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# Students Use Statistics to Justify Senior Project Selection

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# Students Use Statistics to Justify Senior Project Selection


## Abstract

Engineering and technology curriculums typically include senior projects as the culmination of a student's degree program. Students encounter difficulty during the selection process of the project due to uninformed decisions, lack of a structure, method or model, or an insufficient understanding of the resources needed to complete the project. The authors address this issue by introducing the utilization of a statistical model in a senior project course.

In the course, students work in teams and propose, design, test and build their senior project over the course of two semesters. Previously, teams proposed a set of projects and then settled on a final selection after consultation among the members and the professor. In order to make the selection process more structured, the use of metrics was implemented to evaluate alternate project concepts. Students were given a spreadsheet template model for the metrics and instructed to adapt the model for their measurements. The metrics were based on parameters that measure the adherence to the principles of engineering design, man hours estimated, team skills compatibility, resource availability, team interest correlation and team mission statement and public need alignment. For example, the resource metric measured the availability and the relative cost of all major components, hardware, software, and tools.

For each metric, the student team specified how it was to be measured. This process included the identification of what data was available that could be measured. Data sets utilized included relative cost of the proposed components, sales figures of similar products, and consumer satisfaction with similar products. From the data sets, a standardized, normalized score was computed for each metric. Using Bayes theorem, the prior probability was estimated and using the metric scores, the likelihood probability of project success and the posterior probability of project success was calculated using R language programs in the literature.

The results of the utilization of the statistical model indicate an increase in student success, preparedness, and overall achievement of the outcomes of their degree program.


## Introduction

Metrics are used to make measurements about performance in order to evaluate and compare.[1] They are widely used in sports to compare the performance of athletes in a game (e.g. batting averages and slugging average).[2] Likewise, Metrics are used to compare the performance of a task. [3] Software metrics are applied to measure the efficiency of the software/algorithm by measuring parameters such as speed and storage use.[4, 5] A simple metric can measure how long it takes to perform a task in actual time or man-hours (quantity), the number of resources required (quantity) and the quality of the outcome. A metric therefore usually measures quantity and/or quality. Since engineering design is performed using a series of tasks and has an outcome, it can be similarly measured using a metric.[6] The benefit of the metric is that it can be used to evaluate and compare outcomes such as alternate designs. The metric can be used to measure actual performance or projected performance.[7]

Let us look at the metric for measuring the time of a task. In order to estimate the time of each task, the students first time a base task of each type: conceptualize, design, implement and test. An example of a base conceptual task is researching similar products on the market. A base design task is drawing the schematic for a circuit board using Multisim. A base implementation task is wiring the circuit board. A base test task is running the motor and recording the specification data. The time for each of these tasks is measured several times. Each task to complete the project is then measured in relative base times.

In the authors' course in senior project, the students start the course by brain-storming and conceiving three alternative and completely different concepts for their senior project. Project teams typically consist of two to three students. The course eventually will go through four phases: proposal, design, construction and testing. The project typically consists of a control system powered by microcontrollers and sensors and actuators. There are requirements and expectations for the project.

The project must be unique and not commercially available. The project should further the interests and goals of the team members. It should contribute to society; be a potential product that the society will identify with and improve the standard of living or quality of life (make life easier). The potential product must have some part that is unique compared to anything that is in the marketplace. The product can be a totally new technology or a modification and improvement in current technology. It can be similar but cheaper to manufacture than those found in the marketplace. It can be constructed so it is easier to manufacture. Students must research thoroughly similar products in the marketplace. They must document this research and state what difference(s) their potential product has to the similar products they found through their research.

To evaluate each of the three concepts and choose the best one of the three, the authors derived an evaluation system of the seven metrics described above. The evaluation method is shown below. The student teams were given a spreadsheet template for the seven metrics. They were encouraged to modify the metrics as appropriate for their concepts. Each metric included a fuzzy-weighting factor which imposed an increasing or decreasing emphasis on that particular metric.[9] The same seven metrics (Figure 1) were applied to all three senior project concepts.

