The Low Cost Manufacture of High Technology Machines

Graham Mann
School of Information Technology
Murdoch University
South St. Murdoch WA 6150
g.mann@murdoch.edu.au

Abstract. This paper argues for the importance, within the Mars Society in Australia and elsewhere, of the development not only of new kinds of hardware, but of new processes for constructing them. The task of preparing the way for future planetary exploration is a demanding one, especially for volunteers working with limited resources of time, money and skills. Successfully managing high-technology projects under these conditions could depend on teams taking advantage of and further adapting the best management methods and tools available. Project managers should strive from the outset to design hardware and processes that cost less, depend less on skilled labour, are flexible, are economical in short run or once-off quantities, meet the needs of scientific field testing and appear credible to media and public scrutiny. Practical lessons learned by the author while managing the construction of the Starchaser pressurised rover prototype are offered to exemplify some of these principles. The paper concludes with a brief call to the international Mars Society to extend this process beyond manufacturing to the foundation of a new synthetic culture, fostering values of pioneer self-reliance, mastery of technology, recognition of human limits and service to the group.

1. Introduction

The Mars Society Australia (MSA) should be at the forefront of new production methods. The organisation has shown itself to be active in conceptual design of new exploration equipment [1,2,3], field testing of such equipment [4,5,6] and simulated planetary surface operations [6,7]. The missing element is the production of new exploration equipment. It will be argued here that this is a much more important activity for the organisation than is generally believed. As well as designing, building and testing new technologies, there are good reasons to think that MSA should be trying out new ways of doing these things. In other words, we need to be inventing new *processes* as well as new machines. Relative to contemporary engineering production processes which have evolved to mass-produce consumer items for a commercial market, these new processes need to be better suited to the needs of our grass-roots, distributed research and development initiative with its scarcity of time, money and resources. Mars Society production methods must involve much lower costs, must require much less skilled labour, be extremely flexible so as to cope with the contingencies that come up in this kind of "bleeding-edge" R&D, and work with once-off or short runs of high technology prototypes. It is far from obvious that existing ways of doing things will be equal to these demanding requirements.

Project Marsupial is the MSA's effort to build a prototype Mars vehicle capable of carrying a science crew hundreds of kilometers away from the landed base in a shirtsleeves environment [8]. While trying to get the prototype, called Starchaser, built, the author has learned several lessons about practical production engineering. In some ways, an MSA project's predicament of trying to produce quality equipment with limited resources of time and money is like that of a mission to

Mars. There is an extreme shortage of labour, as there certainly will be on that planet. MSA projects have is a strict budget, which constrains what can be done. Actual planetary missions will have a lot more to spend, but it will certainly not be unlimited. And as with every aspect of a space mission, time is a real factor. With few people working on a project, projects can stretch out alarmingly, yet the need to show sponsors results and the requirement for service does not reduce. It is difficult or impossible to hold teams of volunteers or students together over years, and long term projects risk never finishing. So realistically, time pressure cannot be ignored. It will be argued, however, that conventional schedules and completion deadlines are not as helpful as they are in a commercial production environment.

Interested stakeholders for Mars Society projects are relatively few, and scattered widely across the country, or around the world. Reflecting the publicity problem for maintaining public interest over the full duration of a Mars mission, there is a very real need to keep these individuals engaged, as well as informed, possibly for years. Fortunately, we now have advanced communications technologies which can help, and we must take full advantage of these. But good communication requires much more than just good technology. It involves a set of practices and customs which takes practice and patience to put into place.

