Agile Management for Industrial Engineering Capstone Projects – Overcoming the COVID 19 challenge

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Abstract

The Industrial Engineering capstone projects at Tecnologico de Monterrey (ITESM) are usually affected by several uncertainty factors: scopes poorly defined by the company; variable levels of collaboration with company personnel; ignorance about the company, and some technical methods by the students. In the Feb-Jun 2020 semester, this complexity increased due to the COVID19 contingency. The management of academic projects under these levels of uncertainty to achieve the satisfaction of students, clients, and teachers is indeed a challenge. This article presents the results of an innovation methodology for managing full-immersion projects using the Scrum-based Project Management tropicalized to academic assignments. The pilot test was carried out in the Feb-Jun 2020 semester with 30 students. The experimentation group (5 Scrums) used Scrum with three Scrum sprints, weekly 20-minute Scrum meetings, and three complete, customer-validated deliverables. The control group (3 projects) used a project charter, progress presentation, and deliverables at the end of the semester. The exit surveys answered by students, companies, and professors show that agile project management improved the experience and results for all the people involved, supported by Analysis of Variance with a 5% significance level.

Keywords
Agile Management, Scrum, Capstone Project, Educational Innovation, Higher Education.

1. Introduction
In the last year of Bachelor, students in the Industrial and Systems Engineering program have the opportunity to work on projects with companies. Projects have high levels of uncertainty caused by: Companies with unrealistic or un-defined objectives and scopes, conflicts of interest with the project, and poor collaboration with students; teams of students who do not know any aspect of the company and its culture, also quite possibly lack of knowledge of specific technical tools to use for the project. Ensuring the quality of learning of the students and the quality of the product delivered to the company in these projects of high uncertainty represents a challenge for the academy.

Usually, the capstone projects are defined in a Project Charter generated in the first three weeks of work with a presentation of progress in the middle of the semester and delivery of the results and proposals for improvement at the end of the semester. The results of this management have a high variability of the levels of satisfaction of students and companies concerning the achieved results, the level of communication, and the flexibility of reach and deliverables. Given this scenario, it is crucial to have better methodologies or ways to deliver to the company a quality project, where students can carry out more effectively and efficiently project management.

1.1 Objectives

The main objective is to present a new capstone project management proposal based on the agile Scrum methodology, designed to manage high uncertainty projects in their scope, deliverables, and project management. A new project to describe the research protocol to differentiate the process and the results obtained from the control (standard) and experimental (Scrum) groups.
Research questions were raised; the first question is whether agile project management with Scrum can generate better results in projects. The second question is whether agile project management with Scrum facilitated the adaptation of the project to the changes due to the COVID-19 pandemic.

2. Literature Review

In teaching at the university level, teaching techniques such as project-based learning or POL (Project Oriented Learning) have been used. This technique has the fundamental intention that students learn different tools and/or skills such as problem-solving, communication, and teamwork through the team proposal of the solution to a real and limited problem within a sponsoring organization. The POL technique is highly documented, and its application is primarily aligned with international standards such as PMBOK, promoted by the Project Management Institute (PMI), or the competency baseline (ICB) promoted by the International Project Management Association (IPMA). These two standards are generated by two of the most respected organizations for their dissemination and certifications in project management.

The formation of an agile project team to apply methodologies such as Scrum framed within a course with a didactic technique of POL is one of the tools that can be used in many subjects of different levels of school to promote two competencies currently highly valued by companies: Teamwork and digital skills, which can contribute to the increasingly required approach between universities and companies (Martin 2020).

In the training of future Industrial and Systems Engineers, the knowledge and practice of project management is a disciplinary competence highly appreciated by companies. In the current framework of continuous change in organizations, learning agile project management methodologies such as Kanban and Scrum has become necessary. These methodologies, generated in the ’80s clients are highly used in the software industry; however, they have been exploited to a lesser extent in other disciplines such as Industrial Engineering. University of Arizona (ECAdmin 2019) university programs at the Olin College of Engineering (Sarang and Christianson 2016) or Penn State University (Xiaocong 2018) have used agile management methodologies for Capstone Projects from programs primarily related to software development or multidisciplinary. Combining agile methods in a collaborative environment makes learning between students more playful and responsible when applied in social projects (Cornejo 2016).

