Motivating Students to Give World Class Performance via FSAE

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Abstract: *Formula SAE (Society of Automotive Engineers) is the largest student-based competition in the world, involving student teams designing, building and racing a small open-wheeled racing car. Conceived in the USA in 1981, there are now over 200 university teams involved, with events in the USA, UK, Australia, Germany, Italy and Japan, and with growing interest in South East Asia. An overview of the competition and insights into how to build and manage a successful team is provided, based on the RMIT team from Australia. The RMIT team started in 2000, and in a relatively few years has won the competitions in USA, UK and Australia, including concurrently setting lap records and winning the Fuel Economy Event. Strategies are outlined which foster the active student engagement required for succeeding in the competitive world of FSAE and insights are provided with more sustainable FSAE cars needed for sustainable racing.*

1 Introduction – What is FSAE?

The Society of Automotive Engineer International (SAE-Int) defines FSAE as follows;

"The Formula SAE® competition is for SAE student members to conceive, design, fabricate, and compete with small formula-style racing cars. The restrictions on the car frame and engine are limited so that the knowledge, creativity, and imagination of the students are challenged. The cars are built with a team effort over a period of about one year and are taken to the annual competition for judging and comparison with approximately 120 other vehicles from colleges and universities throughout the world. The end result is a great experience for young engineers in a meaningful engineering project as well as the opportunity of working in a dedicated team effort" (from http://students.sae.org/competitions/formulaseries/)

Figure 1 RMIT 2007 car

Figure 2 RMIT 2008 First Electric car

1.1. History

The above statement reflects the rules and numbers of teams for the major event in the USA circa 2009. However, a similar competition has been run in the USA for over three decades. The history of the competition can be traced to 1976 when SAE-Int started to run student Mini Baja competitions; off road races named from the Baja 1000 race in Mexico. The push for a road race equivalent of this – Mini Indy - came from the company Briggs and Stratton, who in 1979 supplied 5 hp engines and thirteen teams competed. The first FSAE competition, held in 1981, permitted any four stroke engine and limited the power via a 25.4 mm (1") restrictor – a regulation that remains to the present day. Since then there has been a single competition held every year in the USA until 2006, when two events were first run; a (new) West Coast Event near Los Angeles and an event in Pontiac, near Detroit. In 2008, due to increasing pressure from the numbers of universities who wished to compete, a third event was run in America. Over that period there were several changes to the rules – the most significant being a revision driven by Bob Woods from The University of Arlington to now include static events and with the overall winners being decided by the summation of points accrued with a possible total of 1000. Now several events are running around the world including in the UK, Brazil, Italy, Germany, Australia and Japan, with more events planned in other countries. Whilst there can be slight variations between countries, the rules are based on the USA competition outlined below. Environmental concerns have led to the adoption of a hybrid competition (run in parallel with the standard IC event), the ability to use ethanol (with minor revisions to the rules, including reducing restrictor size) and a new event for all electric cars, planned to be held in Germany in August 2010.

1.2. The Competition and its Constituent Events

The competition is made up of eight separately evaluated events – three of which are static (i.e. static studies on each car and sometime a presentation to an industry panel) and five dynamic (i.e. evaluation based on measured car performance parameters). A complete version of the rules covering the events, regulations pertaining to the cars etc. can easily be found on the web (Anon, 2009). A brief description of each event, including the points allocated, is given below.

Presentation 75: Here one or two students from each team must present their business case to a panel for the limited volume production of their vehicle. Many aspects of the car, (e.g. design for mass manufacture) are usually presented and other aspects often include potential plant layout and return on investment. We have found it useful to consider this as presenting to venture capitalist to give confidence in achieving a good return on investment.

Design 150: "The car that illustrates the best use of engineering to meet the design goals and the best understanding of the design by the team members will win the design event". A relatively short paper document is produced by each team, backed up with design information via stand alone posters (often for each car subsystem) and/or laptop- based visuals. In some countries there is a design final after the dynamic events, where five teams selected via the initial judging are questioned in considerable detail.

