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Lessons Learned in Systems Engineering Availability and Recommendations for Mission Technical Leaders

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Abstract:

In spaceflight missions at Goddard Space Flight Center (GSFC), the Mission System Engineer (MSE) is the technical leader of the overall engineering team and also is the Independent Engineering Technical Authority. The responsibility of this role includes the definition of the mission design architecture, concept of operations, and mission requirements, management of risk throughout the development, and verification and validation of the final system performance and function amongst other duties. This responsibility inherently requires time management, enabling focus on a balanced development with appropriate risk. Time is the most valuable resource of the MSE.

The system engineer’s availability to interact with the development team (often product or component design leads and technicians, often in different worksites) to discover and mitigate mission risks during development is key to mission success. This paper presents examples from Lunar Reconnaissance Orbiter, Landsat 9, and Neutron star Interior Composition ExploreR (NICER) which represent in-house and out-of-house hardware builds. These examples demonstrate how interactions between the Mission Systems Engineers and other project and partner engineers result in discovery of critical risks, leading to early mitigation with significant cost and performance savings. These three missions would have suffered test failures or on-orbit failures had their MSEs not set aside time to visit engineers and technicians that were working on key pieces of space flight hardware.

Availability is more than just time; it is openness to listen to concerns and questions. It begins by building a level of trust in the team that it is safe to ask questions or share concerns without the fear of blame or additional workload. It also requires enabling informal conversations (over lunch, coffee, in the clean room, or at the team members desk, etc.) where key information can be exchanged, and team members may even provide an easy-to-implement mitigation idea for another subsystem.

Availability is a highly valuable commodity and completely non-obvious to protect and optimize. The natural tendency of engineers is to keep themselves busy with solving problems that they know about. This paper is encouraging MSEs to resist this tendency to try and solve all the complex problems themselves and actively devote daily time to learning and solving problems that are found with informal communications with other team members.

Introduction

NASA Mission Systems Engineers (MSEs, which JPL calls Project Systems Engineers) are increasingly leading more complex space missions with less support systems engineers and discipline leads. In an effort to get the most out of limited dollars, more and more missions are cost constrained missions or build to cost type missions. Likewise, management and organizational tools and higher-level meetings increasingly place demands on MSEs to report status and manage tool inputs. These drive increasing time pressure on the MSEs for the overall technical leadership and independent technical authority portions of their jobs. This paper argues that the MSE needs to make a conscious effort to make sure there is dedicated time in their schedule to interact with the discipline engineers working directly with the flight hardware. What follows are 7 real mission examples of MSEs discovering mission level hardware issues that would have significantly impacted development schedule or performance in flight had they not allocated time with the discipline engineers during tests or other integration activities to discover these issues.

 All of these examples required issue recognition and mitigations that did not occur in meetings or other reporting mechanisms, but in-unplanned thoughtful discussions around the hardware or assessing test data. Had the interactions been through typical reporting structures, or through email, there would have been a real risk the issues would not have been identified until the schedule impact or on orbit issue had been realized. This definitely poses a challenge to today’s MSEs who often interact with partners that are not geographically co-located, but by exercising and ensuring good working relationships and quality frequent tag ups with partner systems engineers this can be mitigated when not meeting in person.

 Having good quality face to face interactions and quality tag ups require the MSE to have weekly schedule openings and to have the right attitudes to absorb information and ask questions. This does not come easily in the midst of long hours and significant demands on MSE’s time. Being in the right frame of mind during interactions also takes conscious effort to ensure burnout is not occurring and MSEs are taking care of their emotional health.

 It is easy to simply try to take on more workload. As the technical leader, you often feel that you may be the best person to complete certain tasks. While that may be true, what is often missed is the interactions that didn’t occur because you happened to be occupied at a task that should have been delegated. The job of the MSE is to be the overall technical lead of the project, therefore a conscious leveling of the risk and focus on some of the perceived high-risk areas is important. Also important is some attention to the other areas of the project that might not be perceived as high risk, but also are critical to complete the project. Often the areas that are lower risk are not staffed as adequately, nor is attention paid to these areas because of the area’s perceive straight forward nature. Perceptions and reality diverge without conscious attention.