The ramifications of new process thinking extend beyond production engineering into project management, funding and staffing, all of which impose great demands on the MSA at present. This paper focuses on new production processes for building specialised hardware under challenging constraints and finds lessons from the existing hardware projects in Australia. But a few words will also be said about other processes needed for the larger international Mars exploration effort, and about what kind of *synthetic culture* the Mars Society needs to create in order to deliver them. The remainder of the paper is divided up as follows. Section 2 outlines the prominence of space hardware as an attention getter, and why it confers disproportionate advantages on those organisations who can design, build and display it; Section 3 describes some process solutions to problems and opportunities to pioneer new sorts of processes for a grassroots, volunteer space research and development organisation; Section 4 summarises some hard-won lessons about production process from Project Marsupial, while Section 5 concludes with some brief notes about what kind of transitions the Mars Society faces in order to become the kind of organisation which can deliver its ambitious goals, namely i) public outreach to instil the vision of pioneering Mars; ii) support of more aggressively-funded Mars exploration programs around the world; iii) conducting Mars exploration on a private basis; and iv) encouraging Australian participation in space education, industry and government policy.

2. The Importance of Hardware

It is essential that the MSA carry out ever more realistic simulations of Mars planetary operations using machines which look and behave as much as possible like the real thing. Credible, good-looking hardware is important for a number of reasons. Firstly, the creation of realistic prototypes or mockups is a part of modern design practices such as Rapid Applications Development (RAD) engineering, Agile software development and user-centred interface design. These methods favour hands-on user experience as part of *formative evaluation* i.e. early feedback from the users and other

Figure 1. Engineer Matt Bamsey outside the F-MARS station on Devon Island

stakeholders then modifies further development [9]. Secondly, Mars Society operations and expeditions need to be performed in ways that the public can see and understand. Press coverage of MSA operations requires text, photographs, web content and video footage of MSA members modelling the exploration of Mars in vivid and dramatic ways. This is particularly important for the under-25 demographic, because of its great focus on visual media. In other words, the experimental hardware not only shows the public one of things we do in a concrete fashion, but also serves as the stage props in a depicted drama about exploring another world.

Third, a realistic experience of exploring and living on Mars is clearly a major attraction for people to participate in Mars Society activities. Since, as in most of today's non-profit organisations, recruitment and succession is a pressing issue, the MSA must be able to offer unique experiences to those who volunteer to be part of it and pay to be members. An important commercial opportunity that could be taken up here is that of marketing MSA activities as *adventure tourism*, in which paying guests form part of the calendar of activities at simulated habitats [10]. This is done to a certain extent with the Flashline MARS and MDRS stations in North America. As well as paying science crews, guests who are not scientists help support the stations. Some of these people evidently consider the experience to be an kind of extreme camping. Again, the chance to operate, drive, control, wear and live in Mars exploration hardware is a vital and unique aspect of that experience.

Central to these considerations is the power of hardware, particularly large, well-presented or innovative new hardware, to attract attention. Attention is a scarce resource in today's information-saturated environment. Competition to capture attention is fierce, and it has credibly been argued that increasingly, those who win the competition enjoy many advantages other than fame - from wealth to exclusive access to influential decision makers [11]. If the Mars Society is to succeed in its long-term goals, it will need such advantages. It will require a growing constituency of public support which will, initially at least, be drawn in by the uniqueness of its visible hardware and activities. Of course, even news stories showing the most spectacular achievements can seem transitory, and so, the challenge is to the sustain the attention for much longer than just a few minutes of evening news, or a quick visit to a website, at least for the interested viewer. That might be achieved by developing a second element for publicity, that of a good, long-term story line. Luckily, the Mars Society has a story that could be told over decades - the epic saga of how Mars was won.

3. The Importance of the Production Process

Earlier it was asserted that MSA production processes must cost less, require much less skilled labour, be very flexible and work with once-off or short runs of high technology prototypes. Let us now examine these requirements in more detail.

