# Performance vs. Requirements: Team and Customer Perspectives

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One of the ways to measure the success of a design project is the final performance of the product or process vs. engineering requirements. This paper investigates the performance vs. requirements results submitted by capstone design teams at the end of the project compared with customer perception of the success of the project. As a group, the capstone teams and their customers had similar assessments of team achievement of requirements. Nearly all teams and nearly all customers indicated that more than 60% of the project requirements were met. The teams that were scored the highest by their customers gave themselves similar or worse scores than their customers assigned. Teams that were scored the lowest by their customers gave themselves better scores than their customers assigned. Customer response rates were low, and future work will include efforts to better capture customer feedback.

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## Background

The Multidisciplinary Senior Design (MSD) program at the Rochester Institute of Technology (RIT) takes student teams on a two-semester capstone journey that begins with problem definition and ends with integrated system testing and public dissemination. A project can be considered a success when:

- The students have integrated their classroom knowledge into a real-world design exercise,
- The students have functioned as a productive team,
- The students have applied elements of project management to the relatively independent execution of their project, and
- The product or process satisfies the customer.

While each of these elements is important, this paper focuses on the last: teams' demonstration that the product or process satisfies the customer's requirements. Since the success of our program requires a pool of willing customers, their satisfaction with the outcome of the project(s) they sponsor is critical.

There is a great deal of literature related to capstone assessment[1], but this is often focused on assessment of learning outcomes. This is indeed important for capstone design, but in order to maintain a supply of high quality projects, it is also important to ensure that students are delivering results with at least some level of success to their customers. Methods for an overall quantitative assessment of prototype performance have been reported in the literature are limited and often consist of subjective scoring[2,3] with a few exceptions. Sobek and Jain[3] developed and tested a separate customer satisfaction survey that included customer perception of % design objectives achieved, but this was not compared with teams' self-perception. Smyzer and Jaeger[4] developed a scoring system for judges to evaluate how well-developed a team's solution is and how much progress they have made toward verifying their solution, but this evaluation did not include validation or customer input on the teams' achievements. Brackin and Gibson[5] identified a performance criterion to "Test and refine the product or process implementation until the product or process design specifications are met or exceeded", but in a program where the focus was on delivering a design concept rather than a functional prototype, so there was limited demonstration of success.

RIT MSD teams conduct reviews with their customers every three weeks through both semesters. During the first semester, these reviews include discussions around setting requirements, and then demonstrating that a proposed design will meet requirements. During the second semester, reviews include the results of testing to demonstrate the extent to which requirements are met.

All teams start with a high-level problem statement and some preliminary customer requirements (attributes or needs), but many teams do not have well-defined engineering requirements (performance metrics and specifications). All teams are expected to critically review and refine any given information.

Teams spend the first three weeks of the semester coming to a mutual understanding of the problem that they are going to solve. They also come to agreement with the customer on a prioritized set of customer requirements, or desired attributes of the finished design, and a set of engineering requirements, or metrics and target values that will enable the team to select the best design concept(s) and eventually create a set of test plans and determine objectively whether or not their design was successful in meeting their customer requirements. As teams progress through their first semester and their detailed designs converge to their final states, some of the engineering requirements may need to be adjusted, after discussion and approval with the customer. For example, a team may determine that time or resource constraints prevent them from pursuing their most ambitious design concept, so they may negotiate reduced expectations with the customer. At the end of the first semester, with their design concept fully detailed, students summarize their *expected* performance vs. final engineering requirements for the customer, based on their proposed design.

Throughout the second semester, students implement their designs and conduct subsystem-level and integrated system-level testing as they progress through their build. At their final demonstration, they should be able to demonstrate satisfactory performance on all of their engineering requirements. Beginning in 2014-15, each team then submits a final requirements document that captures their initial targets, their *expected* performance, and their final *actual* performance vs. engineering requirements.

After the end of the project, customers are invited to provide feedback on the team they worked with, the project outcome, and the program in general, using an online survey. One question specifically asks:

"If 100% implies that your experience with our capstone design program met all of your requirements, please select which of the following best describes your experience: (a) >90%: the team met all or nearly all of my requirements, (b) 60-90%: the team accomplished most of what I required, (c) 40-60%: the team accomplished about half of what I required, or (d) <40%: the team accomplished less than half of what I required"

## Problem Definition: Writing Requirements

Teams begin their projects by conducting background research and interviewing stakeholders. From this information, teams are required to write a list of customer requirements (CR), and a list of engineering requirements (ER) that map back to the CR, complete by the end of the third week of the semester. At this time, the CRs, ERs and overall scopre are reviewed with the primary customer, and the team is expected to improve their requirements. The exercise of writing requirements is generally done in accordance with Ulrich & Eppinger[6]. Students typically use their CR as a starting point to develop their ER, leading to a nearly one-to-one relationship between the CR and ER.