Duties of a Mission Systems Engineer

 Mission Systems Engineers (MSEs) have multiple roles, all of which are important for the success of the project. MSEs are responsible for: Mission Design Architecture, Concept of Operations, Technical Decision Making, Requirements Management, Technical Risk Generation, Verification and Validation, Evaluating Technical Performance Measures, and being the Engineering Technical Authority (ETA). (The ETA on a NASA project is responsible for ensuring the technical integrity of the system and elevating concerns over excessive technical risk to senior engineering management, should the project management choose to accept such risk.) The MSE roles are expressed in plans, master equipment lists, risk databases and requirement documents. This ultimately results in the MSE taking a role as a technical manager, managing a team of systems engineers who fulfil these functions. Being a technical manager means that there is considerable delegation of authority and risk identification to this group of systems engineers.

There are also institutional demands on a MSE’s time. These include support of the project weekly, the project monthly, compiling the systems engineering weekly and monthly charts, and the support of division meetings and other reporting forums. These institutional role activities can consume a considerable amount of time and often are not controllable or delegable to other systems engineers. There can also be task management activities for contractors, and financial reporting that further limit availability.

These tasks of managing direct reports, and responding to institutional demands, limit how much time an MSE has to address emerging problems and build relationships needed for resolving future issues. These tasks carry the very real danger that they will reduce critical technical risk identification by taxing the MSE’s emotional and physical availability.

Neutron star Interior Composition ExploreR (NICER) background

Neutron star Interior Composition ExploreR (NICER) is an astrophysics payload currently located on ExPRESS Logistics Carrier (ELC) 2 on the International Space Station (ISS). NICER is a Principal Investigator led, small explorer that is Class D. This means that the mission delivers a lot of performance for a low cost and allowed to take more risk. The Principal Investigator is responsible for delivery of the payload to meet the science. NICER is an X-Ray spectrometer with the capability of determining Neutron Star densities through light curve modelling. It also has the capability to observe other celestial X-Ray sources such as stars being consumed by black holes emitting beyond the event horizon. Interfacing a state-of-the-art X-Ray telescope with the man-rated ISS presented some unique challenges such as maintaining a stable base and interfacing to the existing ELC avionics. The challenges of delivering an innovative, history book changing tool within a class D budget cause unique systems engineering challenges.

NICER example #1: Partnering with perfectionist outside expert helps eliminate extra mechanism.

In order to point NICER to celestial targets, the system incorporates a dual axis gimbal system and star tracker sensor. Understanding how stable the ISS interface at NICER’s base would be was key to enabling the instrument’s 2 arcminute pointing accuracy. Prior to a trip to Houston, the NICER team learned that the mechanical interfaces between NICER’s hard mounted Active ExPRESS Payload Adapter (ExPAs) were slotted to allow thermal expansion and contraction. The advantage of these slots to the system is that they prevented thermal stress buildup that might prevent the mating and de-mating of the active to passive interface. These slots would unfortunately cause non-linear shifts on NICER’s pointing as it accelerated and decelerated to point at celestial objects. NICER’s MSE, Principal Investigator, and pointing team went to Johnson Space Center to have a technical interchange meeting on Extra Vehicular Activities (EVA) markings and Pointing discussions with the station’s jitter experts. There was a lively discussion with an EVA expert about the Font and Markings on the NICER Pointing system so that an Astronaut would be able to manually stow NICER in the event of an actuator failure. After the meeting was completed the EVA expert offered to stay and talk, while we waited for the next meeting to begin.

