ATLAS

Urban Search and Rescue Robot

Cost Benefit Analysis 2016/2017

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Abstract

The aim of this cost benefit analysis was to justify the costs incurred by Warwick Mobile Robotics' (WMR) project to design and manufacture their new Urban Search and Rescue (USAR) robot known as ATLAS. The social and environmental benefits of this endeavour were also considered as a means of justification for the costs incurred.

The information is documented in the form of four distinct sections which were identified based around a preliminary SWOT analysis:

- The first section 'Cost of the Project' addressed the costs relating to materials and components. It also included the cost of labour, whether it be WMR team members, technicians or any other project related personnel. These costs tallied to a total of £51756.17, which was higher than the previous team's costs of £43,761.97. This 18.6% increase was found to be down to the increased labour time of the project. However, the benefit obtained from this, in the form of a fully functional robot, was deemed sufficient to justify the additional costs.
- The second section 'Project Benefits' attempted to justify this cost in terms of what the ATLAS team achieved. It was believed that the ATLAS project provided benefits to students, academics and wider society as a whole, by acting as a platform to motivate and inspire students in to STEM related activities. A demonstration of this was seen by WMR's increased popularity following their attendance at the 2016 Imagineering Fair.
- The third section 'Outcomes and Achievements' detailed the results and the impact that the project has had overall. This is primarily from publicity, as the WMR website received almost 60,000 more hits over the course of the project than was seen last year.
- The fourth section 'Discussion and Analysis' aligns the costs of the project with the strategy of Warwick Mobile Robotics and the Warwick Manufacturing Group.

It was established that the costs incurred within this project are justifiable as the team have produced a future proof design upon which innovations can be developed upon, whilst making use of re-used materials to minimise environmental impacts where possible. It is believed that publicity and outreach will develop further because of this, validating the project.

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Declaration:

We, the authors, hereby declare that the work presented in this cost benefit analysis relating to "ATLAS – Urban Search and Rescue" is entirely the work of Warwick Mobile Robotics team 2016/17. This is in partial fulfilment of the ES410 Group Project assessment criterion.

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Margaret Low — For allowing us to inspire the next generation of budding engineers.

Edgar Zauls

Stefan Winkzist — For giving us their time to inspect our designs and share their wisdom.

And of course our respected sponsors for their continued support:

1. Introduction

The purpose of this cost benefit analysis is to assess the assets realised by the Warwick Mobile Robotics (WMR) project, ATLAS, and provide justification for the costs incurred; these shall be analysed and project viability determined.

The WMR team identified that previous WMR projects prioritised complex designs. As a result "their robots were unable to reach the completion stage; leaving behind highly specialised components that could not be formed into a foundation for future projects" [1]. It was the intention of the ATLAS project to correct this. "Having been inspired by the best aspects of previous WMR projects, ATLAS has been built from the ground up as a functional robot that will serve as a solid foundation for future years to build upon" [1].

2. Project Specification

"The aim is to design and manufacture a functional urban search and rescue (USAR) robot capable of locating and assisting the victims of disaster zones" [1]. To realise this aim, the following objectives were devised:

- Decide on ATLAS' anatomy, based on what is available through the disassembly of previous years' robots and literature review.
- Design and manufacture initial designs with an emphasis of modularity so that future years can change and innovate on the base design.
- Design and rapid prototype future design possibilities, so that future teams have documented information.
- Validate the designs through real-world testing and evaluation against RoboCup competition requirements.

Throughout the project, the objectives and ten stage plan that extended from them (see Appendix A) provided guidance and were superintended in accordance with the team's strategy of 'function before form'. A SWOT (strength, weaknesses, opportunities and threats) analysis was performed to aid with identifying the objectives of the project. This is a tool that may be utilised in order to recognise the internal strengths and weakness of the project and the external opportunities and threats. A discussion of the SWOT analysis and the analysis of the ATLAS project can in be found in Appendix B. Distributing the objectives throughout all elements of the analysis gave the project a stable foundation, on which strengths could be further improved upon, weaknesses minimised, opportunities seized and threats counteracted.