Cost Analysis 100: Each component on the car is costed (including machining, fabrication etc.) and compiled into a relatively large report. Individual team members are questioned at the event for their understanding on how some bought components are manufactured. Such items could be ignition coils, rose joints, suspension springs. Teams have prior knowledge of which components will be selected.

Acceleration 75: Cars are timed over 75 metres from a standing start. Some of the faster cars can achieve times of 0 to 100 km/h in under four seconds.

Skid Pan 50: Here cars are assessed on cornering ability, with time being measured around a simple circular track, with minimisation of time being the objective.

Autocross 150: The cars are driven separately around one lap of a tight twisty track, with the objective again being to minimise lap time. Since the track is twisty and there are no long straights, designs that exhibit good handling with the ability to turn quickly do well. Top speeds are kept low (average speeds of about 50Km/h), aerodynamic devices that are used on other types of race cars (e.g. F1 and Indy) have questionable merit. This is an area of on-going debate for some teams, with some cars opting for lightweight simple designs and no aerodynamics downforce aids, (e.g. Figure 1) and others having multi-element wings such as the cars from Monash University

Endurance 300: A staggered start event where cars are driven for multiple laps around a tight twisty track, with the objective again being to minimise lap time.

Fuel Economy 100: Here the fuel used during the Endurance Event is measured, with the objective of minimising fuel used. Note that the event was 50 points until 2009 (and the Endurance event was 350).

2 RMIT Formula SAE

RMIT University has competed in Formula SAE every year since the competition was first introduced to Australia in year 2000. After four years of learning the competition and establishing internal management processes and support structures, the team began travelling to international competitions in year 2004. Since that time the team has been highly successful in Formula SAE competition, having won four events outright and finishing outright second on two other occasions. Our lessons learnt are presented below and whilst the intent of this paper is not to provide a detailed technical description of our cars, details are available on our website (RMIT, 2009).

2.1 Competition observations

A student design team has to consider many different and often competing factors to achieve success. There are many useful resources available on the SAE-Int website (www.sae.org), including specific technical information (e.g. suspension tuning and development, Lyman, 2005) and team management information (e.g. Royce, 2005). These are generic and very useful for new teams. Aside from the various vehicle performance compromises that need to be considered (e.g. engine power versus fuel economy, chassis weight versus stiffness, suspension geometry for cornering versus straight-line acceleration, etc.), the students also need to approach practical project issues such as how their design decisions affect cost, manufacturability and marketability. It is worth noting that the first three events listed above, totalling 325 of the 1000 points are based on reports and student knowledge, and a further 100 points are allocated to fuel economy, none of which are traditional criteria for success of a racing car. A holistic, systems approach is necessary to achieve success across the range of events.

Whilst the primary intent of the competition is to expose engineering students to a complete product development cycle (design, build, test), a glance at results indicates that this is not being successfully implemented in many cases. Competition results indicate a large proportion of teams fail to complete all the events, and in some cases fail to get a completed car to the competition at all. At the recent 2006 FSAE Detroit competition, only 41 of 121 attending teams completed all events (a completion rate of 33.9%), and a further 19 teams registered for the event but failed to attend (Anon, 2006). Analysis of further recent competition results indicates that this is typical.

In many cases, the students' perceptions are distorted somewhat by the motorsport aspect of the competition. The base task of designing and building a simple self-propelled vehicle should not be beyond the scope of a team of senior level undergraduate engineers, and the competition regulations and points structure are designed such that a team can be successful even on a modest budget. However students' prior exposure to motorsport (either directly or through the media) often leads to the impression that success is directly related to such factors as large budgets, cutting edge technology and complicated gimmickry. This philosophy is therefore transferred to the team's FSAE project, leading to overly complex design programs and stretched time and monetary resources. This also leads to the non-performance related aspects (i.e. static events) of the competition being overlooked as the team focuses primarily on getting more speed from the car.