3.1 Cost Less. In the last century, space exploration was typically funded by government contracts to aerospace firms motivated by Cold War technological competition during the 1960s and 70s, and later for protection of domestic military-industrial markets, justified as national security. These military-style contracts tended to be generous, even lavish, and there was little incentive for contractors to reduce expenditure. In this climate, space agencies, especially NASA, interpreted the challenge of building space equipment as a basic platform for some very expensive and long term technology infrastructure projects, sometimes with poor returns, sometimes spinning off tremendous benefits for non-space industries. But the resultant exaggerated cost of human space exploration is almost certainly one of the reasons it has greatly declined. Today's commercial space ventures must work much harder to find ways to reduce cost as a matter of fiscal necessity. Firms such as Virgin Galactic will need to keep their expenditure under control, even to tap the luxury space travel niche market, or else go out business like a string of earlier companies [see 12].

Yet the Mars Society needs to go even one step further than this: costs must be kept low as a matter of *tradition*. Since costs (particularly transportation costs) are likely to be a major concern for all Mars exploration in the foreseeable future, optimising for costs must become second nature for practical projects. Reducing costs almost always means trading something off. According to the popular old manufacturing aphorism alluding to the quality triangle, "you can have it fast, good or cheap - pick any two". The Mars Society and its sponsors might wish to replace the last part of this with a new, greedy phrase - "we want all three", but it is not so simple. In trying to optimise the value-for-money in building complex new machines and systems with many components, Mars Society project managers will need to think anew on almost every purchase, every contractor and every plan. Systematic, quantitative ways to optimise the return on investment (ROI) are needed. Here, we may learn from the commercial domain which has been developing this discipline for decades.

Wysocki [13] describes a range of management practices suited to different classes of project, ranging from familiar, traditional forms (TPM) based on linear planning and resource allocation on the one hand to extreme project management (xPM) on the other. An extreme project is one is which the purpose might be undefined or change as the project unfolds, the nature of the project