3. Cost of Project

The team conducted the design and manufacture of both mechanical and electrical components with a re-use and recycle philosophy. The team minimised costs by re-using as much material and technology from previous years as possible and manufactured bespoke components in-house. It is noted that the international RoboCup competition, which assesses robot functionality regarding search and rescue, is a demanding challenge. Robots undergo forces that may permanently deform mechanical components, as well as burning-out the electronics components. This subsequently, results in additional costs being inherited by future projects.

The SWOT analysis, as discussed in Appendix B, allows the identification of areas that may incur costs as a result of complications and also opportunity costs, where improvements may be made. The following section discusses both the monetary costs and non-financial costs associated with ATLAS. The total cost of the ATLAS project was £51,756.17, comprising of components, raw materials and labour costs.

3.1. Materials, Components and Manufacture Costs

The ATLAS team designed the foundations of a new robot inspired by the best aspects from previous WMR projects. A new project may result in large capital expenditure. Thus, re-using many components, taking advantage of the plethora of resources from half a decade of WMR projects, is vital. The costs saved as a result of re-using components may be seen in Appendix C, totalling £6006.5. The team saved further costs by avoiding external manufacture. This was achieved because the team were proactive and communicated regularly with WMG technicians, ensuring designs were error free and submitted early. Thus, allowing the in-house manufacture to occur promptly at the start of 2017.

The procurement of raw materials, essential for the in-house fabrication of many components, accounted for 0.64 % of the total project cost. Purchases of commercial-of-the-self (COTS) components contributed a further 2.93 % to the total project cost. In comparison to the Cyclone project 2015/16 reported at 6.61% [2] and the Orion project 2014/15 reported at 6.67% [3], this was kept to a minimum by re-using many components. The justification between the use of COTS and “re-used” components may been seen in section 4.

ATLAS was built to be future-proof.; focusing the design to be simple and functional and built from high quality components. Modularity or lateral efficiency is one method of achieving a future-proof design. However, this must be considered simultaneously with systematic thinking or how the modules and sub-systems interact. This style of design allows easy optimisation by future teams. The designs of both mechanical and electrical systems included adequate safety factors. The chassis was manufactured from Aluminium "alloy 6082 … a medium strength alloy with excellent corrosion resistance" and 310Mpa yield strength [4]. Typically, applications include high stress scenarios including trusses and transport applications [4]. Adopting high quality materials and components with an adequate safety factor allows scope for future optimisation.

WMG's internal ordering system, OPeRA, is an "eProcurement system which has been introduced to replace paper based requisitions" [5]. Project requisitions requires internal appraisal before an order can be placed. This is performed via the finance department within WMG and ensures that the team comprehensively assesses all options before a purchase is placed. This ensures vendors are selected on merits, affordability and reputation. A breakdown of sub-system costs in relation to the raw material and components may be seen below in Table 1. The full sub-system costs are in Appendix C. It may be noted that manufacturing costs are not included. This is due to in-house manufacture and assembly performed by WMG technicians or by the team themselves. These are included within labour costs.

Table 1. Breakdown of component and material costs.

Sub-System	Raw Material Costs (£)	Components Cost (£)	Sub-System Sub-Totals	
			Cost (£)	% Total
Chassis	288.75	0	288.75	15.6753
Drivetrain	25	1271.8	1296.8	70.3991
Dynamic Tensioning	16.52	0	16.52	0.89682
Electronics	0	239.1	239.1	12.98
Communications	0	0	0	0
Sub-Total (£)	330.27	1511.8		
Grand Total (£)	1842.07			

3.2. Labour

A project of this scope naturally relies upon the number of hour invested by all parties. These hours equate to the labour costs associated with the ATLAS project and comprises of 96.44 % of the total project spend. The ATLAS team, as may be seen below in Table 2, contributed the most hours to the project. Non value-added time spent on the project was reduced by the technician's support during manufacturing. The time other parties invested into the project was valuable and was of notable contribution to the success of the project. The labour costs associated with the ATLAS project may be seen in Table 2.

Table 2. Breakdown of labour costs.

