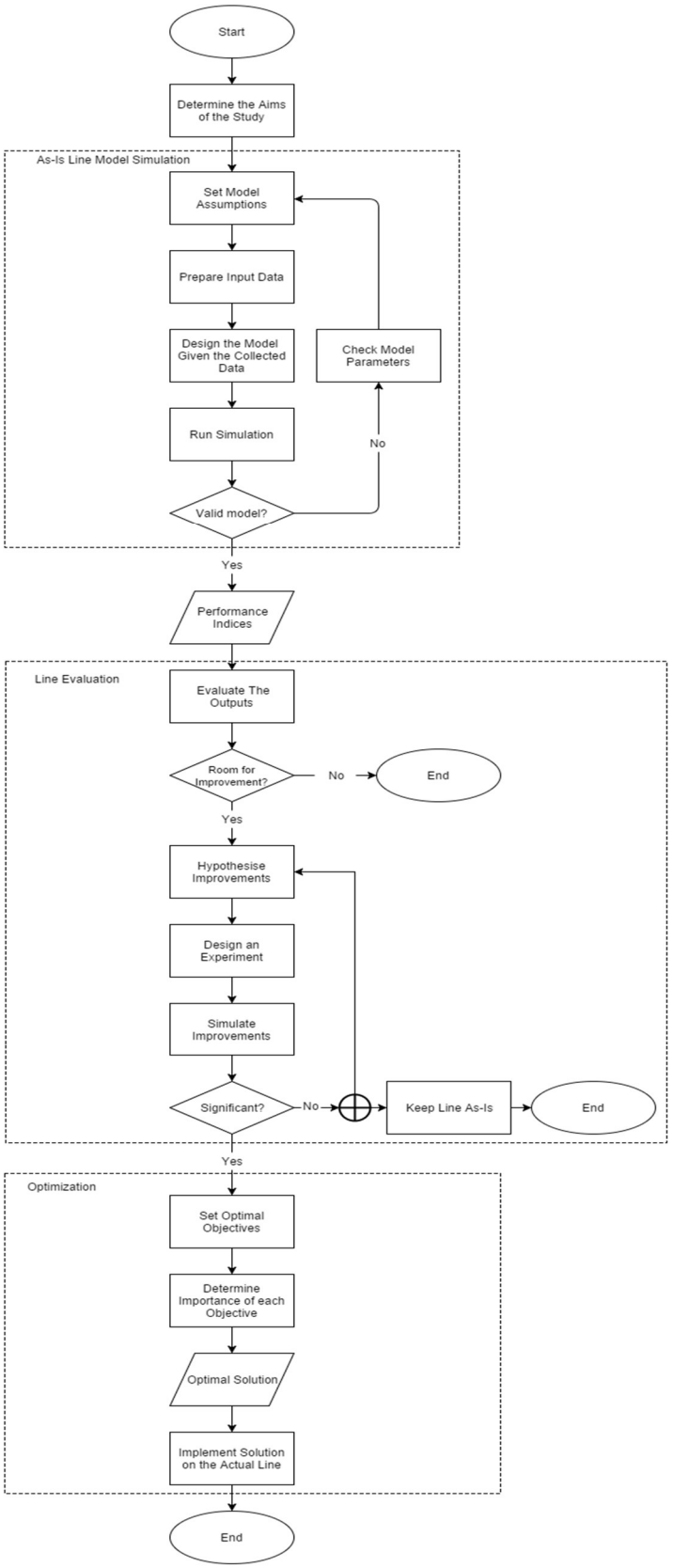

Figure 1. Framework for Assembly Line Improvement

Once the model is run and revealed no technical errors, it is essential to ensure that the model produces results comparable to the actual line. This is well known as model validation. Validating the model involves collecting information from the actual line and comparing it to the output of the model. If there is no difference between the actual and the simulated data, the model will be validated, otherwise, the model parameters and assumptions will need to be checked. The four steps (shown in Figure 1, in "As Is" phase) should be checked and adjusted accordingly.