The principles of agile methodologies are: the continuous delivery of value to the client and/or user of the project, always prioritizing their needs; face-to-face interaction; empowering self-organized teams to work on the project; incremental and/or iterative learning that exploits the imagination (PMI 2017).

In 2001 a group of 17 people met to create the manifesto of agility for software development (Highsmith 2001); this manifesto highlights the following four client’s principles: Individuals and interactions over processes and tools, working software over comprehensive documentation, customer collaboration over contract negotiation and responding to change over following a plan. From these values the 12 principles of agility were developed, these complement the values of agility (Becket et al. 2007), and with this, they mark a reference for any agile project regardless of the methodology used or adaptations.

One of the most widely used agile methodologies is Scrum, the authors of The Scrum Guide describe Scrum “as a framework within which people can address complex adaptive problems, while productively and creatively delivering products of the highest possible value” (Schwaber and Sutherland 2020). This structure is gaining more and more followers in various professional fields since, although they began to be applied in the software sector, little by little more companies and institutions are using them. Therefore, using Sprint methods in practice trains students by handing them over for their future work (Soriano 2013). According to the 15th (Digital.ai 2020) agility report, Scrum was the most popular Agile approach with 66% identifying it as the methodology they follow most closely, with an additional 15% who follow derivations of Scrum (ScrumBan 9% and Scrum/XP 6%).

Scrum combines different roles and artifacts to respond to and manage changes in a project. The roles documented in his practice are: Scrum Master, Product Owner and team members (development team); the first two roles lead the approach and understanding of the client's requirements and the facilitation of the Scrum methodology, so that team members work with the least possible obstacles (Sbok Guide 2016). The Sprint or increment is a critical

element in Scrum, ensuring that the deliverable of the project meets the requirements or "user stories" (Sbok Guide 2016).

In Scrum, planning, communication, and learning are very important. There are procedures for planning the increment or Sprint that are done as a team, demystifying the idea of an unplanned Scrum. The daily meetings (Scrums) between the team and the Scrum Master allow the team to remain focused. In the delivery boards, the team closes the value delivery cycle of each Sprint where the customer validates the functionality of the product, compliance with requirements and negotiates the requested changes, this allows traceability within the project. Nazareno et al. (2013) mention that traceability and the benefits it provides have an impact on the analysis of the impact of changes, product compliance, process obedience, project responsibility, reproducibility of the baseline, and organizational learning. Finally, in the retrospective meeting the team reflects, motivates, and guides itself for the next Sprint.

Torres et al. (2018) mention some benefits of using agile methodologies in university projects related to entrepreneurship: increase in the level of internal cohesion of the work teams, the flow of information, as well as their efficiency and responsibility, the reduction of the time and resources necessary to validate the business idea and allow to base the project on data that allow to objectively verify the progress of the project.

The theoretical and independent explanation of each practice or method (for example, Scrum practices or the explanation of the Kanban method) is relatively simple, the real challenge is its effective application in a particular context, given by the team and client (Penadés and Letelier 2013), therein lies the importance of university students moving from theory to real application.

In summary, we can see that different methodologies have been applied for the improvement in project management, one of the most used is Scrum, many universities manage capstone projects and in some university programs agile methodologies are already used to manage them, however, it was not found in the review that industrial engineering departments are using it for these projects. POL and Scrum can be supporting methodologies to promote teamwork skills and digital skills.

The article presents the results of a methodological innovation for managing full-immersion projects using the Scrum-based Project Management tropicalized to academic projects.

3. Methods

The students of the Industrial and Systems Engineering program study in their last bachelor year the subject of Project of Industrial Engineering (Project Oriented Learning). At the beginning of the course, a training partner and the project they will develop throughout the semester will be provided. The team has an initial meeting with the training partner to establish the initial situation, the objective that is sought, the deliverables, the scope, etc. With this, the students develop a Project Charter to present it to the company and to start the development of the project.

Throughout the semester the students face different difficulties with time, ignorance of the company both in processes and people, and the lack of involvement of the training partner having as result affectations in the realization of the project, causing different results to those established by the company or the realization of the tasks in a very limited time. The methodology that is currently followed begins with an initial meeting with the company, then has a mid-term meeting and for the closing is made the delivery of results; however, this methodology has not been optimal to avoid the aforementioned difficulties. That is why we see it necessary to follow a new methodology that allows greater flexibility, greater involvement on the part of the company, and where students can have greater agility to changes by the company or by external conditions (COVID 19) occurring within the project.