Role	Individual	Cost/Hour (£/hr)	Hours	Costs (£)
Students	Andrew Gilley	15	345	5175
	Michael Rajaretnam		290	4350
	Oliver MacKinnon		350	5250
	Thandiwe Ngoma		336	5040
	Chun Hei Hong		323	4845
	Daniel Carmichael		362	5430
	Guy Baker		344	5160
Technicians	Jacob Gates	30	220	6600
	David Cooper		20	600
	WMG technicians		5	150
	Ian Griffiths		3	90
	School of Engineering technicians		5	150
Project Director	Emma Rushforth	75	75	5625
Other Academics	Stefan Winkvist	50	5	250
	Edgar Zauls		5	250
	Yung-Yu Lau		3	150
	Daniel Riley		10	500
Sponsors	Janjua Amir (Maxon)	50	2	100
	Maxon		4	200
Total			2697	49915

The ATLAS team members were each given a sub-system to develop. The time spent on each sub-system may be seen in Figure 1 and by work performed by category in Figure 2. It should be noted that team members were not restricted to their systems and it was encouraged to share ideas with the entire team as whole. This ensured a balanced workload across the project, creating a solid foundation of knowledge for all sub-systems.

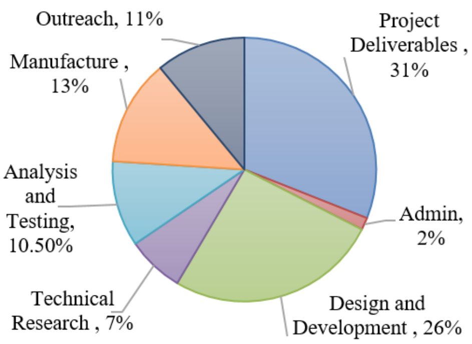

Figure 1. Breakdown of Team Time Spent per System.

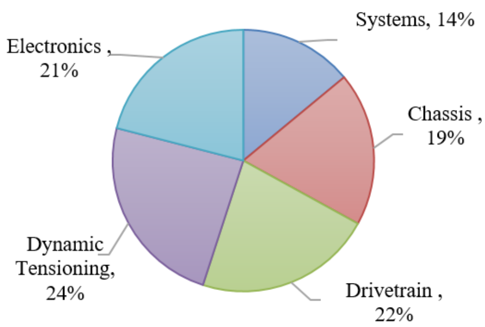

Figure 2. Breakdown of Team Time Spent per Category.

3.3. Environmental and Social Costs

Often disregarded within academic projects, the environmental and social factors may significantly affect project costs. A key motivation for WMR's on-going research project, and especially the ATLAS team, is to help "locate survivors in hazardous environments, such as earthquake disaster zones, thus removing emergency service personnel from danger" [6]. Extreme events, such as earthquakes, are reported in literature to occur more frequently with increasing climate change [7]. This is resulting from excessive greenhouses gas emissions and the disruption of the Earth's crust via oil, gas and mineral extraction. Research suggests that Australia's most damaging earthquakes were man-made [8]. It was crucial that the ATLAS team were aware of the costs, not only of the raw material but the effect these may have upon the environment, including the processes within manufacturing. The requisition of material and manufacturing processes, albeit small at this stage in the project, contributed to the increase in climate change. Through the re-use and recycling of pre-owned parts, the ATLAS team has managed to reduce their environmental impact by minimising the purchase of new materials. The WMR project should continue to develop awareness and ensure that the net impact is beneficial to the planet, especially in the future where the team may see budget increases and be tempted to indulge in large purchase orders.

4. Opportunity Costing

Opportunity costing is defined as a benefit that must be given up in order to acquire or achieve something else [9]. Opportunity costs are fundamental in economics and are used extensively throughout cost benefits analyses [10].

4.1. Outsourcing and COTS

The decision to manufacture in-house or externally requires analysis of the costs and benefits involved when hiring an outside supplier. When considering in-house manufacture, the ATLAS team considered the variable lead time within WMG and labour costs related to technician time. The same WMG technicians were available for feedback which enabled design iterations and feedback. It was assumed equipment maintenance and storage costs could be ignored as they are overheads of WMG. It is also noted that scrap metal found in WMG were re-purposed as spare material which was used in ATLAS. In comparison, when outsourcing manufacturing, the price of the product, shipping costs and any sales tax charged must be considered. There are costs associated with receiving goods into the inventory, however, these are again overheads covered by WMG. Similarly, when considering COTS components against in-house manufacture, the primary trade-off regards design complexity, in-house labour time and the processes requirements.