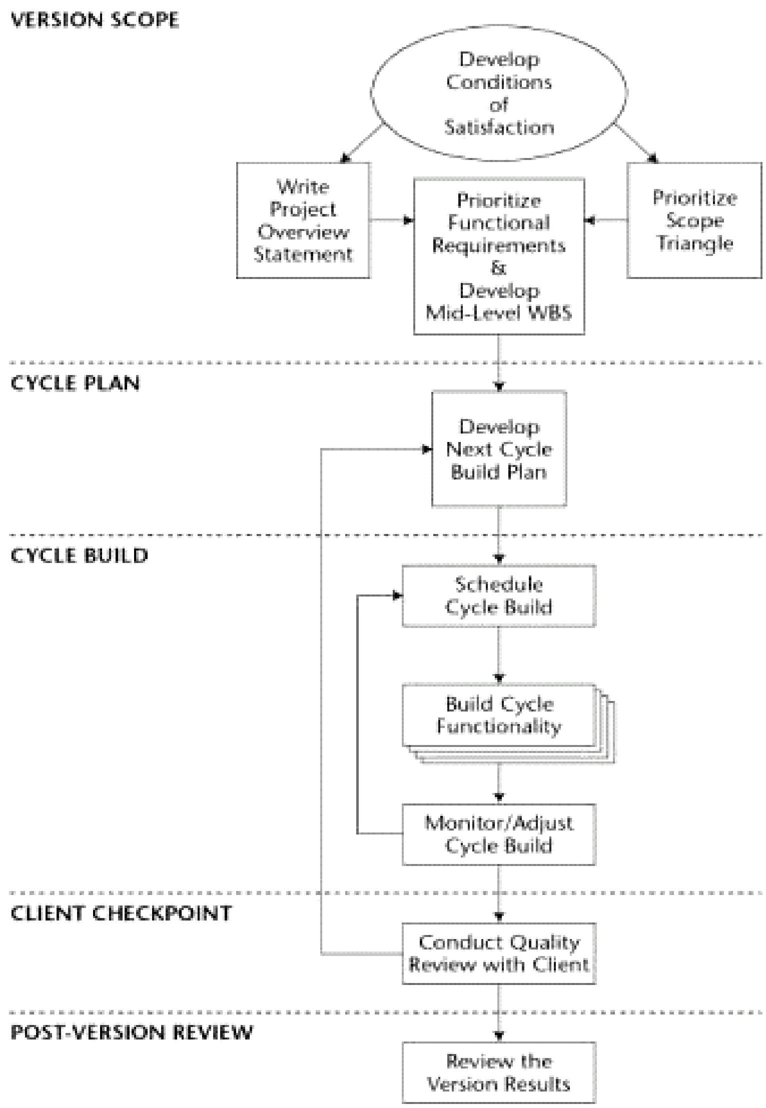

Figure 2. Adaptive Project Framework flowchart (From Wysocki, R. Effective Project Management, Wiley, 2007 p.387)

precludes any use of prior experience and/or the amount of time, labour or resources that can be expended is unknown. Perhaps some MSA projects fall into that category, but of more immediate interest is the middle ground, occupied by what Wysocki calls the Adaptive Project Framework (APF). This is well-suited to research and development projects in which the goal but not the solutions are known in advance, and where there is the risk of wasted resources and effort because of the steep learning curve for all involved. APF is designed to minimise waste and optimise on-the-job learning by organising the project into a limited number of cycles, each of which consists of a cycle plan, a cycle build and a quality review with stakeholders (Fig. 2). Each cycle is planned to concentrate available effort, materials and money into delivering functionality for a particular part (or version) of the project, in priority order. As much functionality as possible is added before the relatively short time allotted to the cycle elapses. At the end of each cycle the stakeholders are consulted to review whether progress is satisfactory and whether anything about the next cycle needs to change in light of what has happened. The APF method has only recently been adopted in the construction of the Starchaser vehicle, so it is remains to be seen how effective it will be for that project.

Modern project management tools should be used as a matter of course. These need not be expensive: many standard software bundles on today's Windows computers include Office tools, such as Project and Infopath or StarOffice on Linux machines which can help with many day-to-day management tasks. The same may be said for financial management of the project - there are plenty of readily available tools for accounting, billing, sourcing, purchasing and stock control on the market. To reduce costs open source management tools such as dotProject (http://docs.dotproject.net/index.php/Main_Page) or TaskJuggler (http://www.taskjuggler.org/) may also be used free of charge. These tools must, of course, be in the service of a working knowledge of the techniques involved, and new project managers should expect to need to pick up new skills as part of their work. Critical Path Analysis [14] is also useful, though event time estimation can be difficult when the user has little or no experience with manufacturing, supply or integration practice (see Section 4.3). PERT is also useful because it takes a different approach to quantifying construction times and may be simplified with respect to the estimates it requires as input [15] . But use of these methods must be kept in context. The results of an analysis may be of little value if the project is dominated by intractable budget, labour, time or other constraints. For instance, in building the Starchaser rover, Critical Path Analysis constantly returns the conclusion that more labour should be expended on the parallel manufacture of certain subsystems, which would clearly help increase rate of progress. But it turns out to be very difficult to do that in practice because i) there was and is a skills shortage that makes it difficult to find suitable contractors even for a single work stream and ii) most subsystems require a degree of specification and oversight during manufacture that could only come from a few key MSA members who are already working at their limit on other parts of the project (or other projects). These remain a serious limitation on the construction plan for the Starchaser, which further analysis will not alleviate.