The discussion turned to a complicated mechanism we were thinking of incorporating on NICER that would pin NICER between the Active and Passive ExPA, effectively rigidizing the slots so that NICER would be firmly attached to its base. In the course of the discussion the EVA expert mentioned that the Passive ExPA (hard mounted to the ISS) had magnets in it that interfaced to metal plates in the NICER side active ExPA. The Magnets and metal plates in the ExPA are completely undocumented by the ISS. But working with the EVA Expert and others at the ISS we were able to avoid designing and building an additional mechanism on NICER.

This story is somewhat unremarkable on the surface, but context is everything. This particular EVA expert had spent most of the meeting critiquing the EVA marking configuration, Font, Font size and content. It had been a frustrating meeting where we had to go back to the drawing board and create a new drawing of the EVA markings for what the team viewed as unnecessary and insubstantial changes. This is where Systems Engineering Availability lessons learned comes in. Rather than expressing our frustration and being dismissive of his presence, we realized the importance of partnering with him for his approval as key to moving forward. As a side benefit of this partnering, he helped us solve a significant problem.

NICER example #2: Simple problem solving, and good will can mitigate months of uncertainty

 ISS payloads are expected to demonstrate that their 1553 and Ethernet connections to the ELC avionics are fully functional with both an ELC spare avionics interface (our payload’s electrical interface) and the ISS Ground System. We had recently received our flight Main Electronics Box (MEB) from the vendor, less than a month before this test was scheduled and we could not delay this test as it was on critical path for the assembly of NICER. The test is conducted at Kennedy Space Center (KSC) in the Payload Integration Facility. Due to an earlier unexpected failure on the ELC spare avionics at KSC for an earlier ISS routine test, these types of interface tests receive tremendous scrutiny by the ISS. Testing is scheduled months in advance for certain windows on the calendar. Our test was scheduled from a Tuesday to a Friday. It started on the Tuesday with testing on the 1553 interface. Each day, it takes several hours for the ISS to configure the ELC spare avionics and ground system as it would be on the ISS and then we can start testing. Each downlinked packet and uplinked command require verbal verification with the local ISS test conductors and often a phone call to Huntsville (where the ground system is) to troubleshoot. The test progress was slow as a result. As is expected when testing both the avionics interface and the ground system interface, there were some significant updates required to get the ground system to accept our health and safety packets. We corrected these and had the 1553 interface and health and status packets corrected by Wednesday afternoon.

We then tried to use the ethernet link, which NICER uses to downlink its science data. There was no response. And then the troubleshooting began. We had two parallel paths: either our flight hardware had an issue, or there was some failure in the ISS ground software interface that was not connecting. We re-examined the MEB test data for the ethernet link measurements and noticed that the signal was on the low side for the Ethernet spec. We had conversations with experts on the Ethernet link (whose interface circuit we had used in the MEB). We were in parallel paths trying to diagnosis what was going on with the ISS Ground System and what they were seeing. And our test time was passing quickly.

The NICER team would meet at night to have dinner together and plot the troubleshooting approaches for the next morning. On Wednesday night’s dinner, we really thought it was something on the ISS interface side akin to some of the problems we had seen on the 1553. But by the end of Thursday’s day of testing we were really frustrated. We weren’t getting anywhere in our diagnosis and time was running out (only one more day before the testing would be deemed a failure and we would need to seek another window of test time on the ISS calendar). We could see with break out boxes our box trying to communicate with the ISS ELC avionics and the signal looked reasonable, but we couldn’t get the ISS system to register any connection.

Our electrical lead had an Electrical Ground Support Equipment background and he had a hunch that maybe we had misunderstood the ISS wiring diagram and switched two of the wires. We didn’t want to go into the test harnesses so he had made a trip to Home Depot and bought some commercial Ethernet cable so that we could swap the wires with a quick extension he made. We only had Friday left, and we knew there wouldn’t be enough time to run all the tests we wanted to run. So, as a team, we talked about it over dinner Thursday night.