Due to the expertise within WMG, the small volume and bespoke nature of the components required, it was concluded that it would be more beneficial to manufacture all viable components in-house. Not only does this allow feedback on designs, but encourages mastery and good practise, whilst costing less. The team decided to buy COTS components when design complexity, proportional to the time required by both ATLAS team and WMG technicians, outweighed the cost of requisition such as the robots tracks.

4.2. Cost of New Design

The 2015/16 Cyclone team continued the Miniature Urban Search and Rescue (M-USAR) project started by the 2014/15 Orion team. The ATLAS team had to make the decision whether it was a better use of resources, time and money to advance Cyclone into an operational robot, capable of competing at the RoboCup, or whether it would be more beneficial for the future of the WMR on-going research project to design a new robot.

After critical evaluation of the Cyclone project, it was concluded, after benchmarking, that the viability of developing Cyclone into a competitive robot at RoboCup, in comparison to designing a new robot was low. The most significant weakness identified by the ATLAS team was the quality of the suspension and dynamic-tensioning systems. Experimental data from a drop test of 1.5 m [11], a task within the RoboCup competition [12], demonstrated the robot must be capable of surviving a force of 15 kN upon the system [11]. The cyclone team simulated a drop test from 0.35 m, resulting in a force of 2.45 kN upon the chassis [13]. It is apparent that Cyclone was not designed to withstand the stresses a robot would encounter in the real-world. Furthermore, the chassis was not large enough to accommodation the electronics, which was undocumented and not operational. These, along with other limitations made designing a new robot more beneficial in terms of project resources, with the aim of entering the RoboCup 2018.

Project incompletion, not entering the RoboCup, or gaining publicity resulted in decreased sponsor interest. The ATLAS team focused their design to be simple but functional. The aim was to achieve a solid foundation of which future WMR teams could develop.

Where possible, the ATLAS team re-used components from previous robots and WMG scrap. The team re-used many costly electronic components, sensors and the flipper arms and tracks from the 2012/13 team saving a total of £6006.5. This excludes the internal manufacture time required to produce the 2012/13 flipper arms and tracks.

5. Project Benefits

5.1. Benefits to Students and Team

The ATLAS team encountered numerous opportunities to develop both personally and within a team; improving communication, negotiation and organisation skills, as well developing a deeper appreciation of resources such as time and money. The multi-disciplinary nature of the project, and specialist sub-systems, encouraged a mechatronic design. A design philosophy becoming increasingly common within the STEM (Science, technology, engineering and mathematics) community. It is reported that graduates with mechatronic knowledge "integrate seamlessly" [14] into positions, with many research fields offering PhD's [14].

The team implemented a specification through to construction with assistance from WMG and external suppliers. Offering a significant scope for the development of future students to improve upon an innovative, simple and effective design.

5.2. Benefits to Academia and University

WMR teams publish research and results at the end of the academic year. The work produced may be seen on the WMR website [15], which is frequently cited in other academic reports. USAR robots are yet to be commercialised and so on-going research grants are crucial for development. The work produced contributes the robotics community and offers the University a platform to further study robotics. This knowledge could form a key aspect of the teaching curriculum, engaging students with valuable hands-one practical experience.

The WMR work is regularly on display within WMG, in the team's work station. This is available to high-profile personal touring WMG and prospective students on open-days. The robot may acts as promotional material for prospective students, demonstrating the industrial contacts offered by the University and the scope of innovative projects available.

The ATLAS team have provided a solid foundation for the 2017/18 WMR team to develop and compete at the RoboCup 2017. The international competition is a perfect showcase for the University of Warwick, who have been previous world champions.

5.3. Benefits to Education and the Wider Society

The team promoted the development of autonomous robots, especially for use in rescue efforts at disaster sites via the outreach programme. Raising awareness of robotics and engineering among the younger generation at Imagineering, WMG open-day 2016/17, Warwick

Technology Conference and Regional Robotics Seminars with the aim to inspire the younger generation to study STEM subjects at university.

The ultimate aim is to compete at the RoboCup where the team can experience pioneering technology. The team have contributed to the robotics community, whilst contributing to the operation of USAR robots in disaster zones. Ensuring safer, more reliable and faster deployment than a human workforce, eliminating human risk from within the danger zones.