During the semester February-June 2020 the pilot test of this innovation was applied with the Scrum methodology in the Course of Industrial Engineering Project with a total of 30 students, divided into 8 projects linked to companies in Querétaro, México, throughout different sectors and with different themes. To carry out the study, two groups of projects were generated: the experimentation group consisting of 5 projects and the control group with 3 projects. Figure 1 shows the typology of companies (left) and the types of projects requested (right) differentiated by project type (blue = control and orange = experimentation).

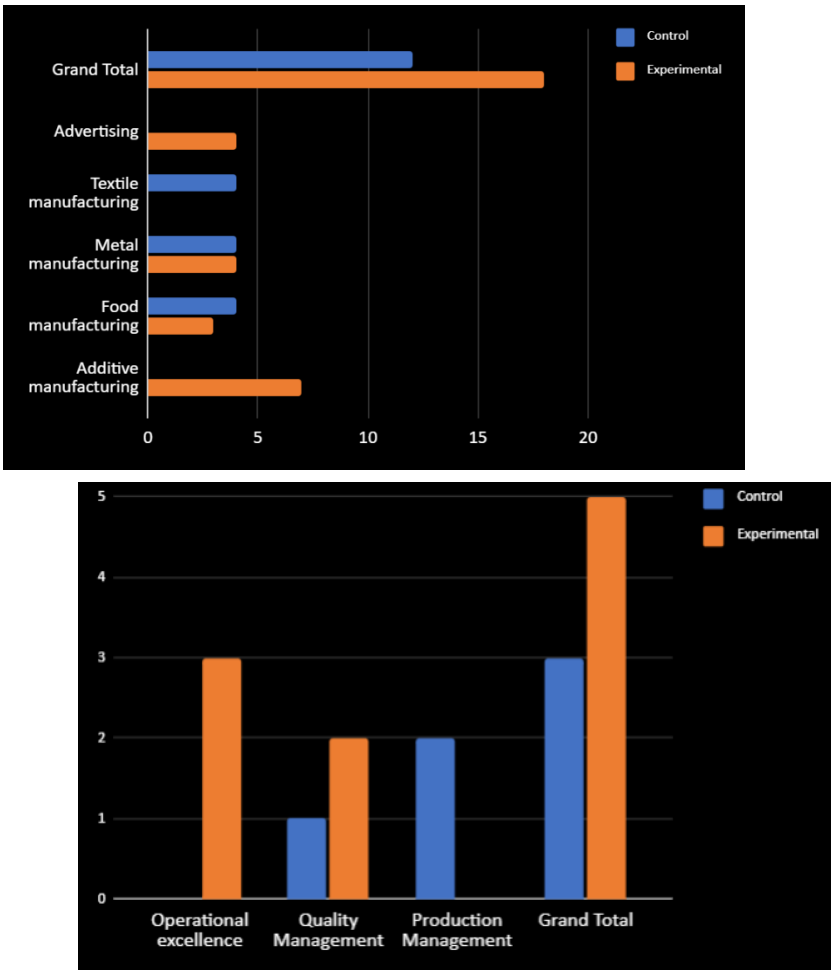


Figure 1. Composition of experimental and control groups

The projects of the control group were managed in the traditional form of the Academic Liaison department model starting with a Project Charter defined by the team in the first two weeks of the project, work meetings frequently defined by the team/client/advisor, presentation of progress in the middle of the semester and presentation of results at the end of the semester. This methodology is represented in Figure 2.