As MSE, I was going to meet with the local KSC folks responsible for running the test to request Saturday work and to extend the test one day. We also had all the NICER team members extend their reservation by one day. What we learned on Friday morning is that it was highly unusual for anyone’s testing to be extended by a day. We (MSE and another SE) had to go personally to each of the KSC employees supporting the test and ask them if they could support for 6 hours on Saturday. We also went to our ISS interface at JSC and at Marshall Space Flight Center (who run the ISS ground system for payloads) and ask for their support on Saturday. The stakes were high. If we couldn’t prove out the Ethernet interface with our MEB, we would have to repeat the test, fly the team to KSC, and delay the overall NICER schedule for a month or two to accommodate it. NICER as a principal-investigator-led mission had a defined cost and tight schedule and did not have the schedule or cost resources to accept a delay.

 We had actively partnered with the local folks at KSC. We also had good working relationships with Marshall Space Flight Center and JSC, so they both agreed. We came in on Friday and by Friday Close of Business we had the Ethernet interface working and had our first packet passed through the ground system. Friday evening’s dinner with the team had much of our anxiety resolved, but there were still important tests on Saturday to demonstrate the ISS Ground System Interface and MEB could handle a much longer Ethernet cable length expected in flight (versus the short test cable) and the maximum data rates that we might experience if we were observing a particularly bright X-Ray source.

The Saturday tests demonstrated that we would be fully functional on the ISS ELC and allowed us to return to GSFC with a fully tested MEB ready to be assembled to the NICER structure. We were very grateful to our partners to allow us to complete our testing and trusting us to complete a crucial test, while giving up their Saturday to support us. This only happens when the Systems Engineering reaches out to the key technical partners and has open lines of communication to request accommodations that are atypical. With this trust, unexpected obstacles can be overcome with minimal programmatic impact.

NICER example #3: End Item Data Package Review Issues are mitigated with solid partners

 NICER engineers and MSE were at an End Item Data Review for the NICER Star Tracker. This review used the NICER Star Tracker Performance Specification and the vendor provided a compliance matrix which provided a compliance column and reference to each of the verification artifacts. We were carefully going through the verifications and examining the artifacts when we got to the in-rush requirement. The NICER Star Tracker vendor stated compliance with the in-rush requirement. But when the verification artifact was examined, it showed the in-rush for the star tracker exceeded the requirement. This was a total surprise for a star tracker that consumed a handful of Watts. The cause of the large in-rush was the unfiltered power link between the Star Tracker power line and the large capacitance in the DC/DC converters. The star tracker was already built and tested at this point and couldn’t be re-designed to minimize the in-rush. The in-rush was substantial enough that the ISS switch providing NICER power would likely have tripped every time the star tracker was turned on. The star tracker is switched on by the MEB. The MEB, built by Moog Broad Reach, was still in final layout at this time. The electrical lead gave the MEB vendor a phone call. Within a week, the MEB vendor had offered a different type of switch which would give the Star Tracker a “soft start” to lower the in-rush without impacting the MEB schedule. Mission Systems Engineering, in this case, had ensured the right discipline engineers were supporting the End Item Data review and encouraged the Electrical Engineer to reach out to the MEB vendor. Though this appears straightforward, the review was in Europe, while the majority of the engineering team was in the United States and time zone differences made this more challenging. The MEB vendor (in Arizona) evaluated a minor design change after CDR (which is also atypical for vendors to do) and switched to a “soft start” on this particular power switch. Without the trust between the electrical engineer and MEB vendor, the careful review of in-rush test data and this quick work modifying the MEB, the NICER team would have taken a schedule hit to build an in-rush filter. Without the support and careful review by the team of the Star Tracker hardware real time, this in-rush issue might have been missed. Engineering teamwork, led and cultivated by the MSE, absent of blame or excess process was the key to NICER’s success.