6. Outcomes and achievements

6.1. Project Outcomes

It was the principle aim of the ATLAS team, not to design an entire robot, but to create a foundation that will offer future WMR teams an opportunity to develop. The ATLAS team have designed a simple and functional platform for this to occur. Although, the framework has been set, robotic enhancements are necessary for future teams to competitively enter the RoboCup. Most notably, in regards to developing the robotic arm and sensor implementation.

6.2. Sponsorship and Publicity

The ATLAS team found it challenging to maintain relationships with external sponsorship. This was due to a lack of publicity in recent years, previous projects not reaching completion and not competing at competition. It was core to the team's strategy that an operational robot was developed, so external relationships could be bettered, re-established and new companies approached.

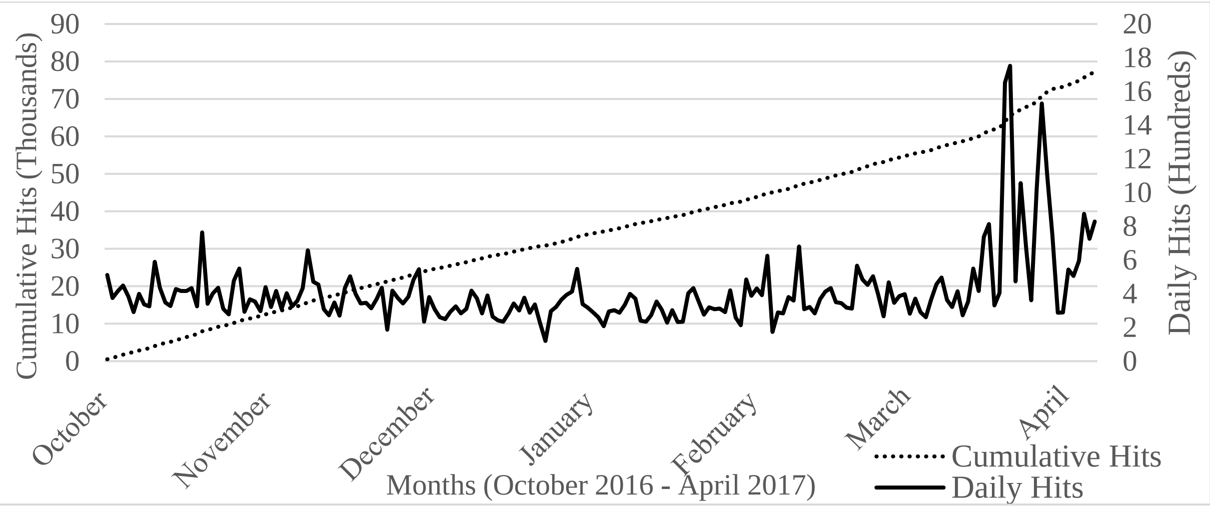

Figure 3 Cumulative and Daily Website Hits.

To generate a larger network and establish a better reputation, it was highlighted that project publicity must be increased. As previously stated, the ATLAS team partook in numerous outreach programmes, including the 2016 Midlands Imagineering Fair and open-days at the University of Warwick; whilst also presenting at the Warwick Technology Conference and Robotics Seminars across the Midlands. The additional work input has massively increased WMR publicity. The WMR website received approximately 60,000 more hits from 1st October 2016 to 1st April 2017 than the previous year. The data for the daily hits and the cumulative hits throughout the year may been seen in Figure 3.

The spike in traffic that occurs at the end of October occurred after the Imagineering event. The most prominent spike occurring at the end of term 2 was in March/April. It is thought the other project groups use the WMR page as a resource, with 2,500 technical reports being downloaded between 2014-16. With 10,000 other reports being downloaded altogether.

7. Discussion and Analysis

7.1. Cost Benefit Appraisal

The ATLAS team incurred at a total cost of £51,756.17, compared with last year's £43,761.97, an 18.3% increase. The increased spend occurred as the team and other parties invested more time into the project, approximately 100 additional hours to that of the 2015/16 team. The total spend on material and new components was approximately halved compared to the 2015/16 team as a result of the Cyclone team "developing a future-proof design" [2]. Allowing the ATLAS team to re-use components, especially the motors from the 2015/16 team. Components were re-used from a multitude of robots, saving the ATLAS team £6006.5. The costs incurred for the requisition of material and components should decrease year-on-year as each WMR teams continue to further future-proof the robot, whilst project achievement increases as a result of increased publicity and competition results. The value of the USAR project, therefore, can be expected to appreciate.