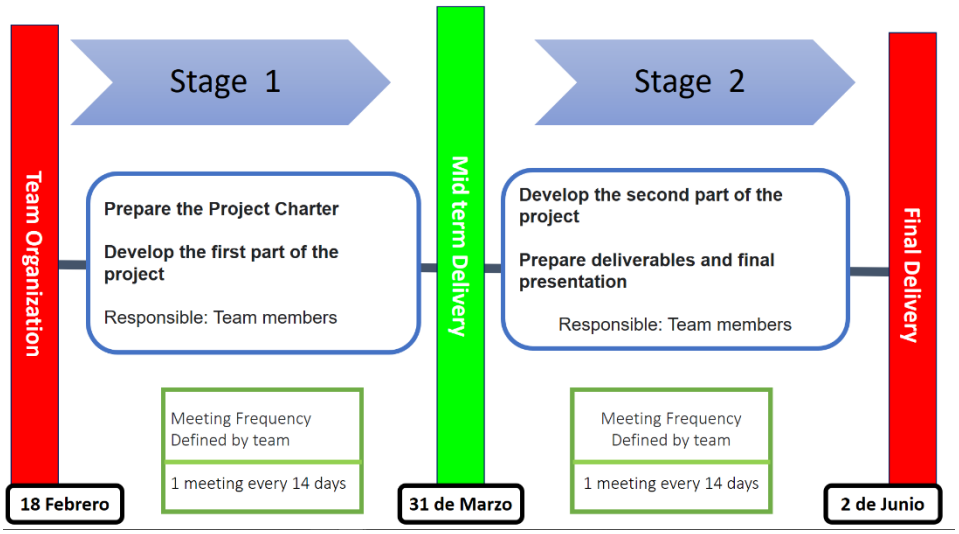


Figure 2. Traditional Management of Industry-linked IIS Projects

The group of experimentation projects began with a 3-hour training in the Scrum methodology for the students of the team (3 or 4 per project). The teams of students elaborate and validate the Product Backlog and the definition of the sprints or stages in the first two weeks. The sprints take approximately 5 or 6 weeks with a well-defined deliverable, with Scrums or weekly team meetings with the advisor (Scrum master) of 15 or 20 min, and a final delivery meeting to the client of about 1 hour, where the changes to be made in the next sprint are also defined, by common agreement between the client and the team. The representation of this methodology is made in Figure 3.

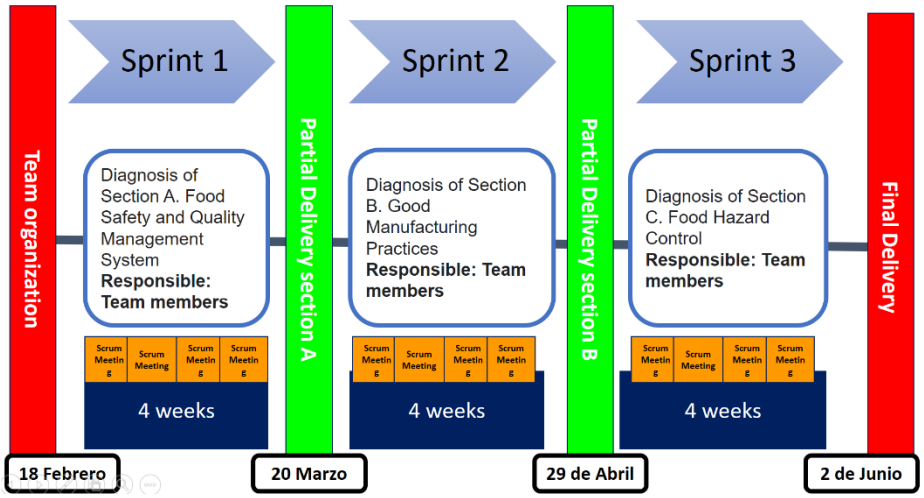


Figure 3. Agile Project Management with Scrum.

At the end of the semester, all projects are evaluated by the team (students), the client (company leader), the Coordinator (Outreach Department), and the advisor (teacher) around the following aspects of project management and its results represented in Figure 4:

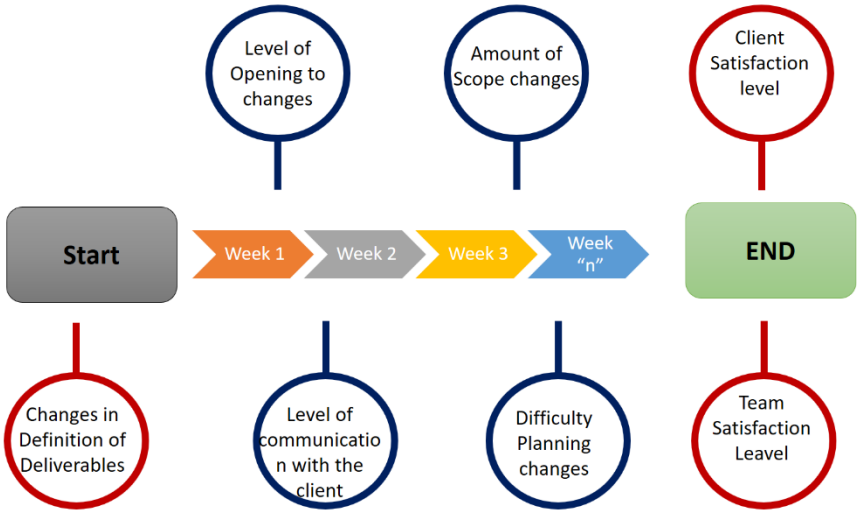


Figure 4. Evaluated dimensions of project management.

