An Analysis of Shuttle Crew Scheduling Violations

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Abstract

From the early years of the Space Shuttle program, National Aeronautics and Space Administration (NASA) Shuttle crews have had a timeline of activities to guide them through their time on-orbit. Planners used scheduling constraints to build timelines that ensured the health and safety of the crews. If a constraint could not be met it resulted in a violation. Other agencies of the federal government also have scheduling constraints to ensure the safety of personnel and the public. This project examined the history of Space Shuttle scheduling constraints, constraints from Federal agencies and branches of the military and how these constraints may be used as a guide for future NASA and private spacecraft. This was conducted by reviewing rules and violations with regard to human aerospace scheduling constraints, environmental, political, social and technological factors, operating environment and relevant human factors. This study includes a statistical analysis of Shuttle Extra Vehicular Activity (EVA) related violations to determine if these were a significant producer of constraint violations. It was hypothesized that the number of SCSC violations caused by EVA activities were a significant contributor to the total number of violations for Shuttle/ISS missions. Data was taken from NASA data archives at the Johnson Space Center from Space Shuttle/ISS missions prior to the STS-107 accident. The results of the analysis rejected the null hypothesis and found that EVA violations were a significant contributor to the total number of violations. This analysis could help NASA and commercial space companies understand the main source of constraint violations and allow them to create constraint rules that ensure the safe operation of future human private and exploration missions. Additional studies could be performed to evaluate other variables that could have influenced the scheduling violations that were analyzed.

Keywords: NASA, EVA, scheduling constraints, violations, safety.

Proposal

An Analysis of Shuttle Crew Scheduling Violations

The Effects of Crew Scheduling Violations

Objective: The Shuttle Crew Scheduling Constraints (SCSC) document defined major criteria for implementing constraints for scheduling on-orbit activities for the Shuttle crews. It guided the compilation of the crew activity Timeline by setting scheduling standards for on-orbit activities. It was the goal of the personnel in the Shuttle Flight Planning Branch at Johnson Space Center to schedule activities for a Space Shuttle mission so as not to violate any constraints in the SCSC. Unfortunately, the required activities that were imposed on each Shuttle mission by the Space Shuttle Program office often oversubscribed the Shuttle crew's schedule. This would lead to violations of the SCSC rules. Common violations occurred on days that had an EVA scheduled. Numerous violations on a mission could cause the crew to work into their off-duty and/or meal time. It could also force the crew to rush through activities and procedures, which could lead to an unsafe situation.

After the STS-107 accident, the SCSC underwent a substantial overhaul with a more concentrated focus on International Space Station (ISS) assembly and operations. However, some violations were found to be unavoidable due to operating with the ISS and its crew. For these violations, the rules of the SCSC were rewritten and some new rules created in order to enable planners to create realistic and safe timelines for the Shuttle crews.

Scope: This project will examine the history of the development of Space Shuttle scheduling constraints through the duration of the program and analyze data from the 16 ISS missions that occurred before the STS-107 accident. These missions were chosen due to their similar mission objectives and since they were flown prior to the SCSC being optimized for ISS missions.

A review of current FAA rules for scheduling commercial airline crews will also be performed as well as a review of United States Armed Forces scheduling constraints for military pilots. Using current scheduling constraints as a guide, a discussion of possible scheduling constraints for future NASA and private commercial spacecraft will be provided. By performing this study, this project will address all possible required Program Outcomes of the Embry Riddle Aeronautical University Master of Aeronautical Science Capstone that are required for the successful completion of this course.

Methodology: An examination of the available literature will be performed by reviewing Space Shuttle scheduling constraint documents, FAA rules for scheduling commercial airline crews and military aircrew scheduling rules.

For the statistical analysis, the missions included will be the 16 Space Shuttle missions to the ISS prior to STS-107. Data will be gathered from the archives of the Flight Planning Branch of the Mission Operations Directorate at Johnson Space Center. Due to ISS assembly requirements EVA activities were a large part of these missions. The scheduled activities required for an EVA frequently lead to SCSC violations on EVA days. Other violations due to other activities performed during an ISS mission did not generate as much scrutiny from reviewing officials. Therefore, it is hypothesized that the number of SCSC violations caused by EVA activities were a significant contributor to the total number of violations for Shuttle/ISS missions. Due to the type of data observed, a statistical analysis using a chi square test will be performed to determine any difference between the two groups with a significance level of 0.05.

The statistical analysis is limited in scope to SCSC violations caused by EVA related activities. However, this analysis could show how scheduling one activity can have downstream effects and cause other scheduling violations.

Program Outcomes

PO #1

Students will be able to apply the fundamentals of air transportation as part of a global, multimodal transportation system, including the technological, social, environmental, and political aspects of the system to examine, compare, analyze and recommend conclusion.

This study of SCSC violations will allow the researcher to review how NASA determined and enforced human spaceflight constraints during the Space Shuttle program. The ***social*** environment in which writing and reviewing SCSC violations occurred will be discussed by describing the operations of the NASA Flight Planning Branch. The effect of ***technological*** changes and how they influenced the constraints will be examined by discussing the differences between system related scheduling constraints of the Space Shuttle and the ISS. The ***political*** aspects of the development of constraints will be investigated by discussing the NASA departments responsible for creating the SCSC constraints and approving SCSC violations. The ***environmental*** aspects will be analyzed by examining the cultural aspects of NASA when creating the constraints and when approving the violations.

Scheduling constraints do not involve just NASA human spaceflight operations. In the near future, constraints will be applied across a ***multimodal*** spectrum of NASA human spaceflight and private commercial orbital and sub-orbital spaceflight. These future constraints will be discussed. The researcher will also investigate the scheduling constraints for the United

States commercial air transportation system and military aviation. Conclusions will be provided based on the research performed.

PO #2

The student will be able to identify and apply appropriate statistical analysis, to include techniques in data collection, review, critique, interpretation and inference in the aviation and aerospace industry

The data collected for the statistical analysis will be violations to the SCSC document for Space Shuttle missions to the ISS from STS-88 through STS-113. A review of the supporting documentation will establish the reliability and validity of the data and the personnel who submitted the violation documentation to the Space Shuttle Program for review. The data will be separated into two groups; EVA related SCSC violations and violations caused by other activities. Having two groups of data will allow the researcher to use a chi-square test to measure differences between the two groups. For this study, an alpha of 0.05 will be used for the significance level. The data will be processed through the commercially available spreadsheet program Microsoft Excel.

PO #3

The student will be able across all subjects to use the fundamentals of human factors in all aspects of the aviation and aerospace industry, including unsafe acts, attitudes, errors, human behavior, and human limitations as they relate to the aviators adaptation to the aviation environment to reach conclusions.

An analysis will be presented of how ***attitudes*** of aerospace crews and management lead to accidents by reviewing the Challenger and Columbia accident reports. The effect of ***human behavior*** will be examined by reviewing FAA accident reports where the behavior of cockpit crews contributed to an accident. ***Unsafe acts*** of flight crews will be addressed by scrutinizing FAA accident reports where crews did not follow cockpit protocols. Flight crew ***errors*** will be examined by reviewing FAA accident reports where crews committed errors. ***Human limitations*** will be examined by analyzing FAA documentation on fatigue that specifically focuses on the physical and mental performance of humans.

PO #4

The student will be able to develop and/or apply current aviation and industry related research methods, including problem identification, hypothesis formulation, and interpretation of findings to present as solutions in the investigation of an aviation / aerospace related topic.

Sometimes when scheduling required activities a Shuttle timeline, conflicts to the scheduling constraints occurred. Conflicts that could not be worked out required an SCSC violation to be written. These violations were reviewed by NASA Space Shuttle program management. If program management could not provide a resolution to the conflict, they would assume the risk and approve the violation. Violations caused by EVAs were particularly scrutinized due to the hazardous nature of performing EVAs. It is hypothesized that the number of SCSC violations caused by EVA activities were a significant contributor to the total number of violations for Shuttle/ISS missions. The statistical analysis of his study will determine the significance of violations caused by EVAs to violations caused by other Shuttle Crew activities. Data for the analysis will be gathered by observation from the archives of SCSC violations at the Flight Planning Branch of the Mission Operations Directorate at the Johnson Space Center for Space Shuttle missions STS-88 through STS-113. The data will be analyzed for statistical significance utilizing a chi square test in the Microsoft Excel tool. The researcher will not manipulate or change any variables from the data. This will make the control of the variables *ex* *post facto*. Interpretation of the results will determine whether EVA activities significantly contributed to the number of scheduling violations. A discussion of the results will be offered to determine whether this data could assist the formulation of future NASA and other aerospace scheduling constraints.

PO #5

Space Studies: The student will investigate, compare, contrast, analyze and form conclusions to current aviation, aerospace, and industry related topics in space studies, including earth observation and remote sensing, mission and launch operations, habitation and life support systems, and applications in space commerce, defense, and exploration.

Earth observation and remote sensing scheduling practices will be discussed by examining the scheduling of personnel operating the Hubble Space Telescope and the Mars Exploration Rovers. ***Mission and launch operations*** will be addressed by scrutinizing the past and current NASA crew scheduling constraints comparing those of the Space Shuttle to the ISS. ***Habitation and life support systems*** of the Space Shuttle and the ISS will be thoroughly examined and their effects on scheduling constraints will be discussed. ***Applications in space commerce*** will be addressed by analyzing current scheduling constraints for aerospace crews and discussing possible future constraints for private commercial aerospace companies. ***Applications in exploration*** will be addressed by examining current long duration scheduling constraints for crews of the ISS. (Note: The subject of ***applications in defense*** was not addressed in the researcher’s course curriculum and will therefore not be covered in this project.)

Background

Space Shuttle missions fostered a new way of operating for the National Aeronautics and Space Administration (NASA). The orbiter was reusable, both a spacecraft and a gliding aircraft requiring the crew to operate and fly the vehicle in ways that previous astronauts never had to do. Shuttle missions would vary from satellite deployments and repair, to zero gravity science missions and to assembly of a space station. Creating the crew timelines would require rules and rationale to guide planners in scheduling the variety of activities the crews would encounter.

