An Affordable Model for Enduring ISS Mission Operations with Increased Scientific Productivity

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I. INTRODUCTION

The underutilization of the International Space Station (ISS) not only affects the tax payers of the countries participating in it, but also the world as a whole. It is no secret that the amount of scientific productivity aboard the ISS is lacking [1]. While there are numerous management paradigms that could be used to enhance its utilization, this paper focuses on one very similar to that which the United States federal, state and local governments currently use for maintenance of public infrastructure. It will introduce an approach for ISS operations that improves its research potential and therefore the return on investment in the future.

II. BACKGROUND

The most current National Aeronautics and Space Administration (NASA) study of the operations architecture of the ISS was performed in August of 2000 [2]. One of the main goals of this study was to maintain the ability to attract world-class researchers, promote commercial opportunities and operate the ISS as efficiently as possible. On top of this, NASA's goal is to perform world-class research on board the ISS [2]. All of the data for this study was collected and analyzed when the ISS was still early in its development stage. No updated analysis has been completed although the station has since moved to a so-called “intensive research phase” [3]. There are currently 14 modules that have been added to the ISS and there are plans to add a 15th, the Nauka, in December of 2013 [4, 5]. In addition to these 15 modules, Bigelow Aerospace announced earlier this year that they will be attaching one of their inflatable BEAM models to the ISS. According to [6], not including the Bigelow module, the ISS has already cost an estimated USD$150 billion [7].
(€112.21 billion) which means the 15 modules cost roughly USD$10 billion (€7.48 billion) a piece.

Under the current approach, the flight crew and ground-based operators manage the ISS systems in order to optimize its research capabilities [2]. However, a pitfall to this approach is that utilization, operations and maintenance are all looked at together. These competing items need to be looked at separately in order to minimize operations and maintenance costs and to facilitate providing the maximum amount of research capabilities. The model of operations [8] for the ISS lists the following preventative, unplanned and corrective maintenance actions:

- Cleaning or replacing filters
- Replacing or recalibrating sensors and/or tools
- Inspecting parts for wear and tear
- Changing-out of expended consumables
- Replacing or repairing failed hardware (unplanned)

In the case of unplanned items, a follow up evaluation (to determine the impact to onboard systems) is completed [8]. All of these tasks are assigned to the astronauts onboard. On top of these, daily tasks such as waste removal and hygiene (of the station) maintenance all negatively affect the ability to perform research onboard. Thus, it cannot adequately produce the amount of world-class research that is desired.

III. PROPOSED MODEL

The proposed model is based off the same approach used by the United States federal, state, and local governments for maintaining public infrastructure. This plan passes management of maintenance related tasks to companies/vendors that specialize in particular areas. It also provides an incentive to the contractor to optimize as much as possible in order to maximize profits while minimizing cost. In the case of the ISS, this model would create many of these same benefits. First, the contractor would be in charge of day-to-day operations, including all maintenance, updates/upgrades, setup, teardown and janitorial jobs.

The model also serves as incentive for optimization in order to maximize profits while minimizing costs. The contractor(s) would be responsible for paying their onboard employees or developing robots that could perform menial tasks. Simplifying tasks and/or the use of structures and equipment that require less maintenance would also be left up to the contractor. Another potential solution is the use of a brain-to-brain interface (an early prototype of which has recently been demonstrated [9]). This would allow for further experimentation in this field while potentially reducing training requirements for contractor personnel on onboard components. By using brain-to-brain communications, the contractor staff member onboard would potentially be able to service parts of the ISS they weren’t trained on. It could also be used to perform complex procedures in emergency situations.

The contractor would get a fixed mass allocation for both uplift and downlift as well as a fixed number of uplift/downlift seats per period. Fees or penalties would be charged for any overages on these while the vendor would be able to sell any unused space or mass. The proposed approach also serves to reduce agency ground-based control jobs. By leaving the contractor responsible for the day-to-day operations there would be no need to involve numerous agency staff in updates on progress or minor issues. The contractor is responsible for deliverables being available on or before the date agreed upon in the service level agreement (SLA). Instead of the ISS crew members having to adjust timelines for the delivery of a new module, this would strictly be up to the contractor, which would be required to provide a date by which an additional amount of workspace would be available.