Landsat 9 background

The United States Geologic Survey and NASA GSFC have been partnering to operate and build multi-spectrum earth imaging missions for over 50 years. The Landsat program provides users worldwide with high-quality, global, land-imaging measurements that are compatible with the existing 50-year Landsat data record. Landsat 9 is the latest satellite in the Landsat series—it will continue Landsat’s irreplaceable record of Earth’s land surface upon its September 2021 launch. To reduce the build time and a risk of a gap in observations, Landsat 9 will largely replicate its predecessor Landsat 8, but with greater sensitivity and a reliability upgrade to one of its instruments.

Landsat 9 has two main instruments: Operational Land Imager 2 (OLI-2) and Thermal Infrared Sensor 2 (TIRS-2). OLI-2 will capture observations of the planet in visible, near infrared and shortwave-infrared light. OLI-2 is being built by Ball Aerospace in Boulder, Colorado. OLI-2 will be substantially the same as the Landsat 8 OLI, but will deliver more sensitivity than Landsat 8. TIRS-2 will measure the thermal infrared radiation, or heat (brightness temperature), of Earth’s surfaces. TIRS-2 is being built at NASA Goddard Space Flight Center in Greenbelt, Maryland. TIRS-2 will provide an upgraded version of the Landsat 8 TIRS instrument, by improving reliability and correcting known issues with stray light.

Landsat 9 example: Observatory Radiated Susceptibility Levels

I started as Mission Systems Engineer on Landsat 9 just before the observatory environmental test campaign. Landsat 9 shares many of the same components and structure of Landsat 8. The Radiated Susceptibility environment that had been baselined was the same as Landsat 8. We had a seasoned and capable Electromagnetic compatibility lead. I noticed that the X-Band Radiated Susceptibility test level was stated as 50 V-m. As MSE, I questioned the derivation of this fairly high test level. The team at first pointed out that test level was heritage from Landsat 8. When I pressed the team on it, they started to look at how the X-band antenna pattern was actually radiating to the avionics on Landsat 9. As the antennas are designed to have hemispheric coverage and the antennas are proud of any other components, it turned out that the X-band radiation on the observatory was fairly low ~10 V/m. We tested at 20 V/m which is 150% below the previous baseline. This lowered the likelihood of damage to the observatory that would have been unnecessary based on the self-radiation the observatory experienced. As the team had been used to the heritage numbers, it took a little time to convince the team to re-examine the levels. But once they saw the actual antenna patterns versus the geometric layout of the observatory, it became apparent to them that this was the right approach. This also had the advantage of eliminating a filter for the instrument deck to lower the RF levels in that vicinity. We were able to save a little schedule during Electromagnetic compatibility as a result. This required a good relationship with the seasoned project engineering team and the contractor, which I had spent time developing as soon as I had joined the project.

Lunar Reconnaissance Orbiter Background

The Lunar Reconnaissance Orbiter (LRO) was originally conceived, in 2004, as the first of a series of missions to the moon as part of a new Exploration Initiative at NASA. The instruments were selected through an announcement of opportunity, and the mission was assigned to GSFC for project management and for an in-house build of the spacecraft. The Exploration organization at HQ wanted to launch the mission by the end of 2008, and the in-house build provided a way to meet that schedule. Funding started in early 2005, the mission was confirmed in May of 2006, and the team maintained schedule until the summer of 2008, when national launch priorities delayed the launch into 2009. Further issues with launches ahead of LRO delayed the launch until June 2009. Until the launch delays, schedule dominated the development. As problems arose during the design and build of the mission, it was critical that the MSE quickly assess those problems for system-level impact and resolution.