3.2 Depend less on skilled labour. The new production processes must depend less on skilled labour because the MSA - in common with many enterprises in 21st century Australia - is suffering a dramatic skills shortage [16]. Skilled labour is at present very expensive, and so a large workforce could be ruled out on that score alone. In Australia there even appears to be a growing scarcity of the *kind of skills* required for high-quality manufacturing. The skilled trades associated with manufacturing have not been an educational priority for decades, at least until recently, with the result that there is a shortfall of new talent entering the stage at the same time experienced workers are reaching retirement age. This is a very serious problem, and not just for the Mars Society. Solutions to the labour shortage include: i) "offshoring" ie outsourcing jobs to overseas contractors ii) offering the work to retired, or semi-retired skilled workers iii) design the machine to be built using minimal labour e.g. iv) having the machine built by robots, using design for robot manufacture. This last option is not practical in most cases yet, but as automation and semi-automation become increasingly cost effective, the Mars Society should be among the first organisations to take it up. One practical example combines offshoring and automation: the US Internet-based service eMachineShop (www.emachineshop.com) offers rapid automated production and delivery of short-run machine-fabricated parts and assemblies specified using the company's online design software.

3.3 Flexible. The new production processes must be very flexible, because getting things built under the above conditions is both tough and full of surprises. There are plenty of challenges involving sourcing materials, obtaining tools, and managing storage and logistics. The author has found that some of the most important challenges involve team management. For example, members of the team, including the project leader, might withdraw from a project without warning. Any organisation has to face staff turnover, but there is naturally far less accountability for the volunteer members of the Mars Society. This is important enough to avoid volunteers as policy, or rather, not depend on them. Students graduate; people change jobs or leave the country; the situations of workers change so that they can no longer devote time to a project. The longer a project persists, the more likely it is to be affected in this way. That means that if the project depends critically on a particular skill, or resource connection related to a single person, this must be considered as even more of a risk than in the commercial domain.

Mars Society project managers also need to beware of another risk. Whenever a very competent, skilled member agrees to do something (whether a volunteer or not) there is a risk that the same person will also be asked to work on other projects. If the person agrees, they will naturally be able to spend less time on the first project. A refusal, on the other hand, may lead to dissatisfactions or accusations of rivalry within the organisation. Even if the competent worker is also exceptionally good at managing his/her own time and effort, it can become spread too thinly. In the extreme case, the person may become overwhelmed with work and withdraw. Project managers should therefore always be on the lookout for new talent, but learn to recognise the signs of impending burnout so that they can take action before a crisis becomes irreversible. For example, one of a pair of demanding specialised tasks could be outsourced to contractors even if it would appear easier to double up on the assignment of existing members of the team.

3.4 Work for Once-Off or Short Runs. The economics of the production process must work with single units or short runs, because it is the nature of prototypes to be disposed of once they have served their purpose. That generally rules out economies of scale that might be enjoyed in conventional mass production (but it also eliminates any real need to develop special supplier relations or manage the supply chain). However, perhaps the limited life of products need not be as wasteful as it first appears. The MSA has already begun to build up an inventory of equipment; depending on how the used gear was funded, it might be able to be donated after data collection to await re-use. And while the global market for second-hand science equipment is not large (but try eBay!), Mars Society members communicate well enough to let us imagine a specialised Internet-mediated marketplace for recycling equipment or test articles. An enterprising member could set up a website that organised the sale of used gear to other projects or expeditions. This could even expand and diversify into a service operating across the entire spectrum of adventure tourism and science expeditions.

The idea, often raised, of making a commercial product from experimental Mars equipment is an interesting one. It would seem to have the potential to offset some of the costs and become a handy way of making money from working toward Mars. The MSA has succeeded here on a small scale by producing mockup spacesuits for sale to an the Victorian Space Science Education Centre in

Figure 3. Examples of credible hardware. James Waldie's MarsSkin PULSS backpack (left); FMARS 2007 science crew Simon Auclair and Kim Binstead drilling through permafrost at Trinity Creek (right)

Melbourne. One can imagine field-testing a prototype self-contained pressurised emergency shelter and then transforming it into a saleable low-environmental impact living module for mining camps. But there are problems with the notion. Commercialisation is almost never as simple as selling the intellectual property to a company. A lot of work is usually needed to find a buyer and convince them to back the idea. Commercially valuable products also have much higher quality and durability demands than prototypes, and substantial redesign would probably be needed for mass-production. In Australia, at least, experience has shown that the developer's road from invention to profit from sales can be very long and very hard. Mars developers are already on another such road, so perhaps only the most entrepreneurial of us should attempt this.