In addition to contracting out of the operations portion of the ISS, this plan also introduces the idea of a progressive SLA. This plan would be created by the international partners with vested interest in the ISS. The SLA would create a financial structure in order to ensure the vendor delivers goods and services in a timely manner. The structure would include both incentives and penalties which would be based upon performance, in order to encourage a high percentage of on-time task completion. The vendor would, as previously alluded to, be free to maintain, operate, and/or update/upgrade the station as needed in order to meet the SLA. The progressive nature of the SLA would encourage the vendor to commit to updates/upgrades in the early phases of the contract. The vendor would be paid back over the term of the contract for these updates/upgrades. All costs would be fixed up front in order to facilitate more certainty in budget appropriation and allocation for national policy makers in all partner nations.

Along with these benefits, the proposed approach also consolidates numerous redundant functions and forms one consolidated management facility. Currently, there are seven operations and management sites throughout the United States. There are over fifteen additional facilities worldwide that play key roles in ISS management and operations for partnering countries.

By combining these into one centrally located facility, costs would be reduced for all participating nations. Both decision making and deliverable production would also be enhanced. This approach of locating all vendors near the central located facility is similar to Toyota’s approach in Toyota City [10]. Using this approach has proven to be extremely beneficial in streamlining operations and reducing the total time of assembly by locating each supplier next to their internal and external
customers. Another important benefit is the ability to select an optimal contractor. While the United States has predominately used Boeing as its preferred manufacturer of ISS modules and parts, it is important to consider newer companies and make this decision in a global context. The contract between NASA and Bigelow for the BEAM module [11] is an example of this type of arrangement. With a fixed price of USD$17.8 million (€13.32 billion), its cost is significantly below that of other modules.

Even with a generous profit margin for the contractor/vendor, this proposal would still be significantly cheaper than the current plan. This concept will be illustrated using the Bigelow/NASA BEAM and Nauka.

Using a hypothetical version of the Bigelow/NASA contract as an example, Bigelow might have the opportunity to collect a bonus on this project. Say for example they are able to meet their objectives early and deliver the module early. The SLA may stipulate a 2% bonus for each month early it is deployed. There would be a great benefit for them to strive to exceed goals. On top of this, ISS operations would benefit by being able to use the additional space earlier, boosting the amount of research possible.

In the case of the delayed Nauka module (using it’s timeline with no other variables, issues or unforeseen events, with an extremely lenient and simple as it will not have a compounding effect which would likely be the case presuming an SLA that has a 1% profit reduction for each month late that the deliverables are), the original plan for this module called for a launch in 2007 [12]. This means that even if the latest compliant date of December 31, 2007 was considered, it would currently be 68 months late which means the supplier’s profit margin would be reduced by over half (68%). On top of this, as the BEAM module has already shown, the private sector can provide lower cost options than government specified and controlled approaches.

The contractor would also be allowed to use excess staff time to perform for-profit research. Examples of this research include pharmaceutical, materials development, and bio-technology.

### Table 1: Breakdown of periods by average time spent in maintenance, grey, and research areas (based on analysis of [13-24]).

<table>
<thead>
<tr>
<th>Period</th>
<th>Maintenance</th>
<th>Grey</th>
<th>Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan – Jun 2011</td>
<td>13:07:30</td>
<td>0:40:00</td>
<td>9:20:00</td>
</tr>
<tr>
<td>Jul – Dec 2011</td>
<td>14:47:30</td>
<td>0:40:00</td>
<td>5:10:00</td>
</tr>
<tr>
<td>Jan – Jun 2012</td>
<td>25:25:00</td>
<td>0:45:00</td>
<td>9:40:00</td>
</tr>
<tr>
<td>Jul – Dec 2012</td>
<td>23:10:00</td>
<td>1:02:30</td>
<td>12:55:00</td>
</tr>
<tr>
<td>Jan – Jun 2013</td>
<td>23:42:30</td>
<td>0:00:00</td>
<td>10:07:00</td>
</tr>
<tr>
<td>Jul – Dec 2013</td>
<td>31:05:00</td>
<td>0:00:00</td>
<td>12:35:00</td>
</tr>
</tbody>
</table>