The RMIT team has noted that in many cases this primary focus on vehicle performance has had a detrimental effect, as teams design beyond their capabilities and fail to bring a tested and reliable vehicle to the event. This is evidenced in the typically poor finishing record in this competition. This observation led the team to question whether it is feasible to trade off a few potential performance points, in the quest to simplify the project and lessen the risk of non-completion of the event.

3 RMIT Strategy

3.1 Car Design

A Systems Engineering perspective asserts that decisions made in the conceptual phase are ultimately what drives the overall success of the project, (Blanchard and Fabrycky). If a project does not meet required deadlines, or if a product is not adequately tested before its release date, it can usually be tracked back to the design decisions made at the beginning of the project. It is the project team's responsibility to fully investigate and understand the resources available to it, (people, budget, facilities, etc), and then make design decisions that ensure the project can be completed within these constraints. Given that typical 60% of FSAE teams to fail to complete the event, it is apparent that many teams are still not fully assessing their constraints before making their design decisions.

The RMIT team develops its design concepts with strong emphasis on the early, conceptual stage of the design process. Two design dictums that the team follows are:

- The simpler, the better (or do less, and do it better)
- Every choice has a consequence

When assessing vehicle design options, emphasis is placed on simplicity so as to minimize the load on team resources and lessen risk of failure. Each component on the car comes with its own weight penalty, manufacturing issues and financial cost, and these must be considered in tandem with the component's performance capabilities. The less components there are on the car, the better they can be understood and the easier it is to tune and develop the car to its maximum potential. Also, it is much easier to reduce vehicle weight by disposing of components and systems altogether, than it is by redesigning components.

A wide variety of applications of high technology is possible on a FSAE car but the disadvantages can often outweigh the advantages. For instance, consider the adoption of an electronic gearshift. This may increase gear shifting speed, but consequences include additional weight and risk when compared to a simple mechanical system and will take time and money to develop reliably. Similarly aerodynamic wings offer downforce, but consequences include increased mass and MOI's, loss of fuel economy, increased vehicle sensitivity to the prevailing wind, compromises in cooling and radiator placement and will again take time and money to develop and implement. In the last few years the RMIT team has downsized to a single cylinder engine that is of smaller capacity than the maximum permitted by the rules. Whilst this reduces our straight line performance (thus lowering our placing in the Acceleration Event) it has benefits in our car's cornering performance, through weight, size and packaging compromises. Since the timelines and budgets are tight, every component design option has to be weighed against the resources required to manufacture or purchase it. It is up to the students as designers to fully understand the consequences of design decisions, and ensure that they fit in with the overall design direction of the team. One of the biggest lessons learnt is the "non-reversible nature of time and money" and the students must realise that they are not dealing with Formula One budgets!

With the above points in mind, RMIT undertook a major design re-direction in year 2003. Until that point in time the team had placed heavy emphasis on developing the engine package, to optimise straight-line performance. The team had experimented with supercharging, variable-geometry turbocharging, pneumatic and electric gearshifts, and twin and four cylinder engines. Each year it was observed that these development programs were costly (in terms of both time and money), and introduced great risk into the project. Two of the first three RMIT entries ended with engine failures at the competition.

The 2003 team thus questioned whether the design emphasis on engine performance was worthwhile. Could the project be simplified, and the risk of failure be reduced, by introducing a simpler engine system? The team undertook to move away from a complex multi-cylinder design, towards a vehicle with a naturally-aspirated, small-capacity single cylinder engine. This would trade off some straight line acceleration for additional benefits in weight, size and simplicity. In particular, the single cylinder option simplified the design of the intake, exhaust and engine wiring systems, which greatly reduced manufacturing and development time.

In practice, the loss of engine performance was outweighed by gains in cornering performance, fuel economy, and reliability. This increase in reliability has particularly played a major role in the team's recent successes, as places are regularly gained through attrition of the competition.