History of Shuttle Constraints:

At the start of the Space Shuttle program there was the Space Transportation System (STS) Work Day Handbook. The rules in this document gave very rough guidelines for the scheduling of the Shuttle crew's on-orbit activities in the mission timelines. Mission timelines consisted of the on-orbit activities that the Shuttle crew would perform. The Handbook primarily focused on sleep cycles and the length of the crew day. As additional missions were flown, the crew schedule became more demanding with timelines filled with activities that took more and more of the crew's time. After working under the Work Day Handbook for several years, NASA found that scheduling crew activities using these guidelines were causing crew fatigue. To help the situation, official NASA memos were written to provide guidance for alleviating the issues. Memos were also written to define other new scheduling constraints (Clevenger, Bristol, Whitney, Blanton & Reynolds, 2011, p. 2).

After the investigation into the Challenger accident was complete, the program took the opportunity to review and better document the scheduling rules that had existed in the Work Day Handbook and NASA memos. New and updated rules would help improve the safety of Shuttle astronauts and missions by focusing on the crew's health and well being. As a result, the program developed the Crew Scheduling Constraints, Appendix K to the Space Shuttle Crew Procedures Management Plan. Appendix K, as it was commonly known, set in place specific rules for scheduling crew on-orbit activities. This appendix defined major criteria for use of crew time for scheduled activities, flight rules decisions, nominal real-time replanned activities and any other forum that directed crew activities (National Aeronautics and Space Administration [NASA], 1992). The guidelines and constraints outlined in this document were necessary to control, standardize and optimize the scheduling of this time (NASA, 1992). Activities that were scheduled and caused violations to the Appendix K rules were called exemptions. The lead planner for each Shuttle mission, known as the Flight Activities Officer (FAO), was responsible for submitting the required documentation for any exemptions that were found when constructing the timeline for a specific mission. Exemptions were approved by the Crew Procedures Control Board (CPCB) and representatives of the Flight Activities office, Flight Director office, Astronaut office, Flight Surgeon office and the Safety office.

As Revision C to the Appendix K document was in work, the decision was made to turn the Appendix K into an official document of the Space Shuttle Program (SSP) office. It would be called the Shuttle Crew Scheduling Constraints (SCSC) document. This decision was made so that management in the SSP office would have insight to any violations, now known as exceptions, and have the authority to approve or reject any SCSC exceptions. This would also make the SCSC a standalone document, no longer an appendix to the Space Shuttle Crew Procedures Management Plan. Exceptions to the SCSC were approved by the Flight Manager and representatives of the Flight Planning office, Flight Director office, Astronaut office, Flight Surgeon office and the Safety office. The Flight Manager was a member of the Space Shuttle Program office.

The SCSC document guided the compilation of the Shuttle timeline by setting scheduling standards for on-orbit activities and directed when major mission activities were to be scheduled. The SCSC was baselined in July, 1999. A year later SCSC Revision A was published with a new section concerning the timing of undocking activities from the International Space Station (ISS) (NASA, 2000, p.3-8).

After the STS-107 accident, the SCSC underwent a substantial overhaul resulting in revision B with a more concentrated focus on International Space Station (ISS) assembly and operations. The document was reviewed and past exceptions were analyzed. Efforts were made to prevent future timeline exceptions by improving the current generic crew procedures and creating new procedures and processes. However, some timeline exceptions were found to be unavoidable due to operating with the constraints of the ISS and its crew. To mitigate these possible exceptions, the rules of the SCSC were rewritten and some new rules created in order to enable planners to create realistic and safe timelines for the Shuttle crews. Revision B was baselined in July, 2004 (NASA, 2004b).

Overview of Shuttle and ISS Mission Constraints

Summary of Shuttle Scheduling Constraints

Space Shuttle missions usually lasted less than two weeks. Each crew member was scheduled for 7.5 hours of work time. The remaining time was given for the crew to awaken from and prepare for sleep and to get ready for the day's activities. Exercise periods were scheduled as was a midday meal. The crews also had time for medical and private family conferences with the ground and were given 8.0 hours for sleep. There was no time off provided for holidays or weekends, although depending on the duration of the flight, the crew was given several hours of off-duty time during the mission that they could use as they wished. The SCSC also had guidelines for any changes to the sleep schedule such as shifting sleep earlier or later. Additionally the SCSC contained specific rules for particular days during the mission. Such days included rendezvous days, EVA days and undocking days. There were also constraints to launch day and landing day activities.

Space Shuttle missions to the ISS posed a unique challenge to flight planners. Mission requirements kept the crew busy throughout the flight. The timeline included a rendezvous and docking, EVAs for ISS assembly, time for logistics and supply transfers and undock operations. Often ISS crew member rotation was also scheduled on a mission. Additionally, crew sleep cycles, the time that they were scheduled to go to sleep, had to be adjusted earlier throughout the mission in order to meet the mission's de-orbit and landing opportunities. In fact, ISS Shuttle missions were so busy that every mission had SCSC violations. Days that had EVAs scheduled in particular, were very demanding on the crew schedule and typically resulted in SCSC exceptions. Other violations were often caused by having to schedule a fixed amount of logistical transfer time and having to schedule handover time between ISS increment crews. Numerous violations on a mission could cause the crew to work into their off-duty and/or meal time. It could also force the crew to rush through activities and procedures, which could lead to an unsafe situation.

Summary of ISS Scheduling Constraints

As Shuttle planners had the SCSC, ISS planners have the ISS Generic Ground Rules and Constraints, part 2; Execute Planning Document (NASA, 2011a). It is an ISS Program level document that guides ISS planners with scheduling the crews of the station.

The ISS is staffed year round and has been for over 12 years. Crews live aboard the station close to six months at a time. Crews travel to the ISS three at a time aboard Russian

Soyuz vehicles. For the majority of the time, there are 6 crew members aboard. The crew rotation schedule is planned so that there is at least 3 crew members on the ISS as one set of three crew returns to Earth and then another set of three launches to the station.

The ISS crew constraints direct that Station crews have a schedule similar to persons on earth. There is a 5 day work week along with 2 days for a weekend. Crews are also allowed to pick a number of holidays to be included as time off. The crew is allowed other off-duty periods to give them some rest time after complex ISS activities, such as an EVA, to compensate for the stressful activity (NASA, 2011, p. 3-4).

Each work day has a number of standard activities for the crew. The time allocated for scheduled experiments or ISS maintenance activities is 6.5 hours per crew member. The rest of the day they are given time to awaken and to prepare for sleep and time to prepare for the day's activities. Time for medical and operational conferences with the ground is also scheduled. Meal time is included in the post sleep and presleep activities with the midday meal being specifically scheduled. On the weekend, the crew is only scheduled for 1 hour of work time per crew member, usually planned on Saturday. The rest of the time is theirs to do as they please. Exercise is very important to the ISS crew to counter the effects of muscle and bone loss while in an environment with no gravity. Exercise is scheduled every day for each crew member. The crew is given 8.5 hours of sleep per day (NASA, 2011, p. 3-2).

When a new crew docks to the ISS, they are given time to acclimate to the ISS systems and environment. Also during this time the current crew members will handover the status of the current experiments and other activities running on the ISS to the new crew members.

At this time NASA and its partners are planning to send two ISS crew members to live on the station for a year. This will allow NASA to study the effects of such a long duration mission on the human body gaining data that could be used to plan for exploration missions of similar or longer duration.

Overview of Shuttle Flight Planning

The Shuttle Flight Planning department at the NASA Johnson Space Center (JSC) was responsible for the preflight production and real-time execution of the on-orbit Timeline for the Space Shuttle crew. Flight Activities Officers were part of the flight control team who staffed the Flight Control Room in the Mission Control Center (MCC). Personnel in the Shuttle Flight Planning office were trained and certified in several support positions prior to gaining FAO certification. The Lead FAO for a mission was responsible for publishing and maintaining the mission specific Flight Plan.

The Timeline

The timeline was part of the mission specific Flight Plan document and contained each mission day's schedule of activities for each member of the Space Shuttle crew and was produced in three formats. The first was an overview timeline displaying a low fidelity view of all the days of the mission, typically on a single page. The next version called a summary timeline, displayed 12 hours of all the crew member's activities on a page. Last, the detailed format had a 4 hour interval with procedure references for activities and typically displaying 3 or 4 crew members per page. An example of a Space shuttle mission overview timeline from the STS-110 Flight Plan can be seen in Figure 1 (NASA, 2002b). Summary level timelines from the STS-110 Flight Plan can be seen in Figure 2 and Figure 3 showing the crew's summary timeline from wakeup through an EVA and into their sleep period (NASA, 2002b). Figure 4 is an example of a detail timeline with the morning activities for three crew members (NASA, 2002b).

The Flight Plan was part of the Shuttle crew's Flight Data File (FDF). The FDF was comprised of all of the hardcopy documents and procedures that the Shuttle crew would need as references to operate the Shuttle and any experiments and tests that were part of each mission.