4. Data Collection

During the semester February-June 2020 the pilot test of this innovation was applied with the Scrum methodology in the Course of Industrial Engineering Project with a total of 30 students, divided into 8 projects totally linked to companies in Querétaro throughout different sectors and with different themes.

To compare the results of the semester using the traditional methodology and the use of the Scrum methodology, at the end of the semester, a total of 53 surveys were conducted (one student and one client did not complete the survey). The measurement instrument was designed with the following sections and questions: Project Identification (1 question), respondent's role (1 question), project definition (3 questions), communication levels

(3 questions), changes and their impact (4 questions), and overall results (3 questions). They were applied through the Google Forms tool and for each project the following composition of the surveys was: 3 or 4 of students, 1 advisor, 1 coordinator, and 1 leader of the company.

The data collection began when the companies were sending information about their project, this was at the start of the semester, the information by the students (quantity, equipment) began to be given from their registration to the course of industrial engineering projects. The data were obtained electronically through surveys as mentioned and were fed to the statistical software, from there it was started to graph them and make the statistical analyses.

5. Results and Discussion

5.1 Numerical and graphic results

During the February-June 2020 semester, there was an unexpected event such as the COVID-19 quarantine that changed the media between team, client, and advisor in a drastic way. As a result, all projects had modifications in the scope, deliverables, and limitations of the original project. For example, a project dedicated to diagnosing and implementing elements of a food quality system that complies with the IFS GM standard was modified to the organization's full diagnosis based on the IFS GM standard.

Research questions aligned to the objectives of the same were generated, each question is deployed in 2 hypotheses that allow statistical analysis using the ANOVA technique with the data obtained in the survey kit. A concern for the ANOVA was the sample size of the experiment (13 and 31 students for each group respectively). To deal with this concern, a power and sample size test was conducted in Minitab using the current sample size, the pooled standard deviation, and the maximum mean difference between groups. As a result, the test power was calculated and the results are shown for each ANOVA test.

The results are shown below in Figures 5 and 6:

Research Questions.

1. Does agile project management with Scrum generate better project results in the perception of those involved?

A. The perception of the Level of Satisfaction of those involved is the same regardless of the type of project management. (*Average questions 11, 12, and 13*).

H_0: Perc. Gral. Results (control) = Perc. Gral. Results (experimentation)
H_1: Perc. Gral. Results (control) <> Perc. Gral. Result (experimentation)

B. The perception of the Level of Satisfaction of the students are the same regardless of the type of project management Filtered by role = *students*
H_0: Perc. Students Results (control) = Perc. Student Results (experimentation)
H_1: Perc. Students Results (control) <> Perc. Student Results (experimentation)