3.5 Other Considerations. It is worth remembering that the primary purpose of an MSA prototype is still to obtain test data that might be of use to the developers and contractors who eventually design and build the real flight hardware. When an off-the-shelf solution presents itself, that should be seriously considered. It is not always necessary to design a new machine simply because it is intended for use on Mars. It is even less necessary to build new machines for feasibility tests or low-fidelity simulations in the field. Depending on the particular machine, and the expected lifetime of use, a prototype need not be really novel (except to be favoured in scientific publications), completely reliable (but reliable enough to get the data during field trials) or even entirely finished. For a single use in a field trip, some of the parts could be borrowed or rented, or obtained from a second-hand market as described above. There is one caveat here, though - because of the nature of the organisation and its relationship to hardware, the prototypes should not *look* too quick and dirty. Remembering the point made in Section 2, all equipment should be painted or boxed up so that they are fit for viewing by the media. The author has discovered that, for a small investment, one can often return from the local hardware store with some of newer tools, some well-designed containers or plastic farings from other machines, which, if of sufficient hardiness, can be painted and stickered with sponsor logos to achieve a credible appearance (see Figure 3). From a stylistic point of view, it should be an article of pride for MSA hardware builders that our machines to look as if they are be used by the future explorers we are actually supporting.

Where better resources and manufacturing skills are available, MSA developers must be on familiar terms with the best local low-cost plastic or metal forming workshops in the vicinity and learn how to efficiently provide them with design information in a form they can use. Perhaps good terms can be obtained in exchange for a sponsorship package, or even if a project member will simply spare the time to explain what the work is for and enthuse about the prospects. As manager of Project Marsupial, the author has been offered free work by companies who wanted nothing more than to be associated with a positive, visionary projects. For them it was enough to see progress on a website, and, seeing their logo, be able to know that they had contributed.

One should also look for opportunities within the local education system to slash the cost of construction. Students in the third year of a Murdoch University computer science course must do a practical group programming project, so their instructors are always on the lookout for clients with modest but interesting software projects. The smarter elements of local industry have already realised that this is an opportunity to obtain, at zero cost, the services of a group of five or six near graduate programmers, for six months. There are some risks, concerning potential intellectual property disputes or drawing a poorly-performing team - but hiring contractors is not proof against these and generally speaking, such student projects can be used to at least kick-start real projects while giving the students real experience in developing a product. Similar opportunities can be found in technical colleges, design schools or engineering departments. For example, an innovative solution to the problem of reliable, long-term robot travel over the surface of Mars called Mars Tumbleweed Earth Demonstrator [17] was designed, built and partially tested over a two-semester period by aerospace engineering students and their professors. The design depends on large inflatable wheels which afford ease of travel over uneven surfaces, using the force of the wind or very low-powered motors. Even local sixth grade school students from a local middle school were involved in the design process. The Tumbleweed concept has subsequently been developed into a serious contender for a surface probe by NASA's Langley Research Centre [18].

A final, very powerful way to generate low cost, innovative technological developments, is competition for a prize. This process is already at work in such projects as the NASA Challenges and the Australian Space Prize [19], while the US Mars Society issues award plaques for special service. But imagine this principle operating at a smaller scale, *within* a project. The creative manager will come up with socially meaningful ways of assessing, recognising, and ceremonially celebrating special effort or resourcefulness. For field trips, the already established tradition of handing out mission patches to participants should always be respected. To this we could add a habitual competition to see who brings the best hardware: make it a tradition to build one's own Mars equipment, with prizes, awards and lavish praise for players. There are good psychological reasons to believe that prizes and praise really works - and not only for school children.