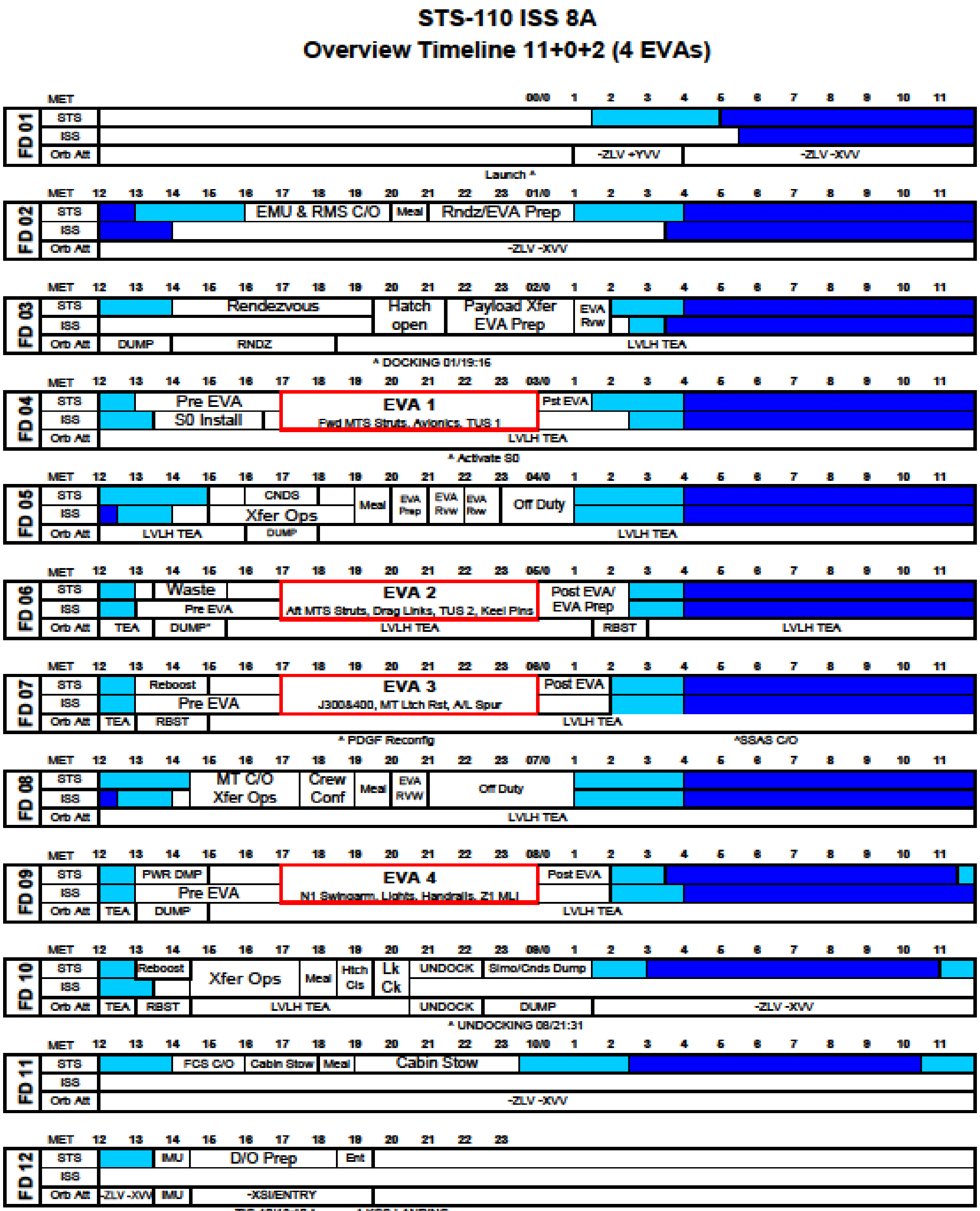

Figure 1. STS-110 overview timeline from STS-110 Flight Plan (NASA, 2002b, p. 1-3).

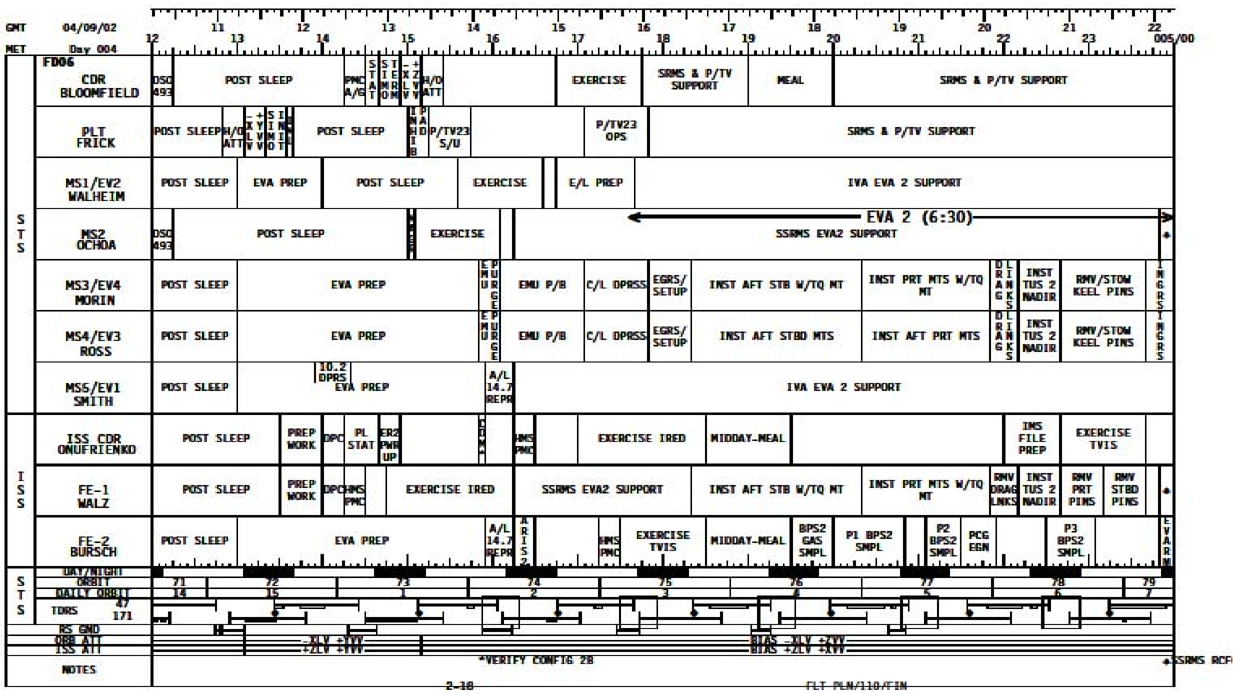

Figure 2. STS-110 summary timeline showing an EVA day from STS-110 Flight Plan (NASA, 2002b, p. 2-19).

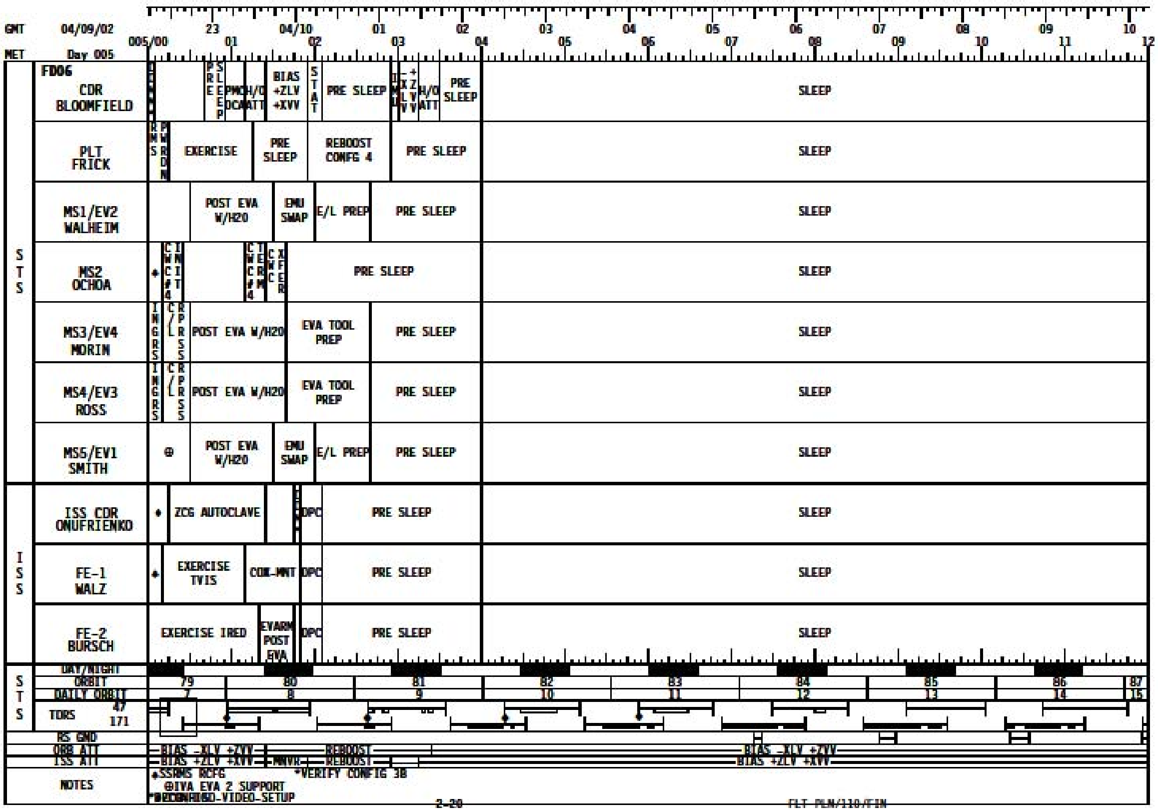

Figure 3. STS-110 summary timeline showing post EVA activities and sleep from STS-110 Flight Plan (NASA, 2002b, p. 2-20).