During the second three weeks, teams perform a functional analysis of their desired system, and they are encouraged to correlate their system functions to ER, similar to the approach described in Otto and Wood[7]. At this point teams also perform first-order feasibility analyses in order establish the completeness and feasibility of their proposed ER. By the end of week 6, teams are expected to have a nearly-final set of ER, with customer agreement, which they will design to during the remainder of the first semester of the project.

While the team and customer must come to a mutual agreement on the final ER list, it is possible that both team and customer may miss an ER. The end result in this case could be a dissatisfied customer, despite testing that shows all documented requirements have been met. At this point in time, we are not capturing this information in team or customer reporting, although some teams do identify additional requirements during their build & test semester that they believed should have been included in their original ER.

## Team Implementation: Test vs. Requirements

By the end of the first semester, teams are required to submit a test plan that details the methods they will use to demonstrate their achievement of each system-level ER. Teams will often define additional tests at the subsystem or even component levels, as appropriate. Component- and subsystem-level tests are typically completed during the first 5-8 weeks of the second semester. Full integrated system testing typically happens in weeks 8-11, and this is when students compile their performance vs. requirements results and share prototyping progress with the customer. A sample document from 2014-15 is shown in Table 1.

Table 1: Performance vs. requirements snapshot

| Engr. Requirement (metric) | Ideal Value | Marginal Value | Current Value |
|---|---|---|---|
| Pressure to leg of AFO (mmHg) | 20 | 40 | 18 |
| Design failure factor of safety | 1.3-1.8 | 1.3-1.4 | >3 |
| Average skin temperature increase from use (°F) | 1 | 3 | 1.42 |
| Battery in water repellant case (IP Code) | IP54 | IP54 | IP54 |
| Time between charges | 8 | 6 | 7.3 |

The class results from 2014-15 are summarized in Figure 1. Nearly all teams submitted this required document, with 41 complete and usable responses out of

45 teams. Most teams submitted actual numerical test results for their performance, but some reported only as "green" (met), "yellow", or "red" (not met). There were inconsistencies in the way teams reported their results, particularly in the "yellow" category. Examples cited by students as reasons for labeling an ER yellow were:

- Capability designed into the system, but not tested due to circumstances beyond team control
- Negotiated with customer: revised, then met, ER
- Achieved marginally acceptable value for ER

To maintain consistency, the results for teams reporting actual performance vs. requirements values were converted to "green" for met or "red" for not met, so that all data could be compared. For teams reporting actual values, a "yellow" was only assigned if the requirement was not tested due to circumstances beyond the team's control. The resulting green/yellow/red ER count was tallied for each team, shown in Figure 1. Each horizontal bar represents a single team's outcome.

### Customer Perspective

The results from the 2014-15 customer survey are summarized in Figure 2. Response rate was low, with only 15 responses for 45 teams. The most common response was that teams met 60-90% of the customer's requirements, and no customer indicated that teams accomplished less than half of what was required.

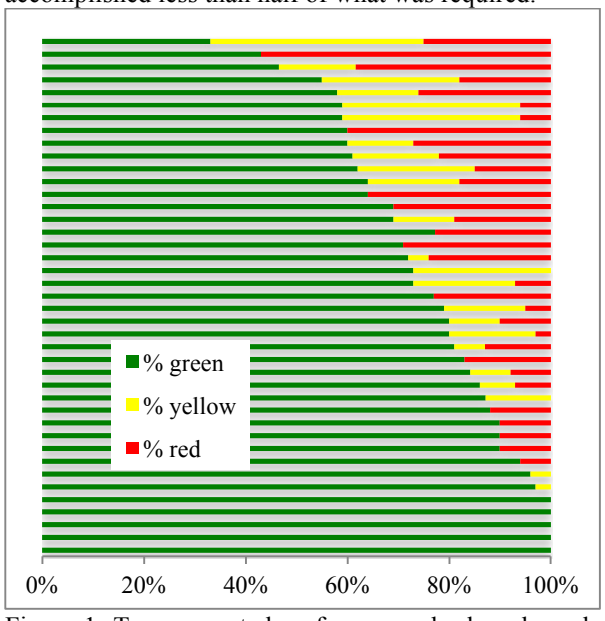


Figure 1: Team-reported performance, broken down by green-yellow-red achievement (n=41).

Customers were also provided an opportunity to provide open-ended comments. One customer cited specifically that the team's documentation requirements were not met: an example of a potential confounding factor. While documentation is not typically listed as an ER, customers may understandably evaluate the project outcome based in part on whether or not they are left with an acceptable documentation package. Another customer discussed distinctions between higher-priority and lower-priority requirements in the comments, while teams made no distinction by priority when reporting on performance vs. requirements.

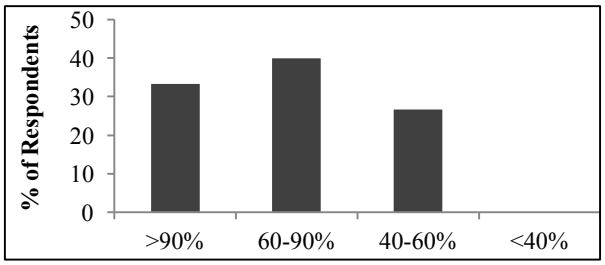


Figure 2: Customer-reported performance (n=15).