4. Lessons from Project Marsupial

4.1 It is possible to over-specify some design elements. The design of the Starchaser vehicle is a mix of high and low precision requirements. To put it less politely, the project has experienced delays because of a mix of over-specifications and under-specifications. In some cases detailed CAD drawings that specified measurements to the millimetre held up vital work, because the contractors did not feel free to deviate where necessary (yet could safely have done so). In others, insufficient detail or measurements in the plans imposed the delay. Sometimes an experienced tradesperson could and did improvise working solutions in the absence of complete information, but they needed to made to feel confident that their decisions would be respected by management subsequently, in the absence of continuous oversight.

4.2 Use new technologies to reduce costs and labour. The Mars Society is nothing if not future-oriented and technically optimistic. It follows that new technologies should be readily adopted for manufacturing, but - because the organisation is also very practical - *only* if it returns a genuine benefit. With so many new innovations on offer, the manager needs to critically assess each new idea, and be prepared to decline if it does not measure up. A tool or technique might be too costly, too difficult to obtain, or too untried. It might take too long to learn how to use it. Yet there is no question that a competitive edge may be had by using new methods. Some conventional CAD methods are beginning to seamlessly connect to CAM (Computer-Added Manufacturing) tools, and the cost is falling constantly. In Australia, there are at present abundant opportunities to outsource form molding, assembly and electronic circuitry to China at surprisingly low cost. It is already possible to order short-run fabrication of parts online as described in Section 3.2. In the future, we can expect to see even less expensive services for the manufacture of short-run metal, plastic or ceramic parts, using ever more sophisticated 3-D fabrication machines.

4.3 Design machines to be built as well as maintained. It is a maximum of good engineering that machines should be built with maintenance in mind. But it also makes sense to impose creative discipline at the design stage to help mitigate manufacturing problems. That can require considerable foresight and experience, which may be difficult to come by. It has been possible in the design of Starchaser in one or two cases. For example, the shape of the composite plastic bodywork on the vehicle body is in part determined by the self-imposed requirement that only one mold should be made for the major exterior panels, in order to cut down cost and complexity. Therefore the curvatures of the side and roof panels have been made identical, and the prismatic shape of the mid-cabin ensures that the single mold will, provided that it is reinforced strongly enough, enable many panels to be pulled from it. A little Internet or library searching may locate written material to help the designer prepare for ease-of-manufacturing, but these will need to be specific to the materials, techniques and type of assembly being made. Consultation with an experienced manufacturer at the design stage can also return invaluable insight, if one can think that far ahead and then take the advice seriously.

4.4 Deadlines imply some control of a labour force and supply lines. It is standard management practice to lay out schedules with expected deadlines for delivery. But deadlines have their problems as well. One is that they can be difficult to calculate when certain assumptions are violated. Conventional practices evolved to meet the needs of commercial manufacturing which normally enjoyed the services of an experienced, paid, predictable workforce, perhaps mass-producing more or less standardised items, or at least working on comparable projects over time. Then one may properly estimate deadlines using methods such as critical path analysis. The difficulty is that these conditions may not hold for Mars Society projects. If the workers are volunteers, or even hobbyists, they may be neither experienced nor predictable, and the hours they can commit are uncertain. The project could involve the development of entirely new kinds of machines, under incomplete and uncertain funding conditions, so that set deadlines have to keep moving ahead in time, which is demoralising and may be self-defeating. The flexible APF and xPM methods described in Section 3.1 go some way toward averting this problem by replacing long-term deadlines into regular, short-term critical client reviews. Time management for the short build cycles is much easier, because the reviews do not depend on completion, and the scope, personnel and resources involved in the smaller unit of time/work tend to be much more predictable.