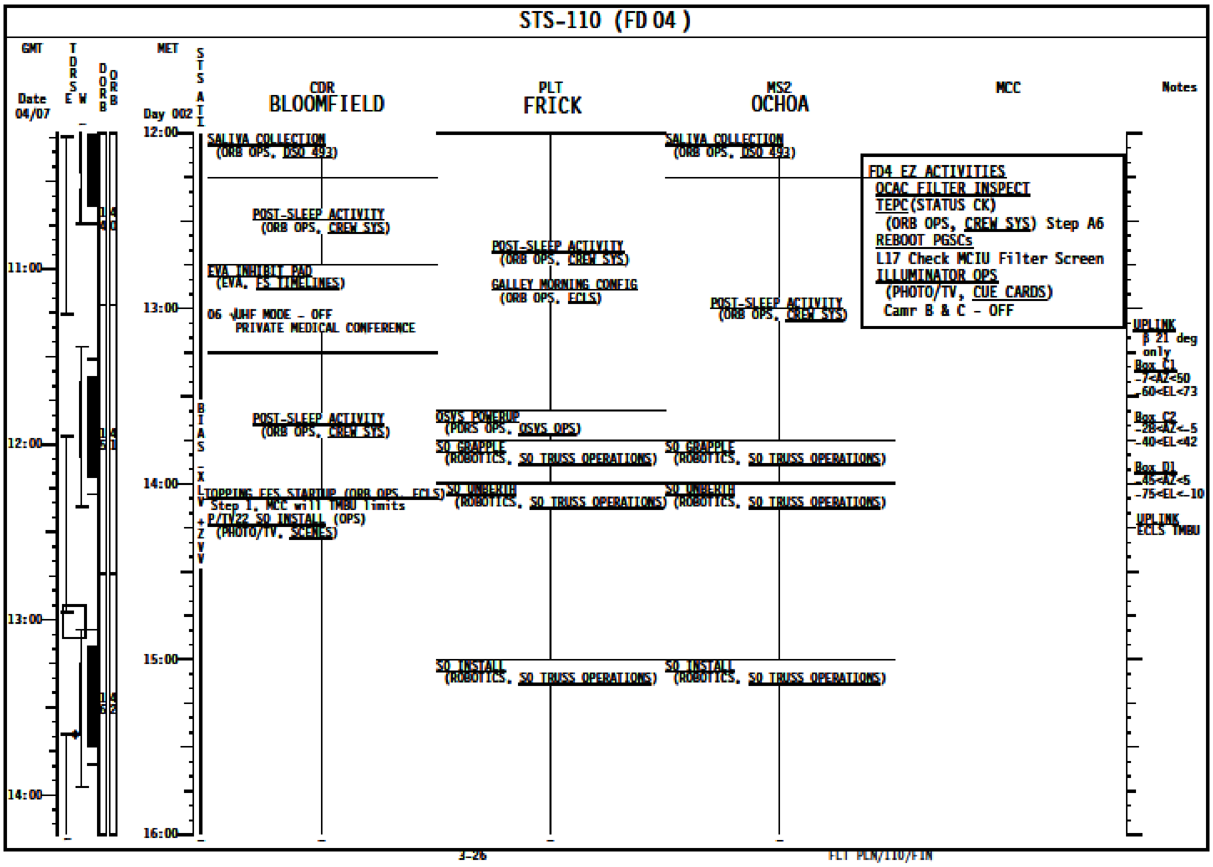

Figure 4. STS-110 detail timeline showing post sleep activities from STS-110 Flight Plan (NASA, 2002b, p. 3-26).

Shuttle Mission Planning

The planning for a Shuttle mission began years in advance with the Shuttle Program office adding the mission to the launch manifest and determining the primary payloads for the mission. Requirements for the specific mission objectives would be determined by the Shuttle Program office makeing assignments based on the availability of Shuttle missions. The major payloads for a mission such as a Hubble Space Telescope Servicing mission or an ISS assembly mission, defined the primary requirements for the flight. There were also numerous secondary payloads waiting to be manifested on a mission. These could be experiments that would take up a storage locker in the crew cabin. Others were small deployable satellites that would be released from the Shuttle's payload bay. Also desiring time were medical experiments and tests on Orbiter systems called Detailed Test Objectives. Crew time was required for the majority of these added payloads, experiments and tests. The Shuttle mission planners had to balance the scheduling requirements for the primary payload, the secondary payloads, the experiments and tests, fitting them into the available crew work time on the mission.

The Shuttle mission planners work began about one year before the mission's scheduled launch date. The planners would prepare a one page overview timeline that would reflect high level activities for the mission. This overview timeline was used by the Flight Design department at JSC to allow them to create an initial trajectory and analyze the initial amounts of cryogenic oxygen, hydrogen and nitrogen that the crew would need during the mission. The fuel load for the on-orbit maneuvering system and the number of water dumps the Shuttle would need to perform would also be analyzed. Prior to the last few years of the Shuttle program, this overview timeline was distributed as a hardcopy document. Later the timeline was linked on a JSC Shuttle Flight Planning flight specific webpage where anyone who had JSC network access could reference it as needed.

At approximately 8 months prior to launch, the Shuttle Program held the Cargo Integration Review/Flight Planning and Stowage Review (CIR/FPSR). At this meeting, the JSC Flight Design department leads would present the initial trajectory and cryogenic gas and propulsion fuel requirements. Smaller secondary payloads and experiments that were requesting to be added to the missions were also identified. Approved secondary payloads and experiments would be added to the mission requirements documentation and, if crew involvement was required, to the crew timeline. The mission planning leads would present the Overview timeline and discuss any possible SCSC violations.

Over the next three and a half months the mission planners created the summary level timeline and detailed timelines in preparation for the Flight Operations Review (FOR) meeting. At the FOR, personnel from the Program office and the operations departments would review the operational documentation for the mission; the FDF and the Flight Rules. For most of the Shuttle Program, the timeline for the FOR was published in hardcopy form as the Preliminary Flight Plan. This was found to be a waste of resources since the Basic version of the Flight Plan was published shortly after the FOR. As the use of the internet in the Shuttle Program for displaying documents increased, the Flight Planning department gained approval to post the FOR timelines electronically on the mission specific website which was linked from the JSC Shuttle Flight Planning website. This allowed JSC to save the printing and distribution costs for this preliminary timeline. At the FOR the mission planners would identify any SCSC violations that existed in the preliminary timeline.

After the FOR, the crew timelines were updated to reflect any changes that were approved at the FOR. The timelines were then published in the Basic version of the mission specific Flight Plan. This publication was edited in-house at JSC by the Flight Data File department and printed and distributed by the JSC Print Shop. Basic Flight Plans were used to support crew and ground controller training and simulations. Integrated simulations started about 4 months before launch and involved the crew and ground controllers allowing them to practice operations for the days of the mission with high level activities. For example, launch, landing, rendezvous and EVA days would be simulated as well as other days with important activities.

During the training period, planners would accept inputs to make changes to the timelines based on the outcomes of the simulations that were held. Changes were requested through the

FDF office with formal documentation and review required prior to approval of the changes. This process originally was completed with hardcopy approval forms being distributed to the respective approval authorities in the operations departments. A few years prior to the closing of the Shuttle program, the FDF office implemented an electronic web-based application to review Shuttle FDF changes. Subsequently, this tool was also used to document and approve ISS procedure changes for the ISS program.

About one month before launch, any updates to the timeline that had been found during the simulations and any changes due to launch date changes were incorporated into the timelines. Any SCSC violations that occurred from the changes were identified and the exception paperwork was submitted for approval. These changes to the Basic timeline resulted in the publication of the Final version of the Flight Plan, again edited by the FDF office and published and distributed by the JSC Print Shop. This was also the version that would be flown with the crew and used by the ground controllers during the actual mission. If any updates to the Final Flight plan were needed, they would be published based on if the Shuttle Program or the operations community deemed it necessary.

The distribution list for the Basic and Final Flight Plans included the operations groups at JSC, Shuttle and ISS Program office personnel, JSC engineering and other JSC management. Copies were also sent to other NASA centers, Shuttle contractor offices, payload control centers, international partners and the primary investigators for experiments that were flown on the mission. Typically there were upwards of 200 copies of the document being published and distributed.

Scheduling EVAs

EVA activities required the majority of the Shuttle crewmembers to execute. A minimum of four crew members were scheduled to support the EVA. Two crew members would perform the actual EVA with two or more support crew inside the vehicle. The two support crew members would assist the EVA crew when putting on and taking off their EVA suits, would operate the robotic arm if needed and would guide the EVA crew through the EVA procedures.

Performing an EVA took up the majority of the crew's workday as illustrated in Figure 2 and Figure 3. Preparation and suit-up for the EVA crew took 2 hours and 50 minutes. The EVA crew then purged their suits and breathed pure oxygen for 1 hour and 15 minutes to remove the nitrogen from their bodies. Removing the nitrogen prevented nitrogen narcosis also known as the bends. The crew would then take 30 minutes to depress their suits to 5 pounds per square inch of air pressure and depress the airlock to vacuum. The EVAs were nominally scheduled for 6 hours and 30 minutes. After the EVA, repressing the airlock and suits took 30 minutes. Taking off and stowing the EVA suits required 1 hour and 10 minutes. Total work time for the EVA was 12 hours and 45 minutes. The duration could be longer if there were other EVA related activities after the EVA was complete.

Researcher's Work Setting and Role:

The researcher has been employed in the Shuttle Flight Planning department of the Mission Operations Directorate (MOD) at JSC since 1996. Initially the researcher was hired as an entry level Shuttle flight controller. After several years of working FAO support positions, many in a lead role, the researcher entered the FAO training flow and became certified as an FAO in March of 2000. The researcher has supported 52 Space Shuttle flights. For eight of those flights, the researcher served as an FAO. The researcher was the Lead FAO for STS-109 and STS-115, assuming complete planning responsibilities relating to those missions.

The FAOs integrated the preflight scheduling of the on-orbit activities for the Space Shuttle crew, monitored the real-time execution of the scheduled timeline and coordinated changes to the timeline. Additional FAO duties also included development of contingency timelines, real-time creation of messages for the Shuttle crew, uplinking messages to the Shuttle and delivery of e-mail and electronic data to the crew (NASA, 2004a). FAOs also were the first point of contact for the mission specific FDF hardcopy procedures and the Shuttle's onboard network of laptop computers.

Social Aspects of Flight Planning

The Flight Planning Branch at the Johnson Space Center has a history of scheduling operations starting during the early Mercury and Gemini programs in the 1960's, through the Apollo missions and Skylab Space Station, Apollo-Soyuz Test Project, Space Shuttle and ISS. The branch has defined the scheduling of NASA space crews and the creation of scheduling constraints. Near the end of the Shuttle program, the branch was comprised of 4 groups. One group oversaw the development of electronic planning tools and one focused on planning and operations for future NASA exploration operations. Two groups concentrated on human mission planning for the Shuttle and the ISS respectively. The branch was made up of NASA and contractor planning personnel, NASA technical managers for the 4 groups in the branch, the NASA Branch Chief and a contractor manager to supervise contractor operations and issues. NASA and contractor personnel and management enjoyed a good working relationship.