LRO Example 1—System-Level Problem Tracking and Resolution

After CDR and prior to system integration, there is a tremendous amount of work going on in parallel. Each component is being built by a different organization, and *unforeseeable* problems invariably pop up. During testing, the builders will discover design flaws, assembly issues, part failures, and other such problems. On LRO, there were over 50 such issues that the project tracked at the system level. The project needed to make decisions that traded technical risk against schedule or traded one subsystem’s schedule against another’s. For instance, an undocumented change to a test fixture resulted in a fastener punching through into a lubricated section of a mechanism on one of the instruments. The team needed to decide whether to try to vacuum any contaminates out through the hole or take the additional time to completely disassemble the mechanism and replace all of the grease inside. It was a system-level decision because of the large impact on schedule. With input from the MSE and mechanical experts, the project manager chose to take the schedule hit and fully clean the mechanism. In another example, the transponder vendor discovered during testing that 6% of the time the receiver would not lock up to a 1010 bit pattern as quickly as required. The vendor understood the cause of the problem, but the fix would require several months of delays. The vendor also showed that a 11001100 pattern would lock up within the time required. The MSE needed to work with the communications team and the ground systems team to determine the solution that would have the least impact on the mission, both during development and in flight. Instead of fixing the transponder, the MSE decided that the ground system would make the change in the idle pattern, allowing the receiver to reliably lock within the time allotted. Throughout this intense period of parallel work, it was critical that the MSE pay attention to each anomaly and assess the impacts on the system of the various resolution options.

LRO Example 2—Risk Management

Throughout development, good risk management was essential to maintaining schedule. The project needed to identify potential problems and mitigate them before they had a major impact on the schedule. The MSE established monthly meetings with each subsystem lead, where the lead would be comfortable raising concerns and discussing whether or not the concern was something the project should track. In one of these meetings, the Command and Data Handling (C&DH) lead mentioned his concern with the delivery of a power-supply part. If the part did not arrive on time, the delivery of the C&DH system would be delayed. The C&DH lead had been working with the project’s parts engineer on this issue, so he assumed the project was aware of the problem. But this information had not made it to the MSE and the project manager until this meeting. The MSE brought the risk forward to the risk board, where the project manager immediately began to apply resources to solve the problem. A flight spare card was assembled with a lower-quality part, while the project worked with the vendor to try to expedite delivery. The spare assembly enabled testing to proceed, keeping the flight integration largely on schedule. Had the MSE not listened to the C&DH lead’s concerns, or had the MSE not had time to hold the meeting with the C&DH lead, delays in the part delivery would have cost months in the flight schedule.

LRO Example 3—Focus on the People

The LRO team solved problems quickly by bringing its full talent to bear. The MSE actively encouraged diverse perspectives and minority opinions. Although these are popularly stated goals, it is not easy to get this input from most people. Especially when there is a close sense of team, individuals are reluctant to rock the boat or express an unpopular position. Frequently people will not express an opinion because they do not want to be a bother, or they do not realize the full, system-level impact of their concern. And sometimes people do not think their voice will make a difference. The MSE countered these effects by actively listening to concerns and following up with at least an investigation. It is important to follow up with the individual to describe the disposition of the concern, even if the best course of action is to proceed as planned. If an individual hears why his concern was set aside (perhaps other concerns were more pressing), then he is more likely to raise a concern in the future, as opposed to the situation where it appears to him that his concern was totally ignored.

It takes time and effort to encourage everyone to express their concerns. Some people will bring up too many issues (the constant worriers); some people’s styles do not match; some people have less experience, so they do not know what might be a concern at the system level; and some people just think differently. But it is the different perspective that adds the strength to the team. Once launched, a spacecraft is usually irretrievable. The team must find all the fatal flaws before that launch. Different perspectives fill in the blind spots, helping the MSE see where things might go wrong.