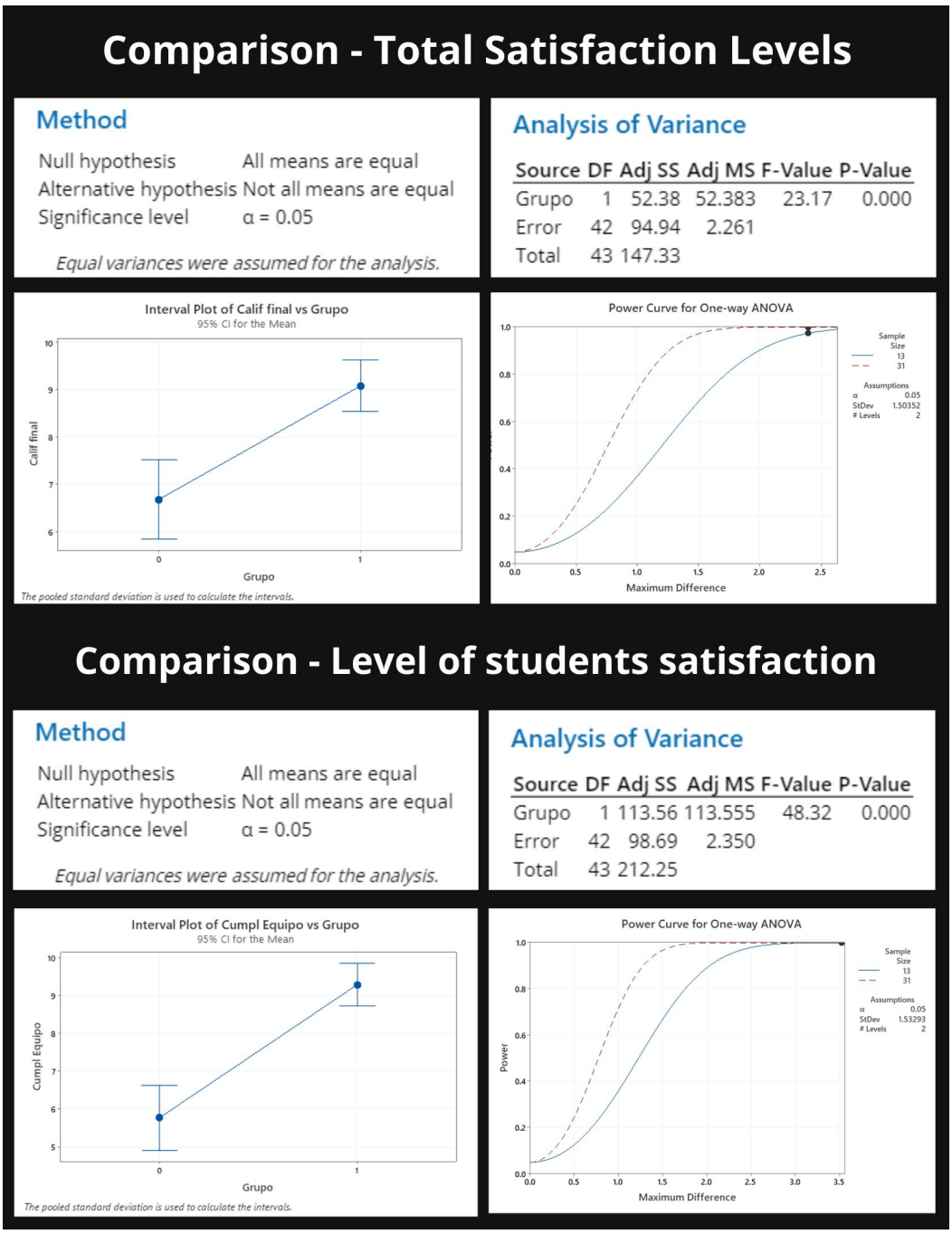


Figure 5. ANOVA results of total satisfaction levels and filtered by students only.

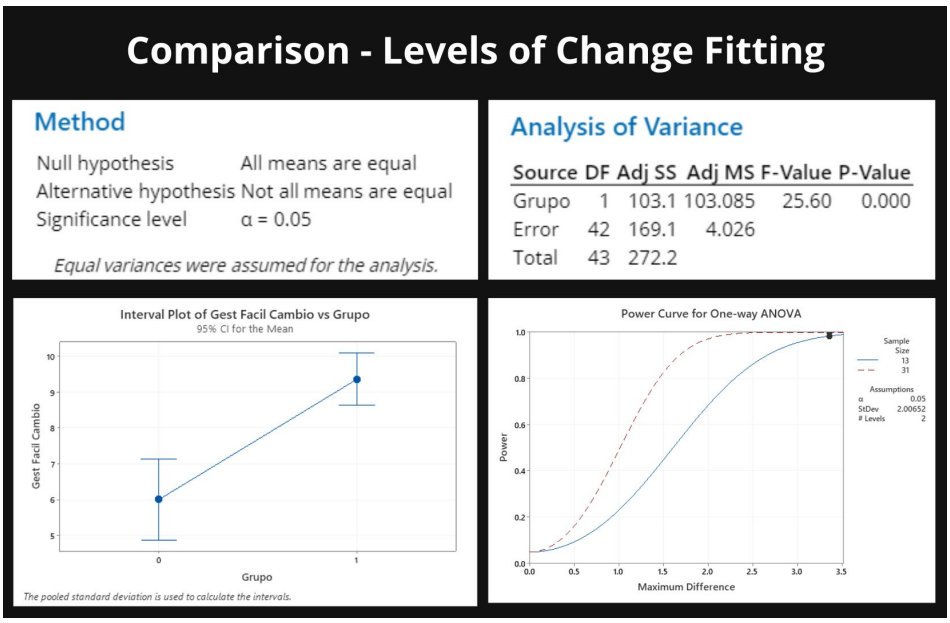
The ANOVA for both hypotheses show a p-value equal to zero which indicates that there are no elements to confirm the null hypothesis and therefore, the alternative hypothesis must be selected. The first ANOVA shows that the "experimentation group" has a truly higher satisfaction level than the "control group". Total satisfaction encompasses satisfaction from all stakeholders (students, company, professor, and liaison coordinator). In the box plot (upper left box Fig. 5) the difference between group 0 (control) and group 1 (experimentation) is clearly observed, depicting higher satisfaction levels for the Scrum-managed projects.