Shuttle planning personnel supported five planning console positions in the Mission Control Center. The FAO, the leader of the planning team, worked at a console that was located in the MCC Flight Control Room. The FAO coordinated changes to the crew's timeline with the other Shuttle systems and payload controllers. The FAO reported directly to the Flight Director who was the leader of the Flight Control team. Located in a separate room in the MCC were 4 other console planning positions that supported the FAO; Timeline, Message and Timeline Support, Orbital Communications Adaptor and Pointing. The Timeline position was responsible for creating and updating the crew's timeline. The Message and Timeline Support (MATS) position was responsible for creating and formatting messages for uplink to the crew and for monitoring the crew's progress in completing activities in the timeline. The Orbital Communications Adaptor (OCA) position was responsible for transmitting electronic data files to and from the Shuttle. The Pointing position was responsible for creating and maintaining the Shuttle Attitude timeline and coordinating Shuttle communication coverage with the NASA satellite network personnel.

Space Shuttle planners started their training reading Shuttle system manuals and taking hands-on system training in high fidelity mock-ups of the Shuttle crew cabin. Training also included review of branch specific documentation of the electronic planning tools and the documentation for each of the 5 planning console positions. Trainees would follow a progressive schedule giving them increased levels of responsibility with each console certification. An experienced employee for each position was assigned as the lead controller for that position. These console leads mentored each trainee as they progressively certified in each respective console position. A NASA technical manager oversaw the training leads and monitored the progress of the trainees. The majority of the training took place during Shuttle mission simulations in the MCC. These simulations used realistic ground systems to replicate the functions and interfaces of an orbiting Shuttle vehicle and the MCC. For the first three or four simulations the trainee would be paired with a person experienced in that console position to help train the new person. The trainees would then support simulations on their own while gaining experience. After working alone for approximately 20 simulations, trainees would be evaluated by the training lead during a certification simulation. If the trainees' performance in the certification simulation was acceptable, the trainee was cleared to work an actual mission demonstrating their mastery of that position's operations while being monitored by a certified controller. If successful during the actual mission, the trainee would complete their certification.

For all positions, the training lead, technical manager and Branch Chief were required to approve the certification. For the FAO position, the trainee would also need to support a certification simulation while being evaluated by a Flight Director and a simulation training lead from the Shuttle Training office. Upon passing the certification simulation, the FAO trainee would submit certification documentation to be signed by the Planning Branch Chief, the Division Chief over the Planning Branch, the simulation training lead from the Training office and the evaluating Flight Director.

Personnel started in the MATS or OCA position taking six months to a year to become certified. Once certified and after having worked several Shuttle missions, the trainee would begin activities to train for the Timeline console position taking 1 to 1.5 years to certify. A certified Timeline person would then be assigned to a specific Shuttle mission as Lead Timeline along with an experienced FAO. This Lead FAO would help instruct the Lead Timeline in how planners worked with the Shuttle Program Office, the Safety office and other entities at JSC and other NASA centers. The Lead FAO and Timeline were considered the planning experts for each particular mission. It was also their responsibility to train the rest of the planning team that would support the particular mission.

After completing two to three Lead Timeline assignments over 2 to 3 years, the trainee would then enter into FAO training. Here the trainee supported simulations in the Flight Control Room working directly with the Flight Director and Shuttle system consoles. Certification typically took less than a year to complete. Once certified, the controller would support missions and be assigned to a Shuttle mission as a Lead FAO.

Human Spaceflight Mission Operations

Shuttle and ISS Mission Overview

Due to the different timeframes between the development of the Space Shuttle and the development of the ISS, the technological differences between the vehicles are significant. The systems were created with the technology of the time to support the operations of the particular spacecraft.

Mission and launch operations are different for both vehicles and requires different scheduling constraints. The Shuttle was a vehicle designed to launch and return to earth on missions lasting about two weeks. The ISS is a vehicle meant to operate in earth orbit while crews are onboard. The ISS has been staffed continuously since November 2000.

The Space Shuttle was designed and built in the 1970s based on the technology available during that decade. The Shuttle was created using systems that were designed for it to act as the launch, orbit and entry vehicle for the astronaut crews and was able to support orbit operations for short duration stays in space. Time available on-orbit varied from mission to mission dependent on the amounts of cryogenic oxygen and nitrogen aboard for the crew to breathe, cryogenic hydrogen and oxygen for water and fuel cell electrical power generation and the amount of propellant available for attitude changes, rendezvous operations and deorbit burns. Components of the ISS were designed in the 1990s and early 2000s with systems that allow the station to support its crews for months in space. The Shuttle was designed carry its crew into orbit and return them to earth. This capability allowed it to be able to deorbit and return to earth on short notice if necessary. This could be due to a crew member medical emergency of for an issue with a vehicle system such as a loss of cabin pressure. The ISS is designed to remain in orbit and rely on other visiting vehicles to deliver crews to the outpost and return them to earth. The ISS has been built with system redundancy so that a single failure of a system will not require the crew to abandon the outpost. The ISS was completed in 2011 and is currently planned to remain operational to 2020. Lengthening its operations may be possible dependent on the performance of its systems.

Shuttle to ISS Technological Comparison

The differences in mission operations are reflected in the design of the habitation and life support systems of the two spacecraft. These designs require differing scheduling constraints for similar activities. ISS systems were designed to require less maintenance in comparison to Shuttle systems. This allows ISS crews to spend more time performing experiments rather than systems maintenance. Since the Shuttle performed short duration missions, maintenance to its systems were carried out by ground personnel.

Human spacecraft require the removal of excess carbon dioxide (CO_2) from the air that the crew breathes. Too much CO_2 in the air can prevent the body from receiving oxygen causing tissue damage and possibly death (Mayo, 2012). The Shuttle circulated its air through canisters filled with lithium hydroxide which absorbs CO_2. Scheduling constraints directed that Shuttle crew members needed to periodically change out the canisters in the air circulation system throughout the duration of the flight. The number of change outs was dependent on the number of crew members on a mission. The ISS has multiple ways to remove CO_2. There is the

Russian Vozdukh and the U.S. Carbon Dioxide Removal Assembly (CDRA) systems. These systems do require periodic maintenance from the ISS crew, scheduled per direction from the ISS system operators in the MCC. The ISS also has lithium hydroxide canisters available to use if the Vozdukh or CDRA fails. (NASA, 2010a, p. 82).

For electrical power the Shuttle operated fuel cells which would combine cryogenic hydrogen and oxygen together. The result of this combination of the two elements was electricity and water. The water was stored in tanks aboard the Shuttle and was used by the crew for drinking. So much water could be produced that the crew could not consume it all. Some of the water would be placed into large bags for transfer to the ISS. Any remaining water would need to be dumped overboard into space. Also, the Shuttle crew would produce urine which was kept in an onboard tank and would periodically need to be dumped overboard. Shuttle scheduling constraints required water and/or urine dumps to be scheduled periodically during a mission dependent on the number of crew members aboard. The ISS has systems aboard that recycle wastewater into drinkable water for the crew and separate the water molecules to generate oxygen for the crew. Maintenance for these systems is scheduled per direction from the ISS system operators in the MCC. Cargo craft bring water to the ISS to supplement its store of recycled water (NASA, 2010a, p. 82).

The Shuttle used three fuel cells to combine cryogenic hydrogen and oxygen together creating electricity and water. The Shuttle carried the elements into space on each mission. The fuel cells were the only way for the Shuttle to generate power. Ground controllers carefully monitored the remaining amounts of hydrogen and oxygen to make sure that there would be enough available to get to the planned end of the mission (NASA, 2002a). For the ISS, it would be too expensive to deliver hydrogen and oxygen to the station in the amounts that it would require for electrical power generation using fuel cells. Instead of fuel cells, the ISS has large solar arrays that capture sunlight and convert it into electricity (NASA, 2010a, p. 90).

For navigation and orientation, the Shuttle was designed to use Inertial Navigation Units (IMUs). These units were made of a mechanical platform with four gimbals that were inertially stabilized. There were three units to provide redundancy to the system. Due to their mechanical nature, the IMU platforms could become misaligned and required the crew to manually update the alignment (NASA, 1998). The SCSC directed that the Shuttle crews have a minimum amount of Post-Sleep time so that some maintenance activities like IMU alignments could be performed during that timeframe. The ISS uses the U.S. Global Positioning System satellites and Russian navigation satellites to calculate the orientation of the craft. These systems are solid state and do not need periodic alignments as the Shuttle IMUs did (NASA, 2010a, p. 91).

To maneuver and perform rendezvous operations with the ISS, the Shuttle would fire its Orbital Maneuvering System engines or its Primary Reaction Control System thrusters. The thrusters in these systems were powerful and the SCSC rules directed that these engine firings not be scheduled during crew sleep. The Shuttle did have a less powerful system, the Vernier Reaction Control System that could be used during crew sleep (NASA, 2002d). The ISS uses Control Moment Gyroscopes and attitude thrusters. The ISS systems are not as powerful as the Shuttle thrusters and can be used during ISS crew sleep (Boeing, 2006).

Onboard crews relish the opportunity to talk to family and friends on the ground. The Shuttle communication system had the ability to allow the crew to video conference or audio conference with people back home. These events were scheduled per rules in the SCSC. Crew members would usually have one or two of these conferences scheduled based on the length of the mission. The ISS also has the ability to teleconference with the ground and these are also periodically scheduled for the crews. The ISS system also allows the crew to make audio calls to people on the ground using a computer based system called a Softphone. These calls can be made at any time as long as the ISS has a communication link with the ground (NASA, 2004c).

Shuttle crew members used either the Shuttle Airlock or the ISS airlock to perform EVAs. The Shuttle airlock is used to store the empty EVA suits and the crew would use the Shuttle middeck to prepare for the EVA and put on the EVA suits (NASA, 2002c). The ISS airlock is larger than the Shuttle's and it has a dedicated compartment meant for preparing and stowing the EVA suits and other equipment (NASA, 2010d).

SCSC Political Environment

The SCSC document was a Space Shuttle Program level document which was maintained by the book manager in the Flight Planning Branch of the Mission Operations Directorate. Any updates to the document were coordinated by the book manager with other SCSC representatives.

The book manager was a member of the Shuttle Planning team who had attained certification as an FAO. This person had extensive understanding of the Shuttle planning process and the constraints in the SCSC. The book manager also had knowledge of the practices of the organizations of the other SCSC representatives. Official approval authority for the Flight Planning Branch for the SCSC was the responsibility of the Branch Chief.