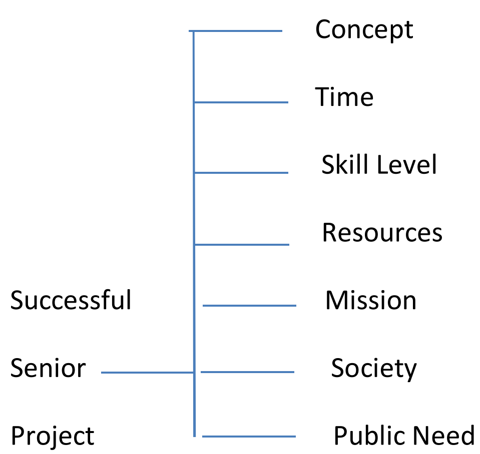


Figure 1: Metrics for Successful Senior Project

The proposed concept for the senior project has quality if it is fully researched, unique and creative. In being fully researched, it should be evident upon oral examination that the student team is well versed in all aspects of the concept. It should be unique in that the student team can describe similar products on the market and indicate in detail how their project differs. It should be creative in that the student team can describe a part of their concept that is completely new either in design, construction, testing or potential manufacturing and sales.

Time is an important metric in engineering design and development. How long does it take to achieve the outcome? All projects have a limit and there is a deadline for delivering the product. Minimizing the time duration and meeting the deadline are considerations in all undertakings. Moreover, if the project cannot meet the deadline, then it is self-eliminating. If the project can meet the deadline, then when comparing project proposals, the project that measures the shortest time, would possess the better time metric in comparison. Time can be measured in absolute time or in man-hours or computer time.

Another metric is skill-level. Skill-level is a measure of performance foremost in output. The number of hits a batter gets in a season is output. A batting average metric is the number of hits a batter gets divided by the number of at-bats. Skill-level can be measured in output, outcomes and error rate. [8] Output is quantity and outcomes and error rate are quality. Other skill-level quality measurements that can only be used for projections are years of experience and certifications.

Resource availability, a metric, is measured by quantity and quality (cost, specs). A resource (parts, tools, information) of a particular quantity and quality is available, can be made available or is not available.

Mission compatibility, a metric is measured by quantity (number of interests and goals) and quality (meets mission goals). The mission is the generic basis of the specific requirements of the project. The project should endeavor to fulfill the mission as promulgated.

Societal compatibility is an important metric that measures contribution. A project and product is most useful if it contributes to society’s welfare. This metric measures the quantity (the number ways the potential project is to help society) and quality (by rating the public identification with the potential product). Improving the quality of life is part of the social compatibility metric.

The public needs metric counts the number of pronounced needs to be fulfilled. The quality rates the competition for these needs and the uniqueness of the potential product. This metric further characterizes the potential market share.[8] Meeting the needs has a threshold. For example, if the need is meeting the accessibility requirements then it must meet the standards of the American with Disabilities Act.

**Results**

Table 1: Metrics

| Metrics | Normalized Score |
|---|---|
| C1 – Concept is fully researched | 1 or 0 |
| C2 - Concept is unique | 1 or 0 |
| C3 - Concept is creative | 1 or 0 |
| T - Time in man-hours required fits schedule | 1 or 0 |
| Sk - Skills needed are possessed | 1 or 0 |
| R1 - Resources available | 1 or 0 |
| R2 - Cost of resources within budget | 1 or 0 |
| M - Project conforms to team interests | 1 or 0 |
| So - Eventual product helps society | 1 or 0 |
| P - There is a public need for the product | 1 or 0 |

The students were instructed to compute the metrics listed in Table 1 above and apply them to their alternative senior project concepts. The score for each metric was set at 1 or 0 according to meeting or not meeting a threshold. The nomenclature for the metrics is illustrated in Figure 2 below.