In 2008 we decided to build the first all-electric FSAE car and in order to minimise the work building another chassis decided to take the 2004 car and "recycle" it. The philosophy was to utilise energy from the RMIT Renewable Energy Park, thus moving further down the path to sustainable racing. The 2004 car featured a partial CF chassis and the rear portion was a steel space frame – enabling relatively simple modification to house the electric motor, chain drive system and associated control system. The electrical system featured a simple brushed DC motor, Lithium-Ion Thundersky batteries (sized to enable the car to complete one heat of the Endurance event) and a simple non-regenerative control system. The car was demonstrated at the FSAE competition in Australia in 2008 where there were no rules for such vehicles (but these are currently being drafted) and despite having had virtual zero testing and driver training time performed well. The vehicle lapped at times that were in the middle of the field for the IC cars, demonstrating the potential of an all-electric FSAE car.

Building on the lessons learnt, we are now designing a regenratively-braked car featuring twin brushless motors independently driving each rear wheel. This has illustrated the new challenges associated with going electric, both technical (such as the control logic for regenerative braking and electronic differential) and managerial, including crossing traditional university boundaries.

3.2 Team Management

Student teams undertaking Formula SAE often see the project primarily as a technical task. However it is not so much the technical skills of the team but rather the overall team management prowess that determines the overall success. Continually high-ranking teams such as Cornell University in the USA concentrate on succession plans and the documenting of project findings to ensure ongoing success. The following outlines some of the management structures implemented at RMIT.

3.3 Team Structure:

Our teams comprise between 15-50 students, mostly from the engineering schools. Some of these students are fully committed to the project, whilst some are merely interested and just wish to learn a little about project management and automotive science. At the core of the team, it is not unknown for senior team members to spend upwards of 70 hours a week on the project. However the team also recognizes the value of those students who cannot make a major time commitment and effort is made to accommodate these students with simple project tasks.

The team structure is broken down as follows:

- Core Management Team – comprising Chief Engineer, Team Leader and select senior team members. This team oversees the top-level project management issues of the team, such as finance, sponsorship, time management, running team meetings, etc.
- Sub-system Design Teams – teams dedicated to the design and manufacture of particular sub-systems of the car, such as Suspension, Chassis, Drivetrain etc.
- General team membership – student members (usually junior) uncommitted to any particular role in the team, but assisting with many technical and non-technical tasks – the latter can include team clothing range, team website etc.

The Core Management Team structure is flexible to an extent, as it needs to accommodate the differing skills of team members. Generally it comprises a dedicated Chief Engineer (the design leader devoted to technical vehicle design issues, with this student often taking responsibility for chassis and using this for academic credit via final year project subject) and a Team Leader who focuses specifically on the non-technical managerial tasks. This sort of structure suits a team where there is strong technical leader who has a prior automotive experience. In some years this distinction is blurred as the Chief Engineer and Team Leader work together interchangeably. Occasionally the two roles are shared across a number of students working as a core leadership team. Such a structure works where there may not be students with enough experience to take on full managerial responsibility, but are willing to work as a team and learn as they go.

It should be noted that whatever management structure is chosen, it is vital that the student or students taking on the Chief Engineer's role have a definite vision of the overall design direction of the car. The Chief Engineer is the technical leader of the team, and has to guide the various sub-system designers along a unified path. Disagreement on the design direction can lead to a poorly integrated vehicle and a confused project overall.

3.4 Personnel Management

Maintaining student interest is a key issue that needs to be addressed in managing a successful Formula SAE project team. For many students this is their first practical design project, and this can be confronting when they realize that real-world projects do not work out as perfectly as they might hope they will. This can cause great frustration to the student, and loss of interest in the project.