The NASA Astronaut office is part of the Flight Crew Operations Directorate. The SCSC representative was a current astronaut. The Astronaut office is made up of astronauts and support personnel involved in the training and operations of NASA astronauts. The astronaut SCSC representative reviewed the SCSC constraints from the view of a Shuttle crewmember assessing if the rules were logically written with respect to operating on the Shuttle (NASA 2011b).

A member of the Flight Director Office of the Mission Operations Directorate served as an SCSC representative. Flight Directors had the responsibility of leading the Flight Control Team for each Shuttle mission. The Flight Director representative reviewed the SCSC constraints from the perspective of how the rules effected the function of the Shuttle systems and the operations of the Flight Control Team (NASA, 2011c).

The SCSC safety representative was a member of the Shuttle Division of the Safety and Mission Assurance Directorate. This representative reviewed the constraints to make sure that the rules did not create any issues that might generate an unsafe condition for the crew or the Shuttle (NASA, 2011d).

The effects of the SCSC constraints from a crew health perspective were reviewed by a representative from the Space Medicine Division of the Space Life Sciences Directorate. The Space Medicine Division was made up of Flight Surgeons and support personnel. Representatives reviewed the SCSC constraints to ensure that the health of the crew would not be compromised by any of the SCSC rules (NASA, 2011e).

Environmental Aspects

Prior to the Challenger accident mission planners had the Space Transportation System (STS) Work Day Handbook to use as a guide for scheduling activities. The rules in the Handbook were very vague and planners found that scheduling activities to these rules was causing crew fatigue. In order to help the situation, official NASA memos were written to provide guidance for the shortfalls of the Handbook rules. Memos defining other scheduling constraints were also written (Clevenger, 2011). NASA culture at the time had a predisposition for issues to be handled internally and not brought to the attention of upper managers. NASA had also become risk-adverse due to having 24 successful Shuttle missions (NASA, 2003, p. 100).

After the Challenger investigation NASA created a new effort to increase safety awareness. During this time the Crew Scheduling Constraints, Appendix K to the Space Shuttle Crew Procedures Management Plan was created. The Appendix K document evolved into the program level SCSC document. This gave the Shuttle program insight and approval authority into scheduling constraint violations. A year later the SCSC Revision A was published with a new section concerning the timing of undocking from the ISS (NASA, 2000). As time wore on, Planners were scheduling more activities into each mission and sometimes violating the SSC constraints. Program managers reviewed the rationale for each violation and approved those they felt were justified.

After the Challenger accident, 87 Shuttle missions were flown before the loss of the Shuttle Columbia. The culture of safety at NASA was scrutinized again. The Shuttle program sought to prevent violations to the SCSC rules and called for a review of the SCSC. Representatives to the SCSC took a fresh look at the current rules and revised them to focus on ISS operations. They also added any new rules that would be required to create safe and realistic Shuttle to ISS crew activity timelines. The result was the Revision B to the SCSC. Using these rules, planners were able to schedule activity timelines that were safer for the Shuttle crews. Violations to the SCSC that occurred on missions flown after the Columbia accident were thoroughly reviewed by program managers and SCSC representatives.

Multimodal Aspects of Aerospace Constraints

As NASA continues to launch astronauts into space and update scheduling constraints as needed, new entrants into the business of human spaceflight are emerging. Private companies are developing spacecraft for sub-orbital and orbital spaceflight. Some of these commercial companies are partnering with NASA with the purpose of flying NASA astronauts into low earth orbit to the ISS. These spacecraft could also be used to open a new era of space tourism and space commerce delivering private individuals into low earth orbit and possibly to a commercial space station for an extended stay in orbit.

Federal Aviation Administration Constraints

This new world of non-governmental space missions raises the question of how to regulate the industry with regard to safety of the passengers and the general public. What constraints will be required and who will determine the constraints? The closest analog is the commercial airline industry where the Federal Aviation Administration (FAA) is responsible for the rules governing pilot and flight crew scheduling in United States airspace. The rules are written to ensure the safety of the flying public and the safety of persons and property on the ground.

FAA rules describe in detail the constraints to air crew scheduling to ensure that pilots and crews are adequately rested and prepared to fly passengers and cargo. FAA rules 91.1057 and 91.1059 detail the flight, duty and rest time requirements for all crew members and the requirements for one or two pilot crews. FAA rules 91.1061 and 91.1062 details rules for flight crews with more than two pilots and rules for flight attendants (Federal Aviation Administration [FAA], 2011c). In particular, for a crew of two pilots on a normal duty day the FAA rule 91.1059 states that the pilots have a maximum duty period of 14 hours with up to 10 of those hours as actual flight time. The pilots then must have at least 10 hours of rest time. For flight attendants, there are similar rules allowing a maximum duty day of 14 hours then a mandatory 9 hour rest time. There are other subsequent rules that cover off-nominal situations such as extended duty days that require additional rest time or flights that operate with a second set of pilots and attendants. As a comparison, the Shuttle crew was allowed a 16 hour day with 7.5 hours of scheduled operations. This time did not include a 1.5 hour exercise period or a 1 hour midday meal. The Shuttle crew received a 3 hour period each for presleep and post-sleep activities that included hygiene and meal time. Crews also were scheduled for an 8 hour sleep period. The SCSC allowed rationale for slight deviations from these rules dependent on the mission requirements.

Just as NASA has made updates to the SCSC, the FAA updated its rules for commercial airline pilots and crew. A Federal Aviation Administration (FAA) Fact Sheet detailed the announcement on an update to the FAA rule regarding commercial passenger airline pilot scheduling to make sure that pilots prior to entering the cockpit are given a longer opportunity to rest. The new rule uses the latest science concerning fatigue to update rest requirements. The rule updated the requirements based on when the flight begins and the number of time zones that are crossed. Also, the rule updated the flight duty period, flight time limits and rest periods (FAA, 2011a).

Concerning private commercial space flight, current FAA rules in FAA part 460 detail some early attempts to bring constraints to human space flight. Rule 460-15 details how human factors need to be taken into account in the design of the spacecraft, mission planning and vehicle operations. The rules do not yet have any details concerning crew fatigue and scheduling (FAA, 2011d).

Applications for Space Commerce

Crews for NASA Shuttle missions were responsible for the direct operations of the vehicle and all were well trained on operating the Shuttle systems. Currently there are private commercial companies planning to offer the public sub-orbital and orbital flights into space. Crews for future private companies will be responsible for their spacecraft and will operate much like airline pilots. They will have to thoroughly understand the operations of their craft and will be responsible for the safety of their passengers and the public. The FAA will need to define rules for pilot scheduling to make sure that the pilots are well rested. There may also need to be a rule stating that pilots need to have flown into space before as a passenger to evaluate how their bodies adapt to a weightless environment. Commercial operators will be restricted as to the location for launch operations, making sure that expended rocket stages do not fall into populated areas. The timing of launches will need to be factored into the commercial airline traffic schedule to make sure that the airspace is clear at the time of launch. At this time, commercial space companies are taking the first steps in making a private space industry. Already, spacecraft carrying cargo have been launched into orbit and safely returned. This year one such company has started delivering cargo to the ISS.

Applications for Space Exploration

The ISS Scheduling Constraints were created for the long duration stays of the ISS crews. Similar constraints will need to be created for long duration exploration missions. Since the ISS does not return to the earth for system maintenance, it is up to the crews to maintain ISS systems. Rules have been written to support the crew health and well being as well as to keep the ISS systems in good working order.

The ISS Generic Groundrules and Constraints contain rules for daily crew activities such as available work time, exercise, ground conferences and sleep. The rules also include periodic activity constraints for time off such as weekends, holidays and off duty time. Many of the rules focus on operating and maintaining specific systems aboard the ISS. There are rules for scheduling EVAs, for servicing the EVA equipment and for performing robotics operations. The ISS receives visiting crew and cargo vehicles and there are rules for interacting with new crews and fresh supplies and cargo. There are also rules for scheduling periodic inspections of safety equipment such as fire alarms and smoke detectors (NASA, 2011a).

Current NASA exploration plans call for human missions to go beyond earth orbit further than ever before spending months or years away from our planet. This will mean communication delays due to the larger distances for the signal to travel. Due to this, NASA exploration crews will have to operate more autonomously than ever before. Crews will need to have very robust timeline tools that incorporate the scheduling constraint rules that govern how their timelines are constructed. This way if the crew decides to adjust their activity schedule, the scheduling tool will alert them of any violations that occur. The scheduling tools will also have to incorporate any constraints that are created to accommodate the requirements and operations for next generation habitation and life support systems that long duration crews will need. Hopefully these new systems will require less maintenance resulting in less crew time used for system repair and replacement.

As an analog to future exploration missions beyond low earth orbit, NASA is using the ISS to test systems and procedures that could be used on spacecraft that venture further into space. Many of the systems that are used aboard the ISS are similar to the systems that will be needed for exploration missions such as the ISS waste water processors. The processors recycle urine and condensate water from the air into drinkable water and oxygen for the crew. Exploration spacecraft systems will need to be robust and have redundancy built in. Sufficient spare parts will need to be stored onboard. Due to the possible communication delays between Mission Control and their craft, crews will have to have the ability to repair system failures themselves.

Crews aboard the ISS live on the station for up to six months. Missions out of low earth orbit will require crews to stay longer in space than their counterparts in low earth orbit. Recently NASA and its partners began evaluating a year-long mission where two ISS crew members will live on the outpost for twelve months. This mission to the ISS will allow NASA to gain valuable information on the effects of long duration space flight on the human body.

Military Scheduling Constraints

Military planners are also interested in making sure aircrews are properly rested prior to performing a mission. A thesis authored from a student at the Navy Post Graduate School was reviewed. The thesis was an analysis of the benefits of the FlyAwake software program. FlyAwake program was created by the Air National Guard to predict the fatigue of military air crews by focusing on their circadian rhythms. The researcher in the FlyAwake study used a statistical analysis to compare fatigue levels between an air crew using conventional scheduling methods and an air crew using the FlyAwake program. The analysis showed improved performance of pilots when military planners used data from the FlyAwake program to create flight crew schedules (Beshany, 2009).