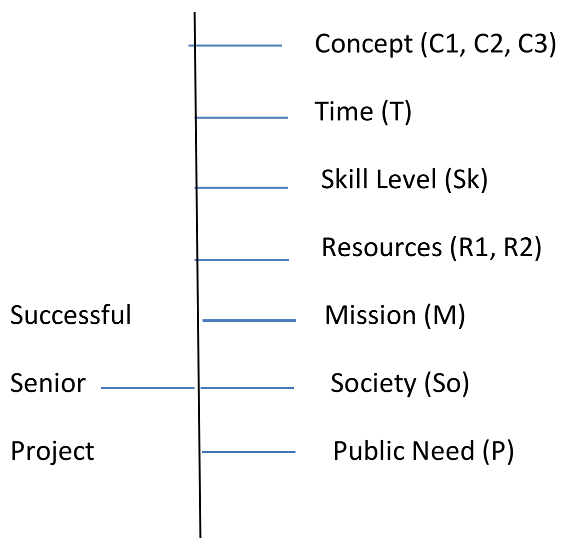


Figure 2: Metrics and Nomenclature for Successful Senior Project

As shown in Table 2, sources of measurements can be team members, professors, peers and external sources. Each source employs the fixed metrics according to a template and follows the protocol to estimate the score.

Table 2: Multiple Sources of Measurements

| Measure | Source | Method | Type |
|---|---|---|---|
| Fixed Metrics | Team Members | Scoring Template | Estimate |
| Fixed Metrics | Professor(s) | Scoring Template | Estimate |
| Fixed Metrics | Peers | Scoring Template | Estimate |
| Fixed Metrics | External Sources | Scoring Template | Estimate |

Below we show questionnaires (Tables 3, 4 and 5) that were used to score a sample student senior project. The computation of the Metric Values is outlined in the next section. The questionnaires (Tables 3, 4 and 5) were completed for a senior project entitled, The Three Wheel Electric Bike. The Three Wheel Electric Bike project was proposed by a student team as a retrofit kit which facilitated the attachment of a battery powered wheel to a normal two wheel bike. The student team promoted the kit as a low cost option that would encourage people to ride bikes more as transportation, save fuel and improve the environment.

**Metrics Values (Table 2 above) were computed as follows:**

**Concept metric (C): three parts, C1 thoroughly researched = 1, otherwise = 0, C2 unique = 1 otherwise 0 and C3 creative = 1, otherwise = 0.**

**Protocol:** *Estimate (1) the amount of research completed, (2) the uniqueness of concept and (3) the amount of creativity. Assign either a 1 or zero for each of the three metrics.*

**Time metric (T): < 30 weeks = 1 > 30 weeks = 0**

***Protocol:*** *List all the tasks and milestones to accomplish proposal, design, construction and testing. Assign time duration to each task in man-hours. Add all the time durations to get total estimated time. Allotted time equals the number of man-hours available in 4 eight week session (proposal, design, construction, testing, and preparation of final report, presentation and demonstration. Assign a 1 if there is enough time to complete all tasks, otherwise assign a zero.*

*The scoring for T is shown in Table 3 using the columns labeled Estimated Time and Estimated Time.*

**Skill metric (Sk): possess all skills (SP) needed =1 missing skills = 0**

*Scoring Procedure: For each task list all the skills needed (e.g. microprocessor hardware design, software design, assembly language programming, C programming, testing, organization, project planning, leadership, research writing, presentation design, speaking, record-keeping, scheduling, and all other required skills) Assign a number of 1-10 for each skill to each team member. Add all the skill numbers and divide by the number of skills to get the skill score. If >7, assign 1 otherwise assign 0.*

*The scoring for Sk is shown in Table 3 using the columns labeled Skills (Sk), Possess skills (Sp) and Number of skills (SN) (number, No.).*

**Resources metric (R): R1 all resources needed by spec available = 1, not available = 0 and R2 all resources needed within budget available =1, not available =0.**