### Team and Customer Perspectives Compared

The team and customer data, grouped by bin (e.g., >90%, 60%-90%, etc.) are shown in Figure 3. As a whole, teams' self-reporting was consistent with the customer perspective. The "green" requirements, which are judged by the team to have been clearly met, give the most conservative representation of the teams' self-assessment. As a whole, customers reported >90% achievement of requirements more frequently than teams. The same was true for the 40%-60% achievement range: customers more frequently put teams in this category than teams did.

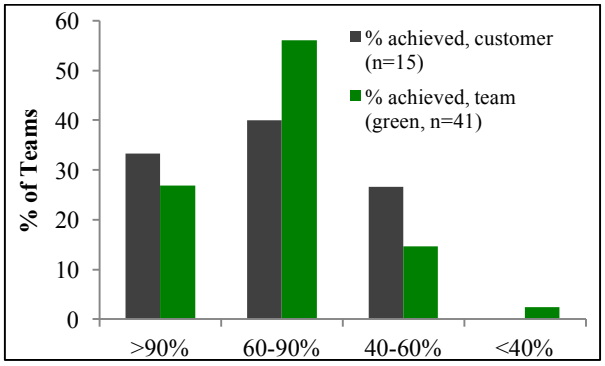


Figure 3: Customer- and team-reported performance.

For a one-to-one comparison of customer and team reported achievement of requirements, the data were limited to those projects where customer feedback was provided. Figure 4 shows the comparison, with team responses given in terms of actual percent of ER achieved and customer responses given at the center of the ranges defined previously. A unity line is provided for reference; symbols appearing above the line are teams reporting *higher* achievement than their

customers reported, and symbols appearing below the line are teams reporting *lower* achievement than their customers reported. In the case of customers reporting that their teams only achieved 40%-60% of their requirements, those teams *all* reported achieving >60% of their requirements. This is the most concerning result, since it represents instances where the customer ranked the teams as our worst performers, but the teams think they are doing much better than they actually are.

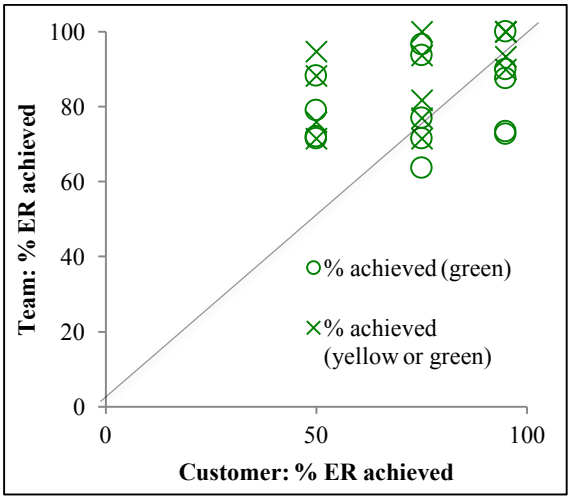


Figure 4: One-to-one comparison of team and customer assessment of % ER achieved (n=15).

## Discussion of Results

One of the key differences in the team and customer perspectives is that the team is solely reporting on performance vs. ERs, which are typically limited to functional requirements, although many teams do include constraints (such as cost) in their requirements list. Some customers may be looking for aesthetics, documentation in a particular format, or more frequent communication from the team. If these "requirements" are not captured in the ER list, their absence will not show up in the team's self-assessment of performance vs. requirements. The customer, however, may still include these in their holistic assessment of the team's performance. Clearer communication to the customer will be key for future information gathering.

Second, some functional requirements may not have been captured during the course of the project, even though the team and customer communicate every three weeks and come to agreement on a final ER list at the end of the first semester of MSD. For example, repeatability, durability, or ergonomic factors may be overlooked before prototype delivery to the customer.

As with nearly every difference of opinion that arises during a capstone design experience, communication is the key to solving problems. In this case, team and customer assessments were collected separately, with no opportunity for discussion. If the customers were asked to assess the teams performance vs. requirements at the time of handoff or at set intervals throughout the build & test phases, missed requirements could be added and unspoken requirements unrelated to functionality could be captured. At the very least, it would allow us to identify the reasons for different team and customer assessment. Until the reasons are identified, underlying problems cannot possibly be addressed.

## Next Steps

The steps that will be taken in future years to improve on this reporting method are:

1. Solicit customer feedback on a written form at the time of final handoff. This will ensure better response rates and enable discussion related to the customer's rationale behind the scoring.
2. Capture customer input as to whether the ER list was complete, or whether failure to meet a requirement was due to a *missing* ER.
3. Clearer performance vs. requirements reporting instructions will be given to the teams and customers, for more consistent interpretation.

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