The second phase involves investigating the outputs produced by the model. A thorough investigation of what influences the performance parameters selected should be done, and from the results of the simulation, the user should be able to determine whether or not there is an area for improvement. Improvement hypotheses should be made based upon one's understanding of assembly lines. Based on these hypotheses, an experiment should be designed to test their significance. Once that is done, one can proceed to making changes on the simulation model to match the improvement hypotheses, and simulate them to see how they affect the performance indices selected. Hence, statistical analysis should be used to test the significance of the effect of each hypothesis. If all hypotheses were not found significant, then either different hypotheses should be proposed or reach the decision that the line is performing at its maximum performance. If any of the hypotheses are found significant however, optimization must be performed.

Optimization (the third phase of the improvement process), also referred to as multiple objective decision making, is a tool used to reach the best possible outcome from all the objectives stated in the first step of the framework. After the objectives have been set, they should be weighted according to the user's perception of each index's importance. The hypotheses that provides the solution needed is what should be implemented on the actual line.

The framework suggested aims to provide a flexible method of improvement. This model may be used to balance an existing assembly line with high involvement of the user as to what changes would be logical to implement. Additionally, once the model has been implemented, the effect of any external changes on the performance indices of the line may be detected, modelled and new hypotheses may be suggested accordingly. The model also takes into consideration several indices the user may want to assess or improve, as opposed to only improving assembly line balancing, for example. In addition, the resources used or needed are taken into consideration and directly linked to the lines output, facilitating the user's ability to evaluate future investments.

3. Implementation on a Case Study

The above model will be implemented on an assembly line from an industrial company that works in the manufacturing and assembly of electric components in the Egyptian market. This company required improvement on the assembly line of Compact Secondary Substations (CSS) which are to be used for power distribution. The product involves a low voltage switch board, medium voltage switch gear and a transformer designed to deliver power from underground systems to residential or industrial facilities. A typical CSS weighs around 1.5 tons, and has a base area of about 6 m^2.

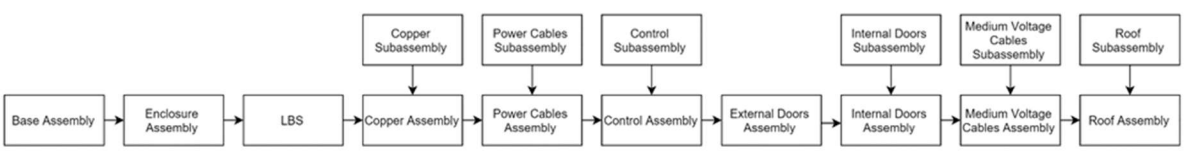

Figure 2. Flow Diagram for the Assembly Line Including Substations

3.1. The Assembly Line

The line is extremely labor intensive, and includes 10 stations summarized in Table 1 below, and a flow diagram for the assembly line is shown in Figure 2.

Table 1. Number of Operators per Station

Station	Number of Workers Operating Each Station
Base	4
Enclosure	4
Load Break Switch (LBS)	5
Copper	6
Power Cables (PC)	3
Control	11
External Doors	4
Internal Doors	4
Medium Voltage (MV) Cables	4
Roof	3

The line starts when the employee begins to assemble 16 pieces of formed sheet metal at the base station on a jig. The assembled base is then mounted on rails and pushed to the next station, where the frame of the CSS is assembled onto the base. This divides the shape into three compartments within which the low voltage switch board, medium voltage switch gear and a transformers' components are assembled. Sheet metal is joined together via nuts and bolts, which are screwed in pneumatically. Each station henceforth assembles the electrical components of the CSS. When needed, the components are prepared simultaneously in adjacent substations. After the internal doors and external doors are added, the transformer is then dropped into the middle compartment, and assembled in the medium voltage cables station. Hence, the roof is secured and the CSS is stored until the batch is completed to be shipped.

3.2. Determination of the Aims of the Study

The assembly line in hand has recently changed the method of assembly from batch to line flow assembly in an attempt to increase productivity. However, the line performance is still below the strategic target. Three performance indices were agreed to and selected to be used in this paper, namely smoothness index, worker utilization and total production rate.

3.3. As-Is Line Model Simulation

This section shows in detail the process of modeling the assembly line prior to any implementation of improvement initiatives.