It is simple to calculate the costs associated with a project. The benefits however, are less tangible. The costs associated with the project have been calculated and the benefits of the project qualitatively reviewed where appropriate. The project has been appraised through its functional outputs:

The publicity gained through the outreach programme has been vast, with 77,302 website hits throughout the year. Reported to be 60,000 more hits than the previous WMR project. Websites statistics show that 99% of these hits are from computers external to the University network.

The potential global publicity achieved via the website and the regional publicity from events throughout the Midlands, increases the awareness of the University. This encourage prospective student to the University. The news may also reach employees potentially increasing the value of a Warwick Degree. McKinsey Quarterly states that "word of mouth generates more than twice the sales of paid advertising" [16], especially in evolving markets. Thus, the positive publicity gained through the outreach programme far outweighs the costs associated with paid advertising and labour costs. The team's goals were to inspire the younger generation to pursue an education in a STEM subject. If the team managed to motivate one child to pursue this, then they believe the project has been worthwhile.

The U.S Office of Management and Budget valued a human life between the range of $7 million and $9 million [17]. It is the ultimate aim of the WMR project to design a robot capable of locating and assisting victims of disaster zones. If this project can have any impact upon the victims of disasters then the costs are easily validated.

Comparing the costs and benefits of the project, the team believe that whatever the timeframe, the benefits outweigh the cost. As the project evolves and the RoboCup is entered, the increased publicity and robot capability will become more apparent and the benefits continue to grow.

7.2. Strategic Alignment

Warwick School of Engineering's strategic vison focuses on an education that encompasses research, teaching and industry [18]. WMG's vision is to deliver "high quality interdisciplinary research" [19]. These visions align with the WMR project and have be used as a means of appraising the 2016/17 project. The multi-disciplinary nature of the project and the outreach programmes encompass both visions to integrate disciplines, whilst also encouraging teaching and research.

8. Conclusions

The ATLAS team demonstrated an appreciation of the importance of planning, controlling and the managing costs throughout the project. A functional platform has been developed, with costs focused on future-proofing the design. The overall cost, to form the foundation of ATLAS was £51,756.17. These costs have been validated as the benefits outweigh the costs. The team has had the opportunity to inspire the younger generation and develop personal skills as well as develop a mechatronic understanding. The team contributed to the robotics community with the sole aim to save lives. If the ATLAS team has had an impact on any of these opportunities it is believed the project is more than validated.