The second ANOVA draws a similar conclusion: the "experimentation group" shows a truly higher student satisfaction level than the "control group", which can be visualized in the box plot (lower left side Fig. 5). For both variables, the power tests showed the following numbers; for *total satisfaction* the power value was 97% (group 1) and 99% (group 0); for *student satisfaction level* the power value was 99% (group 1) and 100% (group 0). Having power values close to 100% confirms that the sample size was sufficient for both groups so mean differences can be identified.

2. Did agile project management with Scrum make it easier for the project to adapt to changes due to the COVID-19 pandemic?

C. The level for fitting to scope changes is the same regardless of the type of project management. (*Average Questions 8, 9 and 10*)

H_0: Fitting for Scope Change (control) = Fitting for Scope Change (experimentation)
H_1: Fitting for Scope Change (control) <> Fitting for Scope Change (experimentation)



D. The level of communication between those involved (team, client, advisor) is the same regardless of the type of project management.

H_0: Communication Level (control) = Communication Level (experimentation)
H_1: Communication Level (control) <> Communication Level (experimentation)

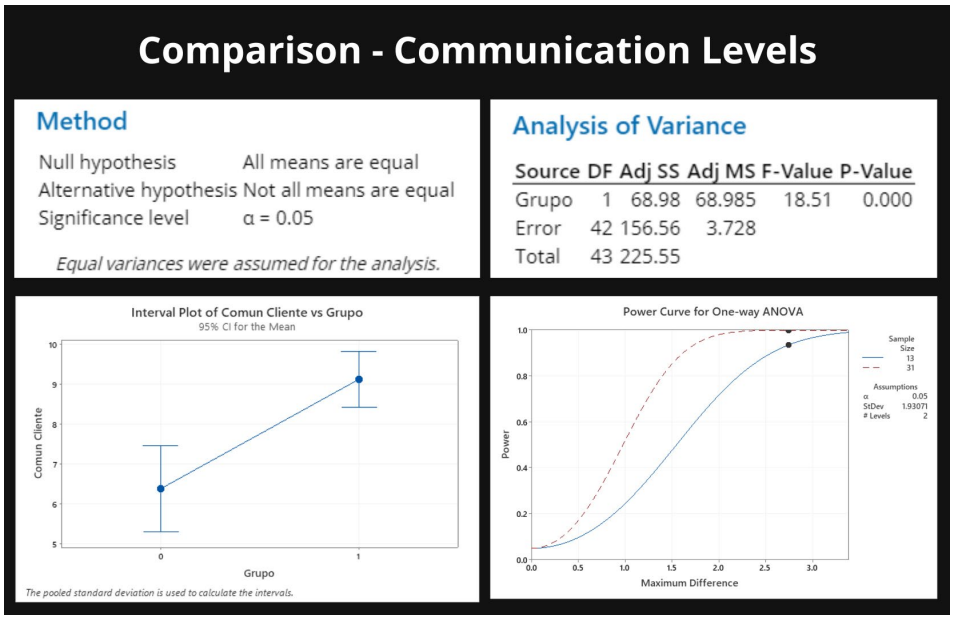


Figure 6. ANOVA Results to Fitting Scope Change and Levels of Communication.