3.3.1. Designing the Model:

Many simulation modeling tools are available in industry, one of the most common tools for assembly line simulation is called ARENA (Version 14.0, Allen-Bradley, 2012). Designing an ARENA Model involves using modules to serve the purpose of adding or changing the attributes of the entities, variables of the model (including time), path the entity flows through, assignment of resources or other parameters. Entities are the parts being moved and processed in the model. One entity flowing through the model represents one CSS being assembled. Entities are generated via the 'Create' module and leave the model via a 'Dispose' module. Each station (including its subassembly station if applicable) will be presented as a sub-model on ARENA, presented in figure 3.

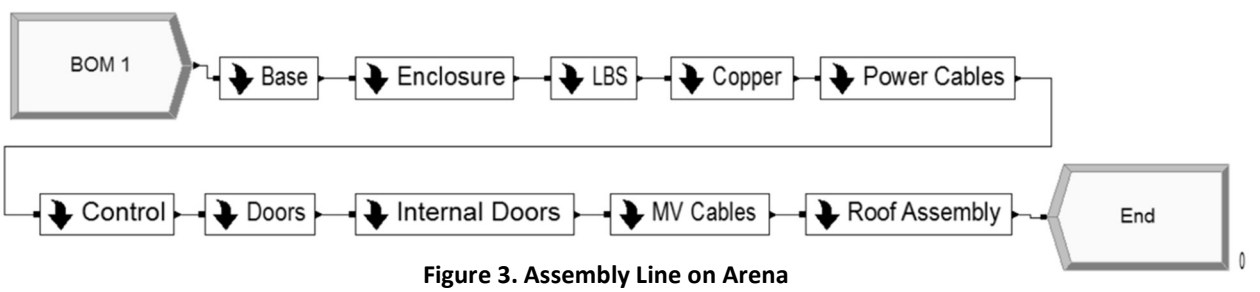

Figure 3. Assembly Line on Arena

Within each station, process modules were used to represent the elements of the time study. A process module requires a value (or distribution) of time that it consumes, the type of process (value added, non-value added, wait, transfer or other) and the resources needed to perform this process. Each process or set of processes require the seizure of 1 or more workers, which are the resources in question. All of these data will be collected as shown in Section 3.3.3 below.

Other modules were used though they do not require the usage of time such as:

- The decide module, used to change the path of the part based on a given attribute.
- The match module, used to represent bringing together a subassembly to the main assembly
- The assign module, used to flag the entity at the beginning, during or end of each station
- The record module, used to record the timestamp at the end of each station, in order to calculate the smoothness index

3.3.2. Preparing Input Data:

To be able to measure model performance, a time study should be conducted. However, a few adjustments had to be made in order for the data to be usable in the model including:

- Workers were not rated while doing tasks. Instead it was ensured that all the tasks were done by more than one worker, and the assignment of a distribution to the types of tasks performed by several workers is expected to even out (or at least give a small significance to) extreme values.
- Averages and totals were not calculated, since they will not be used during modelling.
- Allowances will be included in the model (in the form of failures of resource), and not calculated beforehand.

Table 2 shows a sample of the time study conducted. The sample was taken for the process of peeling the cable ends in the medium voltage cables sub assembly on the 12th of February 2014. The process was divided into elements, and up to 10 cycles of each element's time were measured in seconds.

The entire line was divided into about 500 elements in the same manner. The Input Analyzer feature of the ARENA software was used to assign distributions to the set of data collected. The software fits the data to the most suitable distribution (either normal, lognormal, Weibull, Erlang, exponential, gamma, triangular or uniform). These distributions' parameters were inputted into the ARENA model for simulation purposes.

3.3.3 Validating the Model:

Model validation is done to ensure that the model is not far from the actual process, and that the results are reliable. To get validated data, one must ensure that the run time is sufficient which is done by sample size determination. Sample size determination identifies the smallest sample size that is large enough to produce accurate results (Mohamed, 2010).