4.5 Managing people depends on their age. In attempting to find solutions to our labour shortage, it has been discovered that the age of potential contractors appears to make a big difference. The author's experience is that young people can be of great assistance to a project - provided they are committed. Avoiding the pigeonholing of workers into marketing categories such as "Baby Boomers" and "Generation Y" and their attendant stereotypes, it will be enough to say that as a general rule, younger individuals (say, 16-30 yo), perhaps due to the very dynamic and contingent nature of their experience in the world, have learned to be opportunistic and tend to avoid being locked in to any plan, schedule or job. (It is for this reason that recruiting terms in the Army have had to be shortened, and great variety and freedom is offered in mobile phone plans.) The risk - faced by any organisation taking a person in this demographic - is that they will not stay on, but will constantly be on the lookout for a better, or even just different, offer. Managers worry that they will invest time and training, only to have the recipient disappear before any real returns are made. It is not true of every individual, of course - but it is true often enough to be considered a real risk. To manage this risk is to find ways of continually consolidating the project's hold on its workers, including offering a range of experiences, special privileges and an unusual flexibility in working arrangements.

The situation seems quite different for an older demographic. The author has found that retired, or semi-retired people can have much to offer - provided they can be convinced of the reality of the project. Although they may exhibit skepticism about the prospects of exploring Mars, often great skills, commitment, and experience can be brought to bear by older workers. And unlike middle aged persons, demanding jobs and young families tend not take up all their time.

4.6 Find ways to keep the "communication bandwidth" under control. Today's professional milieu requires not only doing things, but communicating them widely, especially when the stakeholders are geographically distributed. However, the time and effort demanded of modern communication can be quite high, and possibly overwhelming. Project teams are not only required to respond to the telephone and email, but to write and post website or blog reports, build websites, conduct interviews, make press releases, and so forth. The risk here is that a team will spend its limited time describing and explaining machines, not actually designing, building or using them. In a small foretaste of a future problem for Mars explorers, it is necessary to find ways to limit the apparently insatiable demand for information and news, in order to get things done. Mars Society personnel on field trips have learned the value of media specialists to manage the news content, as well as back rooms - specialised problem solvers off-station who can take the load off the explorer on-station. In Project Marsupial, our best solutions to the communications overload have come from committed members of the team who are not physically present (and so cannot physically help build the vehicle) but wish to contribute to the project, and have the necessary skills to build and maintain modern communications. Naturally, there is some information overhead required to stay in touch with these people, but this is generally a good investment.

5. Conclusion: The Mars Society as a Synthetic Culture

The idea of the Mars Society as a synthetic culture is not a familiar one, so a brief concluding note of explanation is in order. Perhaps the most enduring legacy one could hope for from the greater Mars Society would be if it formed the basis of a new kind of cultural movement: one that took the best elements of its membership - vision, dedication, rationality, practicality, imagination, thrift, resourcefulness and so forth - and forged them into a new pioneering spirit which actively developed in their members those personal qualities they need to reach across space and make another planet their own. Many of these virtues are not well-fostered by contemporary society. An adequate culture does not yet exist; therefore, the Mars Society should manufacture one. Synthetic cultures are not new, but 21st century life creates both the needs and the opportunities to form them as never before.

With respect to the theme of this paper, one such virtue would be a new kind of ease concerning every aspect of high-technology machines - their operation, maintenance, strengths, weaknesses and quirks. It is a truism to claim that the lives of future space explorers and colonists will depend on their mastery of the technology they take with them - but that mastery should emerge not only from careful study of manufacturer's manuals, but from part ownership of the research and production processes which created the technology in the first place. Only that will form a solid enough basis for the isolated, machine-dependent society which a Mars colony must be.

The new synthetic culture demands other transitions relative to what we have to work with now. It will require apologists to become lobbyists, dependent consumers to become self-reliant technicians, volunteers to become professionals. It will require a deeper understanding of and respect for human limits, such as a shift from an expectation of overwork to strictly controlled work/rest schedules. And we may hope that it will become a locus for the much-needed shift of values from self-acquisition to group service, from short-term personal gain to long term benefit to the collective whole.

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