*Protocol: For each task list all the resources needed (e.g. parts software, parts hardware, tools software, tools hardware, tools testing, spec sheets, procedure descriptions, research papers, consultations with experts required resources ) Assign a number of 1 -10 for the availability of each resource. Add all the resource availability numbers and divide by the number of resources. If >7, assign 1 otherwise assign 0 for R1 metric. Add up the costs of all resources and assign a number of 1 or 0 for R2, if the total cost is within budget.*

*The scoring for R is shown in Table 4 using the columns labeled Resources(R), Availability (RA) and No. (number, RN).*

**Mission metric (M) = 1 or 0 as described in the protocol**

*Protocol: The project team has a mission statement which lists all the goals and interests of the team and its members and the project. Assign a number of 1 - 10 for each goal and interest and its compatibility with the project. Add all the compatibility numbers and divide by the number of interests to get the mission score. If > 7, assign 1 otherwise assign 0.*

*The scoring for M is shown in Table 5 using the columns labeled Interest Compatibility (M) and No. (number, N).*

**Society metric (So) = 1 or 0 as described in protocol**

*Scoring Procedure: The project team has a mission statement which lists all the goals and interests of the team, its members and the project. Assign a number of 1-10 for each goal and interest and its compatibility with helping society, identifying with the project and improving human life. Add all the compatibility numbers and divide by the number of interests compatible to get the average society score. If > 7, assign 1 otherwise assign 0.*

*The scoring for So is shown in Table 5 using the columns labeled No. (number, N) and So(S).*

**Public Needs metric (P) = 1 0r 0 as described in protocol**

*Scoring Procedure: The team has a needs statement which lists all the public needs fulfilled by the project and the potential product. Assign a number of 1-10 for each public need fulfilled. Public need fulfillment takes into account whether or not the need is already fulfilled or the extent that there is competition (market share) and the probability that it can be manufactured successfully and the probability that it can comply with all regulations and safety and ethical concerns. Add all the public need numbers and divide by the number of public needs to get the average public need score. If >7, assign 1 otherwise assign 0.*

*The scoring for P is shown in Table 5 using the columns labeled Pub Needs, Pub (P) and No. (number, N).*

**Questionnaires/Templates (Tables 3, 4 and 5) to Score Metrics:**

**Table 3: Team Metric Scoring: Time (T), Skills (Sk)**

| Metric Scoring for Senior Project – Three Wheel Electric Bike | | | | | |
|---|---|---|---|---|---|
| Tasks | Estimated Time | Available Time (T) | Skills (Sk) | Possess | No. |
| | ET (man-hrs) | (man-hrs) | | SP | SN |
| Log Book | 10 | 160 | Recording | 10 | 1 |
| Concept | 3 | 60 | Research | 10 | 1 |
| | | | brain-storm | 10 | 1 |
| | | | chart/Excel | 8 | 1 |
| Schedule | 3 | 40 | scheduling | 8 | 1 |
| | | | charting | 1 | 1 |
| Research | 40 | 80 | | | |
| Make diagrams | 20 | 30 | | | |
| presentations | 20 | 25 | writing presentations | 10 | 1 |
| write proposal | 20 | 30 | writing | 10 | 4 |
| proofread | 5 | 15 | planning | 9 | 1 |
| | | | proof-reading | 10 | 1 |
| design | 40 | 45 | software design | 10 | 1 |
| | | | hardware design | 10 | 1 |
| make diagrams | 20 | 45 | diagram making | 9 | 1 |
| design document | 20 | 25 | | | |
| order parts | 10 | 10 | ordering | 10 | 1 |
| receive parts | 1 | 25 | receiving | 10 | 1 |
| construct | 80 | 90 | hardware construction | 10 | 1 |
| | | | software construction | 10 | 1 |
| test plan | 20 | 30 | | | |
| checker | 1 | 30 | | | |
| testing | 60 | 70 | testing | 10 | 1 |
| final presentation | 1 | 50 | make presentation | 10 | 1 |
| final documentation | 40 | 50 | | | |
| orchestrate demo | 10 | 50 | orchestrating | 6 | 1 |
| Total | 424 | 960 | Total | 181 | 23 |
| | 424 < 960 Meets Protocol | | 181/23 Meets Protocol | | |
| Metric Normalized Score | 1 | | | 1 | |