Through a combination of contractor installed upgrades and a reduction of astronaut time spent on routine maintenance and service, the proposed plan will result in more time being available for scientific research. The routine activities described above are tedious and monotonous, degrading crew member performance due to energy waste and boredom. They are also potentially disruptive to experimental schedules. Having a dedicated service and support crew frees up astronauts to exclusively concentrate on research and development activities related to important national scientific objectives. Keeping in mind that some amount of redundancy is an absolute necessity, additional efficiencies should still be gained by the higher level of crew member specialization. NASA’s Commercial Orbital Transportation Services (COTS) and Commercial Crew and Cargo Development (CCDEV) program have created an unprecedented level of uplift capacity for cargo, supplies and experiments. It is also an example of commercial entities providing enhanced capabilities in pursuit of mutually (government and business) beneficial goals.

### IV. METHODS

In order to demonstrate the feasibility of the proposed model, the performance of the current model needs to be quantified. For this analysis, a stratified selection process was used. The stratum consists of 6 consecutive 6-month (January thru June and July thru December) periods with two dates chosen arbitrarily from within each period. A total of fifteen dates were selected as three (January 1, 2013, January 27, 2013, and July 21, 2013) were selected and then excluded due to being crew rest/off-duty days. At the time of data retrieval there was no data available past July 31, 2013. Table 1 shows the averages of each category for each period.

The radiogram of ISS timelines and the On-Orbit Status report were then obtained for each date. While only the timelines were used for this analysis, the On-Orbit Status reports were vital in aiding the decision making process in categorizing each entry appropriately. These timelines have been broken down into three categories: maintenance, research, and items which could not be effectively classified as one of the foregoing. Anything directly relating to the crew members (pre/post sleep, sleep, breakfast, lunch, exercise, etc.) was not included. The maintenance category consists of everything related to hardware/software setup as well as all facilities and equipment/spacecraft maintenance. Items that are directly related to research or data collection were placed in the research category. Items that are unclear (such as some preparations) were placed in the third category, as there was not enough information to determine if it was a maintenance or research item.
All morning inspections were placed in the maintenance category due to numerous occurrences of inspection of hardware, rebooting computers, and such being described as part of this activity. Additionally, all work prep/evening work prep items were categorized as a research related topic. This may be an overly favorable categorization; however, it was placed here due to the occurrences of hardware/software setup being listed and labeled separately. Also, where research/experiments were listed along with the setup/teardown of hardware, these items were included in the research area. Once these timelines were categorized, the aggregate time devoted to each of the three categories was calculated for each day, each item was also multiplied by the number of people assigned to the task. Once these numbers were obtained, the averages for the three categories for each half of the three years were calculated.

V. ANALYSIS
The averages obtained for each half of the 3 sample years shows that 68% of the time is spent on maintenance related activities leaving only 31% of the time for research. Under the proposed model, this 68% of time would become the responsibility of the contractor/vendor, freeing up the astronaut crew to focus solely on research activities. The contractor, in addition to being responsible for all hardware related issues, would also be responsible for the setup and tear down of all of the hardware needed for experiments, conferences, and such. This may also reduce the total time spent on maintenance and preventative maintenance by allowing the contractor to note any issues or items that may need to be addressed while the setup/tear down are being performed and performing maintenance related tasks to hardware while it is already out. Additionally, they would be in charge of stowage and retrieval of all equipment. By using this approach, the astronauts would be able to move from experiment to experiment with as little downtime as possible. Downtime between experiments/research could be filled with providing documentation and log entries or tending to personal matters.

VI. CONCLUSIONS & FUTURE WORK
The comprehensive plan presented in this paper may be extremely beneficial to the scientific community. With the vast amount of money already spent on the ISS, a meaningful return on investment is virtually unobtainable. However, with the proposed plan, there would be a significant amount of research and experimentation that could be completed in the expected remaining life of the ISS. By removing the day-to-day operations tasks from being the responsibility of the researchers onboard, they would be able to focus on research activities. This increased utilization may justify the extension of the end of life of the ISS to 2028. To begin its implementation, NASA could reallocate job duties to consolidate all maintenance related tasks to be one person’s responsibility in order to gauge the amount of scientific productivity that is gained by the remaining crew members. This initial phase would also assist NASA mission managers in determining whether significant additional demand for ISS use exists and what constraints may need to be resolved (such as upmass capabilities) to allow expansion of the use of the station.

References