A great example is the LRO coarse sun sensor (CSS) circuit design. During system-level testing of the CSS’s, the engineers who were performing the test noticed a very small discrepancy in the current flow (on the order of a few micro amps). The MSE encouraged these engineers to keep digging into the source of the discrepancy, even though he expected it was just some bookkeeping

mistake. The engineers scheduled multiple tests on the spacecraft, to the point where the I&T manager started to complain about their chasing of what appeared to be nothing, but the MSE defended them. Eventually, they tracked the issue to a flaw in the circuit that read the CSS’s. Although subtle in the test, this flaw was big enough that the sensors would have been essentially useless in flight. The project needed to remove the C&DH box and change some resistors. Had these engineers dropped the

issue, LRO would have launched with non-functioning sensors that were critical to acquisition of the sun. It is quite possible this flaw would have resulted in a loss of mission. It was critical that the MSE take the time to focus on the people and hear their concerns.

How does MSE Availability factor into these issue driven programmatic schedule and cost risks?

  Building relationships within the team from systems engineering to subsystem leads to partners requires time and care. There needs to be trusting relationships with specific ownership of products within the team and with partners. All levels of the project have project-enabling jobs to complete in order for the mission to be successful. This is enabled by the MSE and his SE team when they have the right attitude about interactions with members of the team. The MSE can earn trust by participating in informal reviews, have an open-door policy, request advice and provide direction as appropriate. Re-direction is best performed first in person, outside of large forums where re-direction could be seen as lack of confidence. We all need to learn, be mentored, and grow in our careers. How we approach each individual, is key to this trust. How we manage our own home-to-work-life balance plays into our availability for connection. This connection is key to successful implementation of most space flight missions.

 At MSE level it is very easy to let process, reporting, endless list of meetings “that you must attend”, and emails that “must have a reply” overwhelm the time that is available to build relationships and interact with partners and subsystem leads. On NICER from the top down, we organized weekly get togethers, periodic picnics and parties, and daily sharing of espresso to bring the team in and have real conversations in casual settings. These weren’t just conversations from top to bottom of the organization chart, they were generally bottom to top. Personal relationship means taking time to informally get to know team members from all levels of the project. Personal relationships with partners that are geographically dispersed requires additional techniques such weekly oneonone telecons, monthly visits, and listening carefully to the needs and wants of the partners. Acknowledge the partner’s interests and then supporting when it is appropriate to do so typically can be done without increasing risk, cost, or schedule. Be fair with evaluating impacts (cost and schedule) to changes that come from external interfaces to the partners. Be complete, run each potential concern to ground, you may find something that you could fix on the ground that “saves” the mission.

Being trusted also requires emotional availability for other’s concerns. This requires active management in every individual. Emotional availability requires taking time off and doing non-work activities. It also means opening up your daily and weekly schedule for impromptu meetings and unexpected discoveries. This is quite impossible if the days have 5-8 hours of meetings a day. This level of scheduled and regimented time ultimately leads to frustration and not surprisingly, lack of availability physically and emotionally. As your availability diminishes, it can then be difficult to determine a clear course of action as the inevitable unexpected surprises occur.

Whenever there was a big decision to make, the MSE, SEs, Project Manager, and/or the PI often would take a walk outside to make sure we had looked at all the sides thoroughly enough but using the length of the walk to ensure we made decisions decisively to move the project forward. Being available means having the space to creatively solve issues and determine the best steps forward by delegating tasks you know you can do well to others to ensure you always have time to listen. These steps need to be free from emotional frustration or focusing on who is at fault. This is also objectively achieved by managing your own schedule to prevent back-to-back meetings. It also has a subjective portion: don’t forgo relationship building and do take time off to think inside and outside the work place.

Conclusions

Modern system engineers’ time is increasingly dominated by reporting and virtual interactions. These take the form of email, building status presentations, and conducting formal meetings. Systems engineers need to preserve available time to have face-to-face or targeted small-group interactions to discover issues and to identify solutions within the team. Preserving team and partner relationships are key to success. Successful missions have timely interactions and trustful communication that enable discovery of design drivers and risks. Trust can only be generated with emotional and physical availability. Trust helps the MSE overcome significant obstacles and anomalies without energy being spent on determining motive. It is essential to mission success that an MSE understands the proper balance of the most valuable resource of all: time.