Constraints for Remote Sensing Operators

The necessity for round-the-clock operations is not just required for human space flight. Satellites that are used for remote sensing can require that ground controllers support satellite operations 24 hours a day all year long. Remote sensing missions can be very expensive and as such there is the desire to get as much science from the missions as possible.

Hubble Space Telescope Operations

The Hubble Space Telescope (HST) was launched April, 1990. The telescope was placed in orbit so that astronomers would have an astronomical observation platform that would not be subjected to the distorting nature of the earth's atmosphere. Ground controllers for HST operated the telescope, monitored its health and maintained ground systems. Ground support for HST operations was scheduled in shifts working year round, 24 hours a day. Ground operators were responsible for planning observations, creating the commands to place the telescope in the correct orientation for observations and for formatting and distributing data from the telescope to the science centers (Burley, 2012, p. 2-3).

In 2006 HST managers began looking at ways to reduce staffing and automate some of the everyday ground operations. This was due to budget projections lowering staffing by 50% in future years. Although a previous attempt at automating some HST operations had failed due to the complexity of the systems, the team decided that making changes across the entire ground operations systems and some telescope systems could lead to the desired staffing levels (Burley, 2012, p. 3-4).

In June 2011 HST operations completed the upgrades to systems and software and transitioned to a ground staffing plan that supported an 8 hour a day, 5 day per week schedule. Ground personnel were required to make changes to their assignments and responsibilities in support of the new operations plan. The restructuring has allowed HST to continue to support scientific observation while operating under a decreased budget (Burley, 2012, p. 1).

Mars Exploration Rovers Operations

January, 2004 was a landmark day for NASA and the Jet Propulsion Laboratory. The Mars Exploration Rovers (MER) Spirit and Opportunity landed successfully on the surface of Mars. Ground controllers for the two rovers were placed on shifts that would correspond with the length of a Mars day also known as a Mars sol. One Mars sol corresponds to 24.65 Earth hours. This required that personnel working the MER mission would need to shift their work schedule 39 minutes later each day (NASA, 2008, pp. 1-2).

NASA sponsored a study of the sleep habits of personnel working the MER mission to determine any effects the constantly changing shift schedules for this and future Mars missions. The study was conducted over 4 months and included 30 volunteers from a pool of 250 MER personnel. Data was gathered using paper and pencil surveys and Actiwatch recorders that estimated sleep by measuring participants' gross motor activity (NASA, 2008, pp. 3-4).

Participants in the study were allowed to use countermeasures to help them adapt to the changing shift schedules. These countermeasures include drinking caffeinated beverages, taking naps, exercising and using days off to make up sleep (NASA, 2008, pp. 62-63). The continually changing schedules required participants to adapt the schedules of their personal, family and social lives (NASA, n.d., p. 6).

The study found that supporting the 24.65 hours a day shift schedule caused increases in fatigue, decreased the ability to sleep and increased irritability. The participants also had decreased levels of energy and concentration (NASA, 2008, p. 65). The MER team realized that this schedule was not sustainable. The team created a new schedule that did not require the 39 minutes of later shift each day. They also automated some of their software tools which allowed them not to have to support weekends or holidays (NASA, n.d., p. 6 - 8).

Human Factors

Part of the reason for the creation of scheduling constraints was to prevent the negative effects of the human-in-the-loop. People have performance limitations both mentally and physically. Unfortunately, sometimes these limitations are not recognized by the individual or their peers and lead to disastrous results.

Human Attitudes

Any tasks that involve humans have the risk of being performed with errors. The activities for Shuttle missions were practiced numerous times on the ground in the months prior to the launch of the mission. Mission hardware and software was tested to make sure that it would function properly and the crew practiced to become familiar with their operations. Procedures were written for the crew to use when performing on-orbit activities. These procedures were reviewed many times by the crew and ground controllers in simulations preparing for the mission. Even with all this training, crews would miss steps in procedures, flip the wrong switches or input the wrong information into the Shuttle computers. Fortunately, Shuttle telemetry was downlinked to the ground so that flight controllers could watch as the crew performed the on-orbit tasks. The controllers were able to recognize the errors and alert the crew to correct them.

For NASA, the Challenger and Columbia accidents were difficult lessons in human factors. Seven astronauts and a Space Shuttle were lost on each mission. For each accident a panel of industry and government experts was assembled to investigate the causes of the accidents and provide recommendations to prevent future accidents. The panels, known as the Rogers Commission for Challenger and the Columbia Accident Investigation Board (CAIB) for Columbia, found that decisions made by management and engineers contributed to each accident and that there had been opportunities before the launch of the missions to recognize the issues and design a repair for the faulty hardware.

The Challenger accident was caused by a defective seal in a joint between the lower segments of the right Solid Rocket Booster (SRB). During ascent hot gasses leaked past the joint and caused a structural failure of the external fuel tank. The seal failed due to the cold ambient air temperatures at the time of launch which made the seal stiff and brittle. This was the mechanical cause of the accident but the commission noted failures of NASA management contributed to the accident. The night before Challenger's launch engineers for the SRB contractor, concerned with the cold ambient air temperatures at the next day's launch time, recommended a launch delay. NASA managers decided to accept the risk and proceed with Challenger's launch (NASA, 2003, p. 200).

Issues with the joint in question had been observed on flights preceding Challenger. NASA nor the booster manufacturer required that the booster joint be sufficiently tested to establish the cause of the issue and develop a new design. Managers also ignored internal warnings concerning the seal, deciding that the issue was an acceptable hazard that could be cleared for flight. The commission also found that NASA's safety system was not performing as it should. Safety trending analysis was not calculated properly. Safety did not have a proper problem reporting system and was not participating in critical deliberations. In addition, the Commission found that there was schedule pressure due to an increased Shuttle flight rate. This caused shortened training schedules, limited spare parts and management focusing on near-term issues (NASA, 2003, p. 100).

The Rogers Commission made many recommendations for changes inside NASA including redesigning the faulty SRB joint and establishing an Office of Safety, Reliability and

Quality Assurance. The management of the Shuttle program was moved from Johnson Space Center to NASA Headquarters with the intention of creating a management organization similar to that of the Apollo program with the hope of preventing the communication shortcomings that contributed to the Challenger accident (NASA, 2003, p. 101).

The Columbia accident was caused by a large piece of insulating foam breaking away from the bipod area on the external fuel tank and striking one of the Reinforced Carbon-Carbon panels along the leading edge of Columbia's left wing. The foam created a hole in one panel which allowed extremely hot gasses, generated by friction with the atmosphere during reentry, to penetrate he wing and weaken the left wing structure. Foam loss to some extent had occurred on all shuttle missions before Columbia and managers had accepted the shedding of foam as a routine risk. As with the Rogers Commission, the CAIB also found that failures of NASA management contributed to the accident and the lack of action prior to Columbia's re-entry (NASA, 2003, pp. 195-196).

The shedding of foam was a common occurrence on Shuttle missions sometimes creating slight damage to the Shuttle's thermal tiles on the lower surface of the craft. Damaged tiles would be repaired or replaced prior to the next mission. Two missions prior to the launch of Columbia a piece of foam broke off the bipod area of the external tank. Management treated the event as an action item to be reviewed instead of a major issue and accepted the risk of foam shedding on the next two missions. Again, the safety system was not operating as it should, engineers were not communicating their concerns to management adequately and NASA was operating under schedule pressure due to the construction of the ISS (NASA, 2003, p. 199).

The CAIB made many recommendations for changes inside NASA including identifying the foam issue and finding a solution and separating the scheduling and budget management from the technical authorities. NASA incorporated the changes that the CAIB suggested including finding the cause of the foam shedding and incorporating processes to mitigate the shedding. NASA also changed its organizational structure and creating a new emphasis on safety (NASA, 2003, p. 225).

Human Behavior

Human behavior can be described as the way a person functions based on their attitudes and beliefs. Flight crews are provided operating rules and procedures to guide them through nominal and contingency situations. If a pilot makes assumptions based on inferred information accidents can result.

A case in point is the March 27, 1977 accident at Tenerife in the Canary Islands. A Pan Am 747 and a KLM 747 collided on the runway killing 583 passengers. The official cause of the accident as determined by the Spanish government was that the KLM aircraft has begun its take-off run without clearance from Air Traffic Control (ATC). At that time there was heavy fog at the airport and the Pan Am 747 was still taxiing on the runway toward the KLM 747. The KLM pilot believed he had received clearance even though the KLM flight engineer was not sure that the Pan Am 747 had cleared the runway. Also, there were ambiguous communications between the ATC and the KLM 747 that resulted in misunderstandings as to the intentions of the KLM 747. The behavior of the KLM pilot not confirming his take-off clearance was a major contributor to the crash. Had the KLM pilot established that the Pan Am 747 was clear of the runway and that he was clear for take-off, the accident would not have occurred (The Tenerife Information Center, 2009).

Unsafe Acts

There are also examples where air crews have disregarded flight rules and protocols resulting in deadly accidents. As an example of these unsafe acts, at the Fairchild Air Force Base outside of Spokane, WA, on June 24, 1994 a B-52 bomber crashed killing its four crew members. While practicing exercises prior to an air show, the aircraft stalled while in a steep banking turn and fell to the ground. The cause of the accident was determined to be the pilot of the B-52. This pilot had a history of pushing aircraft to their limits and ignoring safety rules. During an earlier flight at the 1992 Aerospace Day at Fairchild, he performed a dangerous maneuver in a B-52 that damaged the fuselage of the plane. Unfortunately, this pilot only received verbal reprimands for his previous infractions and was allowed to keep his flight status (McClary, 2008).

Flight Crew Errors

Air crews are responsible for understanding the capabilities of their aircraft. Part of the pilots duties are to be aware of the limitations of their aircraft particularly when operating in unsafe weather conditions. Crew errors when working in hazardous weather can amplify the outcome and cause an accident. A Southwest Airlines flight landing in Chicago, IL, on December 8, 2005 ran off the runway, through two fences and onto a roadway. The plane crashed into an automobile killing a child. Weather conditions just prior to the crash included 1/2 mile visibility, a broken ceiling 400 feet above the ground and moderate snow and freezing fog. The cause of the accident was found to be the failure of the pilots to use the engine thrust reversers in a timely manner to help slow the airplane in the existing weather conditions. The crew was not familiar with the use of the plane’s autobrake system and this distracted them from engaging the thrust reversers at the proper time (National Transportation Safety Board, 2005).