It is crucial to engage the students meaningfully from their first contact with the team. It has been noted that for each RMIT FSAE project, over 100 students will initially show interest in the project. This number drops rapidly to a core team of 10-20 members unless some active means is employed to retain the new students. Also, with the high turnover of students it is necessary to establish succession plans, so that knowledge is not lost with each graduating team. Some of the project management strategies that have been implemented at RMIT to address these issues include:

- Student-run technical seminars
- Training / mentoring schemes
- Multi-year vehicle development plans

Student-run technical seminars:

Throughout the project, senior team members and faculty advisors are encouraged to present short technical design seminars to the younger students, on a topic of their choice. Usually the topic aligns with the speaker's particular design project on the car, but can also be on other topics such as FSAE history, competitors' vehicle designs, advantages and disadvantages of the adoption of wings etc. These seminars take place during the weekly team meeting, and the team endeavours to present at least one seminar per fortnight. Note that these seminars are separate from any assessment requirements specified for a student's Final Year Design Project.

The primary benefit is increased attendance at team meetings and involvement in team activities. Regular structured seminars were first introduced in June 2006, when it was noticed that attendance at the weekly team meeting had dwindled to around 8-10 core students, which was not enough to maintain project momentum. After introduction of the seminars, regular attendance at the team meetings rose to around 30 to 40 students, across all year levels. Feedback from the newer team members indicate that seminars are valuable and help them make sense of design fundamentals.

Further benefits are that team members get a holistic perspective of vehicle design, as they are continually exposed to design issues across the breadth of the project, not just a particular design sub-system. Also, the scheme enables the senior team members to practice their public speaking and presentation skills, building their confidence and aiding in their professional development.

Training / mentoring schemes:

In addition to the regular short seminars above, the team has assorted mentoring and training programs that operate through the year. Senior team members hold workshops or informal sessions to train incoming members in such fields as CAD modelling, dynamometer testing and project management. Such schemes are vital to set in place succession plans, and to ensure that knowledge gets transferred from year to year. It is also gratifying for the senior team members to engage in this mentoring activity, and it builds a sense of ownership and investment in the team's long-term successes.

The team also occasionally invites speakers from academia or industry to speak on a topic of relevance or interest. Recent speakers have included an academic investigating the vehicle dynamics of

"Drifting", and an industry expert on Lean Design and Manufacture. The intended goal of such activities is to make the team members feel that they are part of a dynamic and active team, and that they are benefiting from their time commitment to the FSAE team.

Multi-year development plans and Academic Credit:

The nature of Formula SAE competition is that each year, a new group of students enters the team and a new car is designed and built. This can lead to issues in retaining acquired knowledge within the team, and also in individual teams feeling they are operating in isolation from their own university's past and future teams. The former issue can see teams make the same design mistakes year after year. The latter can manifest itself in over-zealousness as the students attempt too much and try to revolutionise the competition in just one year. Both issues hamper a team's ability to succeed.

A strategy that RMIT employs to combat this is the use of multi-year development plans. Major design changes are planned and researched in the background over a number of years, sometimes a final year projects, and the team is conscious not to implement too many of these major design changes in the one year. Only changes that have proven to be entirely reliable and that can be built to time and cost will be incorporated on the car.

An example is the strategy undertaken over a three year cycle from 2003-2009. In 2003, the RMIT team took on a new design direction in the employment of a single cylinder engine for FSAE competition, in comparison to the more complex 4 cylinder engines used by the majority of competitors. The design philosophy was to trade off some engine performance for the benefit of a lighter overall engine package, reduced vehicle size and simplified manufacturing. Some other teams had already experimented with this direction, although mostly these experiments were unsuccessful. The RMIT team noted that in such cases, the teams concerned tried to compensate for the lesser engine power by undergoing a massive weight saving program over the course of only one design cycle. The final result was an unreliable and unsorted car that did not operate to potential.

The 2003 RMIT team avoided this by implementing a three year development plan for the introduction of the single cylinder design concept. A new car would be built for each year's competition, but rather than attempt to build the lightest car possible in one attempt, a staged program was implemented. It was intended that this would lessen risk of competition failure through gradually developing vehicle and team knowledge at the same time. The stages are shown in Table 1 below.