Table 2. Sample of Time study

DATE: 12th Feb 2014

OPERATION: Peeling the Cable Ends

STATION: MV CABLES

Element	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10
Getting the Cable & Secure on Vice	9.37		8.92		9.93		7.73		9.57	
Measure required length	6.66	6.43	4.16	4.73	11.26	5.17	5.17	4.98	4.00	4.59
Radially cutting the red layer	4.44	17.37	5.26	5.70	5.26	5.38	5.54	5.79	5.75	5.61
Longitudinally Cutting the red layer	10.50	13.41	8.15	8.55	9.43	8.76	18.28	10.41	11.76	9.16
Removing the Red layer	15.02	16.88	6.04	15.21	9.37	8.32	18.65	10.28	8.51	7.14
Removing the plastic film	6.69	12.79	7.33	14.33	8.46	9.46	12.73	11.74	11.30	8.85
Cutting First Layer of copper		10.79		8.11		6.57		7.27		8.93
Wrapping the Copper	28.58		32.02		32.27		34.65		30.00	
Taping the Copper	8.06		7.55		9.16		8.51		8.12	
Cutting the Remaining Copper	30.45	30.23	32.26	25.54	27.47	32.43	29.18	23.91	25.16	38.37
Cutting the black isolator	23.87	23.23	14.41	22.72	20.77	17.88	23.54	16.98	18.17	24.01
Turning the Wire & securing it on vice	8.30		7.69		12.11		11.84		10.95	
Unloading the Cable		12.79		10.42		7.88		11.52		8.17

3.3.4 Validating the Model:

Model validation is done to ensure that the model is not far from the actual process, and that the results are reliable. To get validated data, one must ensure that the run time is sufficient which is done by sample size determination. Sample size determination identifies the smallest sample size that is large enough to produce accurate results (Mohamed, 2010).

Figure 4. Run Length vs. Average Cycle Time

From figure 4, the average cycle time stopped decreasing drastically after 6 days. The run length will be taken as 10 days, starting from day 6 to day 16. The number produced during the simulation period was within 2.75% accuracy to that produced by the actual line, proving that the simulation's accuracy is within acceptable limits and this is how the simulation model is validated.

3.4. Line Evaluation

This section focuses on evaluating the current line; deducing improvement hypotheses; and testing those hypotheses to evaluate their significance.

3.4.1. Evaluating the Outputs and Hypothesizing Improvements:

After the line is simulated in its current state, the simulation results were collected as shown in Table 3, Table 4, and Figure 5 below. These results are then used to indicate the changes that may be hypothesized to improve the parameters in question.

Table 3 shows the average time that the CSS spends at each station. Wait time is excluded from the station times in order to use the processing time of each station to balance the line.

Table 3. Station Times

Station	Station Time (Hours)
Base	0.626
Enclosure	0.601
LBS	0.23
Copper	0.4473
Power Cables	0.1084
Control	0.4108
External Doors	0.9843
Internal Doors	0.2282
MV Cables	0.1393
Roof	0.0599

There is a large variation between the times the part spends at each station which increases the wait time on the line. Due to the nature of the Base and Enclosure stations, they were the hardest to split up or merge, thus it was aimed to try and make all the stations as close as possible to 0.6 hours (Base and Enclosure stations times). Hypotheses A to D aim to do just that by reducing the amount of sequential work in the external doors station and merging the other stations together.

A. Merge the Roof Assembly, Internal Doors Assembly and MV Cables into one Station
B. Reallocate Assembling the Hinges from the External Doors Station to the preceding Station (Control) and Reallocate Assembling the Door Knob from the External Doors Station to the succeeding station (Internal Doors)
C. Merging the Control and Power-Cables Stations
D. Merging the LBS and Copper Stations and Reallocate the first task in the LBS Station to the Enclosure Station (Assembling Divider Sheets)

Hence, the worker utilization was addressed. Table 4 shows the number of workers scheduled based on the actual labor allocation and the maximum number needed based on the simulation.

Table 4. Actual Versus Maximum Worker per Station

Station	Actual Workers Scheduled	Maximum Workers Required
Base	4	4
Enclosure	4	4
LBS	5	4
Copper	6	6
Power Cables	3	3
Control	11	11
External Doors	4	3
Internal Doors	4	3
MV Cables	4	4
Roof	3	3

From the above table, it is evident that the results showed that one worker from the external doors station, internal doors station and LBS are never needed. Hence they can be moved to stations where they're more essential without affecting the performance of their current stations.

Figure 5 below shows a graph for the scheduled utilization of the workers at each station.