**Table 4: Team Metric Scoring: Resources (R)**

| Three Wheel Electric Resources (R) | Bike Availability R1 | cost R2 | No. RN |
|---|---|---|---|
| word processor | 10 | 10 | 1 |
| Library | 10 | 10 | 1 |
| search engines | 10 | 10 | 1 |
| Excel | 10 | 10 | 1 |
| MS project | 10 | 10 | 1 |
| Drawing programs | 10 | 10 | 1 |
| Presentation software | 10 | 10 | 1 |
| Diagramming Software | 10 | 10 | 1 |
| internet, telephone | 10 | 10 | 1 |
| Postage | 10 | 10 | 1 |
| hardware tools | 10 | 10 | 1 |
| software tools | 10 | 10 | 1 |
| Checklist | 10 | 10 | 1 |
| testing tools | 10 | 10 | 1 |
| Signs | 10 | 10 | 1 |
| Total | 150 | 150 | 15 |
| 150/15 meets protocol | | | |
| Metric Normalized Score | 1 | 1 | |

**Table 5: Metrics: Mission (M), Society (So), Public Needs (P)**

| Three Wheel Electric Bike | | | | | | |
|---|---|---|---|---|---|---|
| Interests | Interest compatibility | No. (N) | So(S) | Pub Needs | Pub (P) | No. (N) |
| environment | 10 | 1 | 10 | environmentally compatible | 8 | 1 |
| economic | 10 | 1 | 10 | Economically sound | 7 | 1 |
| safety | 7 | 1 | 7 | Dependable, rugged, safety features | 5 | 1 |
| convenience | 7 | 1 | 7 | Transportation ease | 5 | 1 |
| Total | 34 | 4 | 34 | | 25 | 4 |
| 34/4 meets protocol | | 34/4 meets protocol | | 25/4 does not meet protocol | | |
| Metric Normalized Score | 1 | | 1 | | 0 | |

A bar graph profile (Figures 3, 4 and 5) was developed from the metric values for each senior project concept. The profile illustrates the strong points and weak points of the concept. As this method gains experience, it should be possible to recognize categories of senior project concepts from examining the metric profiles. Below we compare the bar graph profile for the three student senior projects: The Three Wheel Electric Bike which was described above along with the Training Pad Force Finder and the Eye Tracking Mouse. The Training Pad Force Finder was a project for an electronic device to be attached to a training pad such as used in football practice. The device would track and save data on the forces that the player applied to the pad. The intent of the device was to improve the training of the players. The Eye Tracking Mouse was a project to control the normal mouse with the movement of your eyes rather than your hand or fingers. The advantage to the user would be to allow the user to be hands-free and surf the internet or engage in other tasks. It would also be helpful for anyone unable to use their hands or finger in a normal fashion.