Table 1. RMIT FSAE Vehicle Performance Goals: 2003-2009 (Final values in brackets).

Project Year	Vehicle Mass Goal	Engine Performance Goal	Chassis Construction
2003	Under 200kg (197kg)	50hp (52hp)	Full steel space-frame
2004	Under 180kg (175kg)	55hp (58hp)	CF front / steel space-frame rear
2005	Under 160kg (154kg)	Over 55hp (58hp)	Full CF composite tub
2006	Under 160kg (154kg)	Over 55hp (58hp)	Full CF composite tub, suspension
2007	As above, some minor mass reduction, plus carbon wheel rims (see Figure 1)		
2008	As above, plus data acquisition. 2nd car – simple electric demonstrator (see Figure 2)		
2009	As above but running ethanol, 2nd car to use two brushless motors and regenerative braking		

Of particular note was the staged introduction of carbon fibre (CF) composite chassis construction. It was expected that implementation of a carbon composite chassis would greatly aid the light-weight design concept, but given the changes imposed by the new engine package it was deemed wise to introduce the carbon chassis concept gradually. For the first year the team continued with a steel space-frame, a known construction process used in pre-2003 RMIT vehicles.

The strategy has been very successful, with each car running reliably and strongly in FSAE competition. Although seemingly quite heavy compared to cars of similar concept, the conservative 2003 car won the 2004 Formula Student (UK) by a 100 point margin. This was primarily due to the car running strongly and with 100% reliability, whilst many of the opposition teams suffered mechanical failures. Ongoing development saw the 2004 car come 2nd outright at the 2004 FSAE Australasian event, and the 2005 car then went on to win the 2006 FSAE Detroit event outright, closely followed by a second place at the inaugural 2006 east coast event. Returning again to the UK in 2007 with the 2006 car, we won the FISITA FSAE World Championship staged at Silverstone.

Furthermore, an ongoing cycle gives team members a sense of belonging to something greater than simply the current year's project. There is a motivation to transfer acquired knowledge to incoming team members, as the present team understands that the work they are doing currently will be contributing to future teams successes. It is worth noting that such schemes cannot be implemented if membership of the team is limited to senior or final year project students only.

Typically 40% of the students in our team will be in the final year of the degree programs (Automotive, Aerospace, Mechanical or Manufacturing) and the majority of these will be aligning their activities with the final year project for course credit. Final year project accounts for one quarter of the subjects in our final year, but FSAE nearly always takes a disproportionately large amount of time. Whilst credit can be accrued in other subjects for working on the car (and some academics recognise this, permitting aspects of student work to be used for say, a management project) it is far from universal. This causes understandable concern. We are currently considering the adoption of another "external project" course which the students can use to bring further academic credits.

4.0 Concluding Remarks

In our experience FSAE has provided a motivating experience like no other, and has resulted in graduates having very strong skills in a wide range of areas, that are directly transferable to their future work opportunities. This is clearly recognised and rewarded by the automotive industries, but not always by academia. FSAE results in enhanced skills that include self and team management skills that are reinforced in a manner that does not usually occur in traditional subjects. Here the challenge to the universities is to provide adequate subject credits for the enhanced learning that occurs. Whilst the adoption of FSAE in a traditional university environment can prove problematic and at times very challenging, the outcomes are well worth it and include being the most motivating thing that one is likely to encounter in the university environment.

The changing face of the automotive industry, as it moves away from traditional fossil fuels, is providing both barriers and opportunities for FSAE. Sponsorship for the "traditional" IC cars is increasingly difficult to obtain, yet for bio-fuelled, all-electric and hybrid cars there are new sponsorship opportunities and technical challenges. Universities must be flexible enough to accommodate increasing interdisciplinary efforts in order to train the engineers needed to ensure a sustainable world – part of which will be sustainable racing.

5.0 Acknowledgments

The authors would like to acknowledge the financial and moral support of RMIT University and the AutoCRC, but most especially the RMIT team members from 2000 to 2009.

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