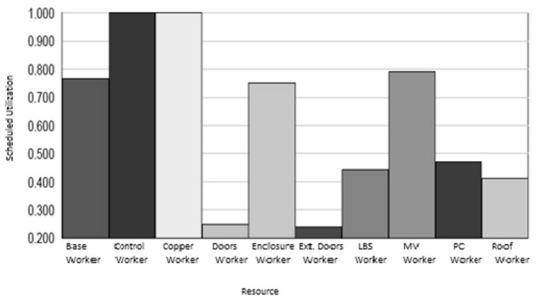

Figure 5. Employee Scheduled Utilization

From this graph, it can be shown that the copper and control stations are where the workers are most needed. Since hypothesis D already suggests merging the LBS Station with the Copper Station, reallocating a worker would be redundant, and hence hypotheses E, F.

E. Reallocate an external doors worker to the Control Station

F. Reallocate an internal doors worker to the Control Station

3.4.2. Design of Experiments and Simulating Hypotheses:

An experimental design was used to test the significance of the implementation of the above six hypotheses. The hypotheses were the factors controlled during the experiment. Each hypothesis was either implemented or discarded in the design, hence bearing 2 levels. The sample size taken was 1, since running the line several times had hardly any effect on the output as this is a simulation experiment. The responses of interest were the number of output products during the runtime; the smoothness index; and the average utilization of each worker, as clarified in the Table 5.

Table 5. Factorial Design Summary

Factors	Levels	Responses
A	1: Implemented	Smoothness Index Number Produced Utilization
	0: Discarded	
B	1: Implemented	
	0: Discarded	
C	1: Implemented	
	0: Discarded	
D	1: Implemented	
	0: Discarded	
E	1: Implemented	
	0: Discarded	
F	1: Implemented	
	0: Discarded	

Since 6 controllable factors (A, B, C, D, E, F) each at 2 levels are involved in this experiment, a 2^6 factorial design may be used. Sixty-four (64) combinations were implemented, simulated and inputted. In order to test the significance of the tests, an ANOVA table will be formulated using Design Expert (Version 9, Stat-Ease, 2014).

3.4.3. Testing Significance:

Before the ANOVA results may be rendered reliable, the model's adequacy must be checked. The ANOVA table tests whether or not

differences between the results yielded from each test exists due to the significance of the factor, or random errors. However, if the randomness of the errors was violated, another significant factor would be controlling the results as opposed to the hypothesized claims. Randomness exists when the errors are normally and independently distributed with a constant variance (Montgomery, 2012). All residual plots (Normal Probability Plots and Factor Plots) have been tested for all three responses and revealed no violations for the ANOVA assumptions.

Tables 6, 7, and 8 show the ANOVA Table for the responses, utilization; number produced during runtime; and smoothness index respectively. If a confidence interval of 95% or higher is achieved, the factor is considered significant.

Table 6. ANOVA Table for Worker Utilization

Response 1 Utilisation Analysis of variance table [Partial sum of squares - Type III]					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	0.094	7	0.013	16255.63	< 0.0001
B	1.770E-003	1	1.770E-003	2148.84	< 0.0001
C	0.028	1	0.028	34310.32	< 0.0001
D	0.041	1	0.041	49190.85	< 0.0001
E	0.012	1	0.012	14043.61	< 0.0001
F	0.012	1	0.012	13998.90	< 0.0001
BC	1.682E-005	1	1.682E-005	20.42	< 0.0001
CD	6.300E-005	1	6.300E-005	76.47	< 0.0001
Residual	4.614E-005	56	8.239E-007		
Cor Total	0.094	63			

Table 7. ANOVA Table for Total Number Produced During Runtime

Response 2 Total Number Produced Analysis of variance table [Partial sum of squares - Type III]					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	24064.56	6	4010.76	1194.58	< 0.0001
B	3192.25	1	3192.25	950.79	< 0.0001
C	13282.56	1	13282.56	3956.14	< 0.0001
D	175.56	1	175.56	52.29	< 0.0001
E	3690.56	1	3690.56	1099.21	< 0.0001
F	3690.56	1	3690.56	1099.21	< 0.0001
CD	33.06	1	33.06	9.85	0.0027
Residual	191.38	57	3.36		
Cor Total	24255.94	63			