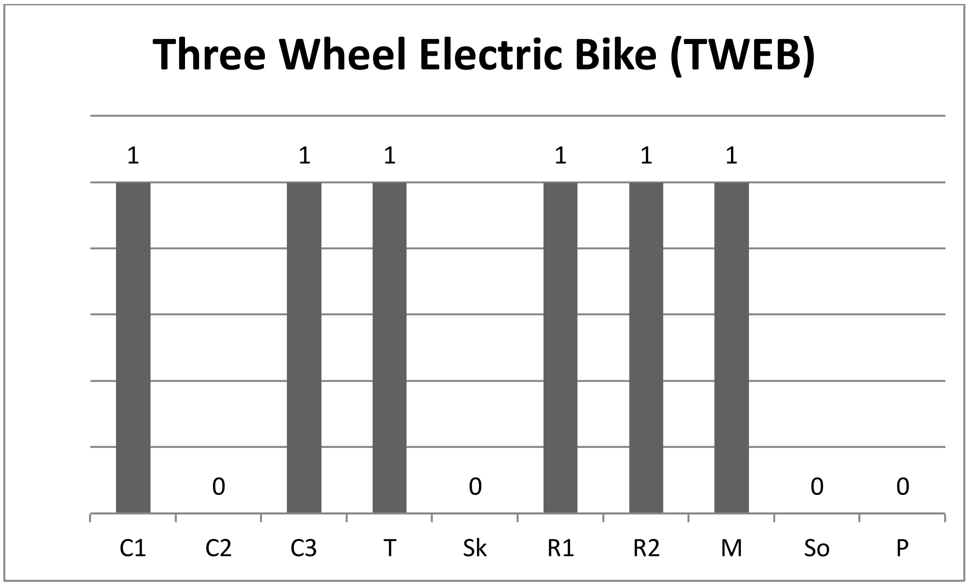


**Figure 3: Metric Profile for Three Wheel Electric Bike Concept**

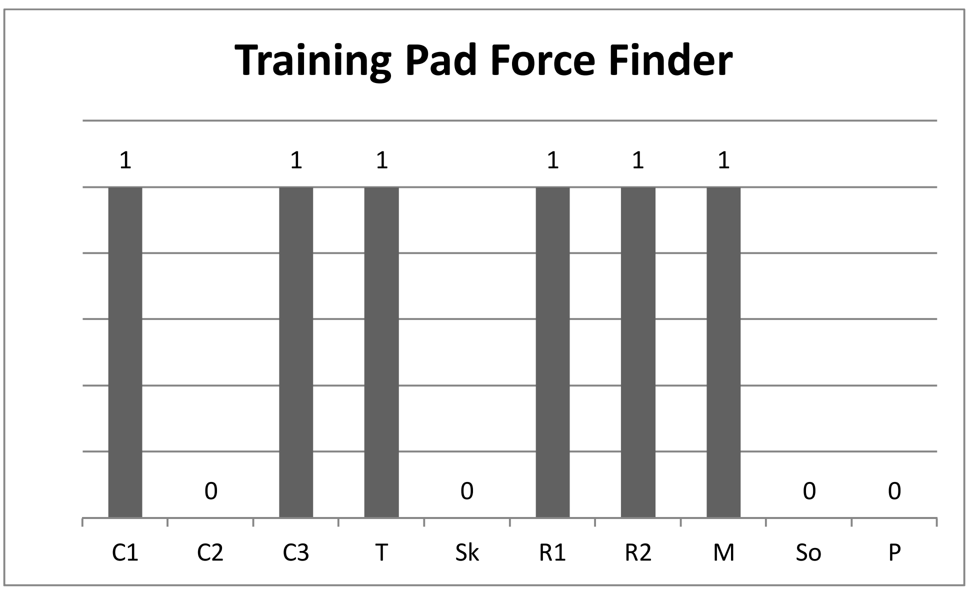


**Figure 4: Metric Profile for Training Pad Force Finder Concept**

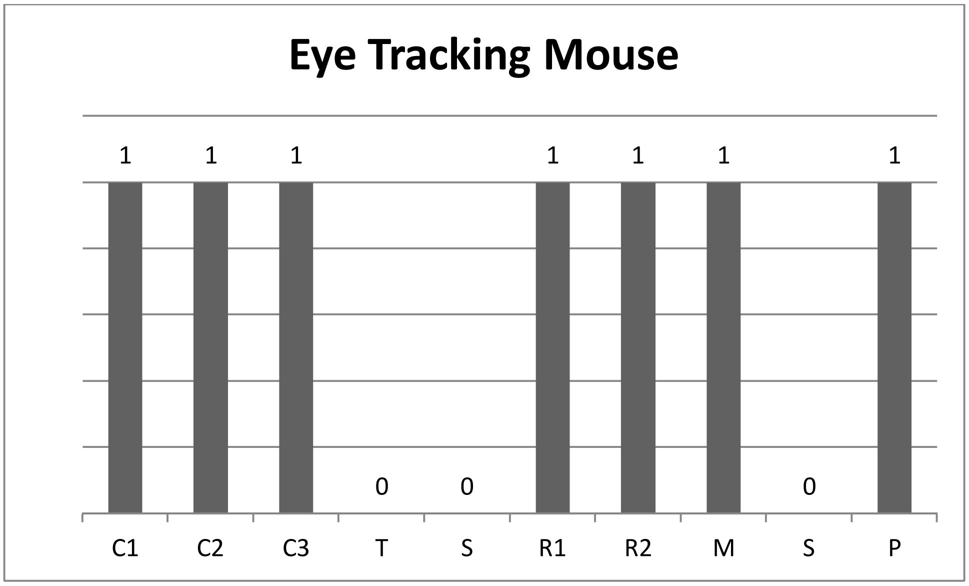


**Figure 5: Metric Profile for Eye Tracking Mouse Concept**

Each student team calculated a metric data set of three alternate concepts for each senior project. This allowed for comparison and selection of the best and most probable concept. The highest scored concept would be selected. This is illustrated in Table 6.

**Table 6: Binomial Metric Data Sets for Senior Project Concepts**

| Concepts | | | | | Metrics | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | T | Sk | R1 | R2 | M | So | P |
| 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| 2 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 |
| 3 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 |

The data sets were used to generate a success probability for each senior project concept using Bayes' Theorem.[12]

**Application of Bayes' Theorem to Estimate the Probability of Success of the Senior Project Concept:**

As per Bayes' Theorem [12], the probability of success of the project concept given the metrics can be computed using the following equations:

$P(\theta|D) = p(D|\theta) * p(\theta) / p(D)$

Where $P(\theta|D)$ is the posterior probability of success of the concept given the values of the metrics (D) generated.

$p(D|\theta)$ called the likelihood is the probability that the metrics (D) could be generated by the concept. In the case of the metrics, the likelihood can also be expressed as $p(z,N|\theta) = \theta^{z} * (1-\theta)^{(N-z)}$ where N is the number of metrics and z is the number of metrics with normalized value of 1 (see plot of likelihood below).[12]

$p(\theta)$ is the prior probability or the strength of the belief in the concept with the metrics. In our study, the prior was approximated as increasing the more metrics that had a normalized value of one (see plot below).

Where $p(D)$ called the evidence $= \int p(D|\theta)\, p(\theta)\, d\theta$ over all values of theta – in this case all possible values of the metrics

Programs written in the R programming language are available to generate plots of the posterior probability, the likelihood and the evidence.[12] R is a programming language that is used by a large population of statisticians. As an open source language, a vast collection of statistical routines is available for computation and plotting the results. In this application, the user inputs data for the measurement of the concept (in this case normalized values of the metrics) and an estimated or calculated prior probability density. We show below (Figure 6) the graphs of the posterior probability densities generated for the senior project concept. These plots display the posterior probability of success of the entitled senior project concepts.