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Appendices

Appendix A: Ten Stage Plan

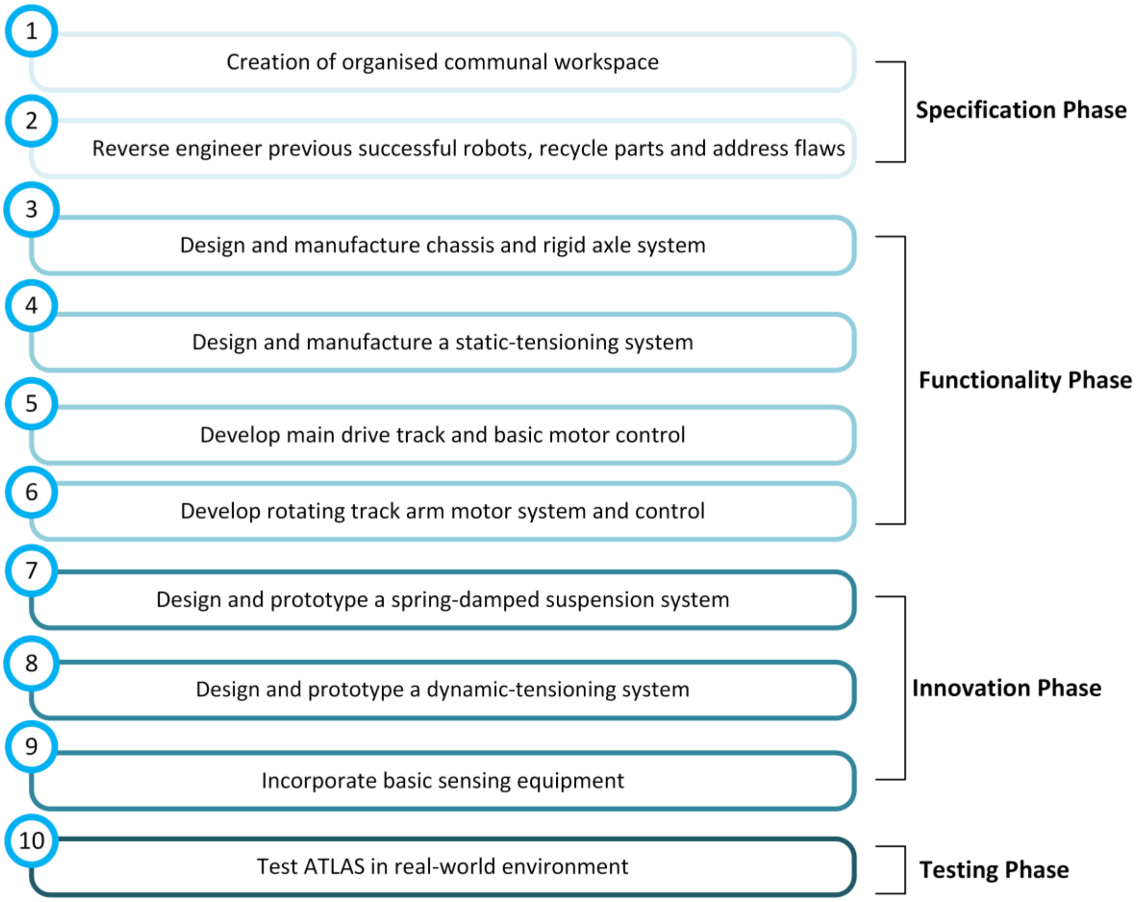

***Figure 4*: Warwick Mobile Robotics' '10 Stage Plan 2016/17'**

Appendix B: SWOT Analysis

A SWOT analysis may help recognise and understand key issues that are effecting, in this case, the project. However, it should be noted that SWOT analysis does not offer a solution [20]. SWOT analysis helps the user to consider "the internal strengths and weaknesses, and the external opportunities and threats" [21]. It allows the user to better understand the task and identify areas that require improvement. It is important to be aware of the limitations of such a tool, as well as the benefits. Knowing what you expect to achieve is more useful and it allows the user to established realistic goals.

A SWOT analysis has been performed on the WMR 2016/17 project. This was performed to recognise the projects' objectives in accordance with a strategy that would identify areas for improvements and where costs should be spent.

Table 3. SWOT Analysis of WMR 2016/17 Project.

Internal Environment	
Strengths (S)	**Weaknesses (W)**
• Simple modular design allowing easy modification.	• Sensor implementation and interfacing.
• Critical review of previous 5 years identified WMR robots achievements and also the challenge encountered.	• Simple electronics designed to create a functioning robot. Not optimised to their function.
• Iterative designed methodology, redesigning the challenges encountered by previous years.	• First stage of a continuous yearly project and as robot testing and reliability are limited.
• Platform and benchmark for future projects.	• Many undocumented electronic components and robot chassis.
• Realistic aims – not attempting to build an entire robot in one year.	
External Environment	
Opportunities (O)	**Threats (T)**
• Vast opportunity for sponsorship across many sectors.	• Each year teams typically attempt to design and manufacture a new robot.

• Potential to introduce a UK robot competition or a local competition.	• Lack of completion has damaged relations with sponsors, resulting in loss of sponsorship.
• Offer inspiration for young generations and encourage partaking in STEM subjects.	• Lack of funding has resulted in the team having to be very limited with purchases, preventing progress.
• A decade of resources from past project with some team members still local.	• Lack of entry, for many years, of the competition has resulted in our relationship with RoboCup being damaged.
• Team to have a specialist technician from WMG.	• The robot is built to the edge of current regulations. Changes to the competition design criteria could be problematic.

Appendix C: Sub-System Costs Breakdown

Chassis

Table 4. Chassis Cost Breakdown.