Table 8. ANOVA Table for Smoothness Index

Response 3 Smoothness Index Analysis of variance table [Partial sum of squares - Type III]					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	16.88	15	1.13	18523.96	< 0.0001
A	4.91	1	4.91	80763.23	< 0.0001
B	9.94	1	9.94	1.635E+005	< 0.0001
C	0.92	1	0.92	15159.24	< 0.0001
D	0.84	1	0.84	13888.46	< 0.0001
AB	0.015	1	0.015	247.63	< 0.0001
AC	0.089	1	0.089	1465.89	< 0.0001
AD	0.062	1	0.062	1013.50	< 0.0001
BC	0.040	1	0.040	659.31	< 0.0001
BD	9.265E-003	1	9.265E-003	152.42	< 0.0001
CD	0.027	1	0.027	441.19	< 0.0001
ABC	8.228E-003	1	8.228E-003	135.35	< 0.0001
ABD	3.355E-003	1	3.355E-003	55.20	< 0.0001
ACD	0.015	1	0.015	241.17	< 0.0001
BCD	2.486E-003	1	2.486E-003	40.89	
ABCD	3.969E-003	1	3.969E-003	65.29	
Residual	2.918E-003	48	6.079E-005		
Cor Total	16.89	63			

From the ANOVA tables above, one can conclude that when it comes to worker utilization and the total number produced, all the hypotheses were found significant except 'A'. 'A' suggests merging the last three stations together, all of which had very short station times. If merging these stations did not result in a bottleneck station, this would explain why 'A' was found insignificant to the number produced. The station with the longest station time is what controls the rate of production and since 'A' does not affect the bottleneck, it does not significantly change the production rates. The 5 other hypotheses however either directly make changes to the stations with the highest worker utilization, and hence the bottlenecks. Merging the three stations should result in the averaging out of the utilizations of the workers from all three stations, but the difference between their utilizations was small relative to the overall utilization.

As for the smoothness index, it was expected that hypotheses E and F were not found significant since they did not suggest changes with regard to the amount of work at the stations which is the only factor that is used to compute the smoothness index. Since all of the other hypotheses reallocated tasks or merged stations, they had a significant effect on the smoothness index.

3.5. Optimization

Even though all of the hypotheses showed significant effect in at least one of the three responses, it does not mean they should be implemented. Optimization involves selecting a combination of hypotheses that would best help achieve a set of goals. In this case, the Number Produced and Utilization are aimed to be maximized and the Smoothness Index to be minimized. Achieving the absolute best in one response may mean the other could be compromised. One must determine the importance of each response since the other responses may be compromised accordingly.

The optimization was designed such that controllable factors are restricted to bearing only values of 0 or 1 since they were either

implemented or not. The responses were assigned different values of importance (5 being extremely important and 1 being least important, and 0 means not used in the optimization) to see which responses should be implemented. Table 9 summarizes the results yielded. Weights selected is according to the preference of the decision maker. The first three rows in the Table shows the case where the model optimizes only one factor (Utilization; Number produced, and Smoothness index respectively) and the other two were excluded from the optimization model.

Table 9. Optimization Results

Importance of Factors			Implemented Hypotheses
Worker Utilization	**Number Produced**	**Smoothness Index**	
5	0	0	C,D,E,F
0	5	0	C,E,F
0	0	5	A,B,C,D
5	5	5	A, B, C, D, E, F
5	3	1	A, C, D, E, F.
5	1	3	A, B, C, D, E, F
1	3	5	A, B, C, D, E, F
1	5	3	A, C, D, E, F
3	1	5	A, B, C, D, E, F
3	5	1	A, C, D, E, F.

Although B was found to have a significant effect on both Work utilization and number produced (relevant ANOVA tables), they were not recommended to be implemented as this effect was against the goal of the decision maker, i.e. implementing factor B reduces both worker utilization and number of units produced.

It is also clear from Table 9 that whenever smoothness index is of high importance, hypothesis B should be implemented.

4. Conclusion

Upon implementation of the proposed framework, it was evident that the framework provides a flexible basis upon which improvements can be made. The framework may be generalized to involve all of the resources and inputs on a line, or be used to specifically test certain selected indices as presented by the case study. As the ANOVA tables show, the hypotheses were all significant since they were deduced from the limitations presented by the simulation results. After implementing these improvements, one may then address the utilization of other resources or other performance indices and follow the same methodology to improve them.

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