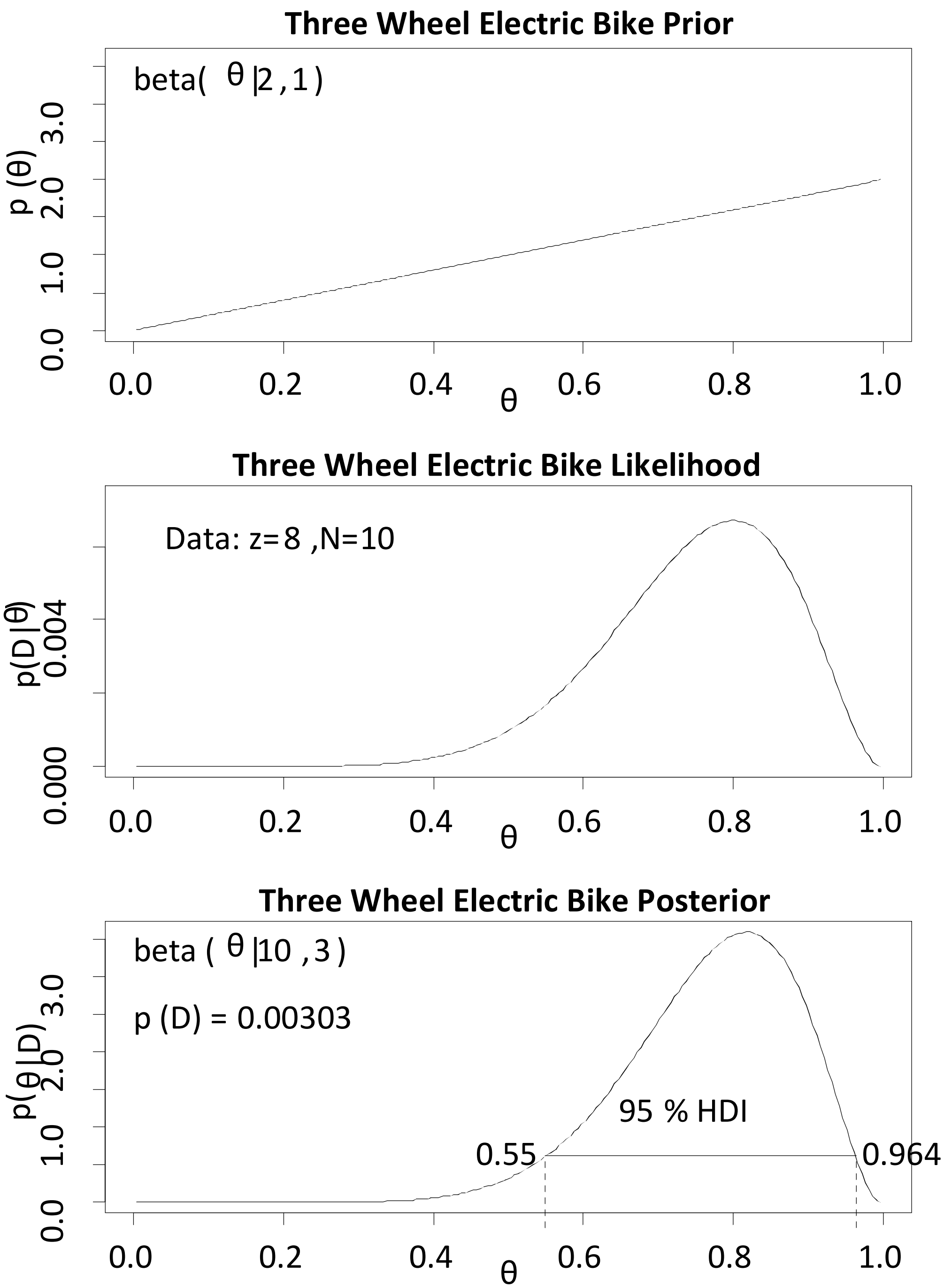


**Figure 6:**

**Priors, Likelihood and Posterior Probability Density of the Senior Project Concept**

These computations and plots and posterior probability densities are upgraded based on new evaluations of the metrics, modifications of the metrics and use of the former posterior probability as the new prior. The posterior probability of success of the concept improves by adding more metrics with a normalized value of one that make success of the concept more probable. As the project continues, metrics that contribute to success are amplified and metrics that do not contribute to the success are downgraded or eliminated.

## Conclusions

Students used these statistical methods to select the senior project design that was ultimately designed and constructed. By adding these metric and statistical provisions to design assignments in engineering and technology courses, students are better equipped to make selections of the best designs in terms of performance, cost, and return on investment and success when faced with new product situations and in their future careers.[13]

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