Part	Supplier	Cost (£)
Aluminium 6082 1000mm x 800mm x 10mm	Colt Materials	114.5
Aluminium 6082 1400mm x 1600mm x 6mm	Colt Materials	174.5
	Total	289

Drivetrain

Table 5. Drivetrain Cost Breakdown.

Part	Supplier	Cost (£)
Aluminium Rod 1/8" dia x 500mm	Colt Materials	12.5
Steel Rod 18mm dia x 1000mm	Colt Materials	12.5
Oilite Brushes ID= 28mm OD=36mm, length 20mm	HPC Gears	32.48
Delivery	HPC Gears	8.87
Main Tracks	TransDev	487.5
Motor and Gear Housing	Maxon Moters	742.95
Delivery	Maxon Moters	20
	Total	1316.8

Dynamic Tensioning

Table 6. Dynamic Tensioning Costs Breakdown.

Part	Supplier	Cost (£)
Linear Bearing, diameter 12mm	IGUS	240.24
Threaded Bar M12	ONECALL	2.91
Silver Steel Rod, 1000mm x 12mm OD	RS Components	13.61
	Total	256.76

Electronics

Table 7. Electronics Costs Summary.

Part	Costs (£)
Over-Current Proctection	46.09
Battery Monitoring	23.73
Power Distribution	21.21
Motor Control	148.92
Grand-Total	239.95

Table 8. Electronics Cost Breakdown.

Part	Supplier	Cost (£)
Over-Current Protection		
5V Regulator	RS Components	4.98
5V Regulator	ONECALL	2.15
Current Sensor	ONECALL	12.13
MicroSwitch	ONECALL	3.6
Transistor	ONECALL	1.05
Power Relay	ONECALL	8.38

Surge Diode	ONECALL	1
Capacitors	ONECALL	5.24
Resistors	ONECALL	7.56
	Sub-Total	46.09
Battery Monitoring		
Microcontroller	ONECALL	8.85
Relay	ONECALL	4.04
7 Pin Crimp	ONECALL	1.8
Connector	ONECALL	0.36
Trimmer Pot	ONECALL	8.16
5V Regulator	ONECALL	0.52
	Sub-Total	23.73
Power Distribution		
5-Point Terminal Block	RS Components	5.28
PCB Terminal Block	RS Components	3.17
PCB Terminal Strip	RS Components	6.11
2-Point Terminal Strip	RS Components	1.64
PCB Slide Strip	RS Components	3
Fuse	RS Components	2.01
	Sub-Total	21.21
Motor Control		
Dual 15A Motor Controller	RoboShop	143.92
Delivery	RoboShop	5
	Sub-Total	148.92

Re-Used Material and Components

Table 9. Re-Used Components Costs Breakdown.

Part	Supplier	Cost (£)
x1 Motor 2012/13	Maxon Motor	742.95
x2 Motor 2015/16	Maxon Motor	1052.8
x1 PICO 842 2015/16	Impulse	403.11
x1 Mega Arduino 2015/16	ONECALL	22.11
x1 Buffulo WMR 433 2015/16	Amazon	34.99
x1 D-Link AC750 2015/16	Insight UK	58.79
x1 IMU Xsense 2010/11	Xsens	1947.2
x1 HOKUYO LiDar 2012/13	Active Robots	1522.5
x2 EyeToy 2014/15	PlayStation	49.99
x1 CO2 DFR Seno 159 2013/14	n/a	34.97
x1 TENCO-2412N 2015/16	Powersolve Electronics	82.83
x1 TENCO-2411N 2015/16	Powersolve Electronics	54.17
	Total	6006.5

Hours Worked

Table 10. Breakdown of Hours by System.

Systems	**Hours**	
Systems	291.564	14%
Chassis	395.694	19%
Drivetrain	458.172	22%
Dynamic Tensioning	499.824	24%
Electronics	437.346	21%
Total	2082.6	

Table 11. Breakdown of Hours on Category.

System	Hours	
Project Deliverables	725.4	31%
Admin	35.1	2%
Design and Development	608.4	26%
Technical Research	163.8	7%
Analysis and Testing	245.7	10.50%
Manufacture	304.2	13%
Outreach	257.4	11%
	2340	Total