The first ANOVA (upper side Fig. 6) shows a p-value equal to zero, indicating that the projects are done by the "*experimentation group*" are perceived to have higher flexibility to adapt to scope changes than the "*control*

group". The corresponding box plot also depicts the difference in means between group 0 (control) and group 1 (experimentation). Finally, a power and sample size test is performed to verify the level of power from the test due to the sample size. The calculations show high power levels (98% - experiment group, 100% - control group) that indicates the sample size is sufficiently large to identify mean differences in the study.

The communication levels among the stakeholders in both groups of projects are analyzed in the second ANOVA (lower side Fig. 6). The results show similar perceptions among students, project leaders, and advisors from both groups. The teams in the experimental group that used Scrum as a project-management methodology were ranked much better in communication outcomes than the teams in the control group that used the traditional approach to project management. Test powers are also close to 100% providing certainty that the sample size, although small, is sufficiently large to identify significant differences between group means.

Overall, the results were promising, leading to continuous application of Scrum-managed projects for outreach, capstone-like projects for our students, especially in these times of high uncertainty caused by the COVID19 pandemic. The survey includes variables of the respondent's role, type of company, type of project, sources of project information which support the overall finding of better project performance with the Scrum methodology.

5.2 Proposed Improvements.

It is planned to continue with this innovation in future semesters to expand the sample size, as well as the analysis of the impact of variables such as project type, scope, and type of companies on the levels of satisfaction of students and companies with the projects.

5.3 Validation.

All of the hypotheses were tested using ANOVAs done in Minitab, showing that indeed the Scrum-based projects were better for student and stakeholder satisfaction (Fig. 5) and adaptability to scope change and stakeholder communication (Fig. 6). Normality was monitored in the results, which were statistically significant with p-values equal to zero in all four hypotheses presented here.

A special concern was the sample size since the projects were done only by students to-be-graduating, which usually are less than 60 people per cohort. This concern was addressed through the application of "power and sample size" test in Minitab, using as inputs the experiment levels, maximum mean differences, and pooled standard deviation. All power results were higher than 97% for each group, indicating that even the "experiment group" sample size was sufficiently large to identify the mean differences in all four variables. Fig. 7 shows the power test results from Total Satisfaction ANOVA, indicating the power per sample on the left side and the power curve on the right side. Group 1, the smallest sample size (13 students), has a power of 97% which means a high probability to correctly reject the null hypothesis.

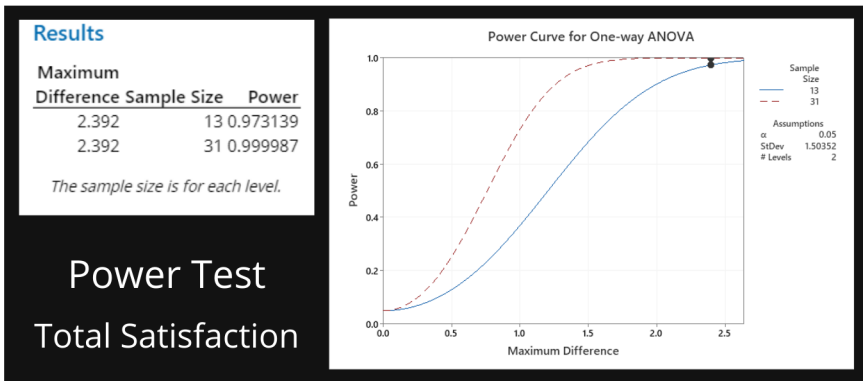


Figure 7. Power Test for Total Satisfaction

6. Conclusion

The integrative projects of the course IN3044 Industrial and Systems Engineering Projects (IIS) linked to training partners have high levels of uncertainty in the definition of their scope; the level of commitment, technical knowledge, and cultural differences of those involved. Managing these projects of high uncertainty through the agile management of Scrum, adapted to the specific conditions of the team and the company is the heart of the proposal tested in the semester February-June 2020 in 8 projects. With the participation of 30 students, 4 teachers,

and 8 different companies, it was possible to create two groups of projects: 1) experimental with agile Scrum management and 2) control with traditional project management. The teams faced various changes in scope and deliverables through the specific management of the project, the main change being remote work for the entire team as a result of COVID-19. The results of the proposal show significant evidence (mean perception difference of 20 points with a significance level of 5%) of the best performance of projects with the agile methodology of projects with Scrum to meet the needs of students, clients, and teachers both in the final result and in the project process.

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