Human Limitations

Human performance is limited by how well the mind and body is functioning. Fatigue can reduce mental and physical abilities. The FAA has studied fatigue and its effects on humans working in the aircraft industry. They have found that fatigue has been a factor that played a role in maintenance errors that led to accidents. The FAA has also studied Air Traffic Controller fatigue and ways to counter it.

Fatigue causes a person to suffer impairment in one or more of these areas: speed, balance, strength, coordination, decision-making, cognitive ability, reaction time and coordination. A fatigued person can lose the ability to focus clearly and hold attention on tasks they are performing. They can also be subjected to mood swings and short term memory loss. The results of fatigue can manifest as poor judgment, poor decision making and an increase in mistakes and can also cause a person to lower their standards (FAA, 2011e, pp. 14-18).

Fatigue can be caused by a lack of sleep, stress and/or overwork. The prime treatment for fatigue is to get plenty of sleep on a steady schedule. Short term remedies include taking caffeine and medications, although over time this can make the fatigue worse if the prime cause is not identified and preventive actions taken. Supervisors and peers need to be aware of the signs of fatigue and assist employees in finding the cause of the fatigue. Then a plan can be made to help the employee mitigate the effects of fatigue (FAA, 2011e, pp. 14-18).

The FAA is particularly interested in fighting fatigue in ATC and other aviation shift workers. The ATC operates around the clock all year long directing air traffic in the skies above the U.S. Aviation maintenance technicians often perform shift work maintaining airplanes during the late night and early morning hours when there is little passenger traffic. This timeframe occurs during low periods of their circadian rhythm. Circadian rhythm is the natural cycle of a person's alertness level being lowest during the night when most people are asleep. Being awake and performing work during this time means the body is going against the natural sleep cycle. This can lead to degraded performance, low morale and safety issues (FAA, 2011e, pp. 14-18).

The study of human factors has led to better understanding of the limitations of human mental and physical performance. Humans are not infallible and can be prone to distraction and sometimes dangerous acts that can lead to accidents. Shift work is a common requirement in the aerospace industry and the effects of fatigue is a frequent hazard.

Review of Relevant Literature

The subject matter of this study directed the researcher to perform a literature search seeking out relevant literature on the subject of scheduling constraints. The ERAU Hunt Library online databases and the Google search engine were used to perform the literature search. Searches for 'scheduling constraints' resulted in links to websites and documents that focused on how to create software programs for constraint based scheduling. Searches for 'crew scheduling constraints' resulted in links to airplane crew schedules and regulations. Searches for 'space crew scheduling' resulted in references to crew scheduling but no results to specific rules for space crews. This was not unexpected since very few countries are able to place humans into space. It was found that the United States Government was a good resource for scheduling constraint rules and information with numerous references came from the Federal Aviation Administration and the National Aeronautics and Space Administration.

Searches for aviation accidents and incidents resulted in references for a U. S. Air Force bomber crash (McClary, 2008) and a crash of two 747 airliners (The Tenerife Information

Center, 2009). The National Transportation Safety Board provided a reference for an incident involving a 737 jetliner (National Transportation Safety Board, 2005).

The literature search led to a paper from NASA JSC personnel submitted to the American Institute of Aeronautics and Astronautics (AIAA) Space 2011 Conference and Exposition in September 2004. The title was NASA Flight Planning Branch Space Shuttle Lessons Learned. The researcher was a contributor to the paper. One section the paper described the history of Shuttle scheduling constraints and updates that were made during the program (Clevenger, 2011).

An AIAA paper from the Space ops 2010 Conference detailed the experiences of six people as they inhabited the Mars Societies Flashline Mars Arctic Research Station for a month in 2009. The participants expressed their personal trials and accomplishments during the expedition. One section of the paper was devoted to the observations of the health and safety officer. She described how fatigue affected the crew members. In particular, crew members would go to sleep and wake up at different times. This would disturb the other sleeping crew members, leaving them fatigued in the morning. This added to the stress of living in such a harsh environment (Ferrone, 2010).

A Master’s thesis from the U.S. Navy Postgraduate School was found that analyzed the use of a program called FlyAwake to create better flight schedules for its Naval aviators. The program predicts crew fatigue based on their circadian sleep cycles. Improved performance was found when using the FlyAwake program (Beshany, 2009).

Information was found concerning the scheduling of ground operators of the Hubble Space Telescope (Burley, 2012) and the Mars Exploration Rovers (NASA, 2008).

Methodology

The subjects of the analysis of this study are the SCSC violations that were recorded in SCSC exception documentation for Space Shuttle missions to the ISS. Data was taken from the 16 Space Shuttle missions to the ISS beginning with mission STS-88 through STS-113. The version of the SCSC used during this timeframe was the baseline and the Revision A. The ISS missions flown after the STS-107 Columbia accident were planned using the Revision B of the SCSC. In the SCSC Revision B the rules were changed to focus more on exclusively ISS missions. Due to the differences to these documents, this study will focus on the missions that flew using the rules in the SCSC baseline and Revision A. SCSC violations were reviewed and approved in SCSC exception documentation. One exception document may contain details of multiple violations.

Shuttle missions STS-88 and STS-96 were ISS missions flown before the publication of the baseline revision of the SCSC. As the SCSC was in the final stages of review at the time, these missions were held to the rules in the final review of the baseline version of the SCSC. Exceptions to these missions are included in Appendix A of the SCSC and the violations will be included in the data for this study.

Of particular interest are SCSC violations that were caused by EVA related activities. Due to the fact that EVAs were such a high profile activity and garnered much review and scrutiny, EVAs were perceived to be the main contributor to the total number of violations that occurred. There are many other non-EVA activities that caused violations to the SCSC. Although these violations were reviewed and approved using the same rigor as violations due to EVAs, they had the perception as being not affecting the mission as much as violations from EVAs.

The Flight Planning Branch at Johnson Space Center has detailed records of the violations to the SCSC from Space Shuttle missions. Branch representatives were responsible for documenting the violations, writing and presenting the official exception paperwork to SSP and operations forums. This violation data was reviewed and violations were recorded. The documentation for the violations was reviewed to determine the cause of the violation. From this the data was categorized into the types of activities that lead to the violations. Once categorized, the data was ranked as either a violation caused by an EVA or a violation not caused by an EVA. A statistical analysis was performed to determine if EVA violations were a significant contributor to the total number of violations.

Hypothesis

The purpose of this study is to analyze the SCSC exceptions written for Space Shuttle missions to the ISS prior to the STS-107 accident. EVA activities were a large part of these missions. The scheduled activities required for an EVA frequently lead to SCSC violations on EVA days. Therefore, it is hypothesized that the number of SCSC violations caused by EVA activities were a significant contributor to the total number of violations for Shuttle/ISS missions. A statistical analysis was performed to determine any significance from the data. A null hypothesis will show that there is no significance.

Ho: $\text{Significance}_{(EVA)} = \text{Significance}_{(non\text{-}EVA)}$, H_A: $\text{Significance}_{(EVA)} \neq \text{Significance}_{(non\text{-}EVA)}$

Significance of Research

This study will provide insight to the Flight Planning department as to the significance of violations caused by EVA related activities. This information could be used for constraints documents created for future human exploration missions that will more than likely perform EVAs. Future crews operating far from earth may have more autonomy in managing their daily timeline. New scheduling constraints will have to be robust and clear so that any changes that the crew makes to their timelines will not cause any scheduling violations. These rules will need to be incorporated into the software of the on-board timeline tool so that the crew will be informed of violations that might occur if they make changes to the planned timeline.

Research Technique

This study used a descriptive quantitative research design. The data was not changed or modified. The investigation was a descriptive study of the data that has been recorded for SCSC violations by the Flight Planning Branch at JSC. The type of research conducted was applied since the results of this study may be used in the creation of scheduling constraints for current and future human space missions. A formal study was conducted to accept or reject the hypothesis. This involved the collection of the data and a statistical analysis of that data.

Time Dimension and Scale

This study used a snap shot time dimension. The data population is restricted to the Shuttle missions to the ISS beginning with mission STS-88 through STS-113 that were planned using the rules in the SCSC basic publication and the SCSC Revision A. This could be considered a longitudinal study based on the data population. However violations to other versions of constraint documents had occurred on Shuttle missions before and after this data population. The researcher divided the data into two groups; violations caused by an EVA related activities and violations caused by non-EVA related activities. Restricting the names of the groups in this way allows the researcher to classify the data as the nominal scale.

Method of Data Collection

The data for this study are violations to the SCSC document that were included in the approved SCSC exceptions for Shuttle missions to the ISS beginning with mission STS-88 through STS-113. The data collection procedure was by observation. The data was recovered from the official records held at the Flight Planning Branch at JSC. Each violation was reviewed to determine if the violation was caused by EVA related activities or other activities. This allowed the researcher to identify and categorize the types of activities that lead to the violations. The data was then ranked as either a violation caused by an EVA or a violation not caused by an EVA. The analysis did not manipulate or change any variables from the data. This made the control of the variables *ex post facto*.

Research Environment

The research environment where the data was collected was in the field at the Flight Planning Branch at JSC. The records of SCSC approved exceptions and rule violations are kept electronically on servers that are accessible by Flight Planning personnel. The researcher is a member of this group and has access to the servers.

Reliability

Personnel in the Flight Planning Branch at JSC were highly trained in planning and scheduling Shuttle missions. This training was progressive allowing for increased levels of responsibility and understanding of the planning processes and rules. When personnel attained FAO certification, they had demonstrated that they were able to understand and follow the scheduling rules in the SCSC. They were also able to document and explain any SCSC violations in the form of exceptions. This exception documentation was reviewed by branch, operations and program management. Due to this scrutiny, the researcher can accept existing exception documentation to the SCSC rules under the calibration reliability.

Validity

The SCSC contained the rules for scheduling crew activities for a Shuttle mission. The rules were defined by representatives of the Flight Planning branch, Flight Director office, Astronaut office, Flight Surgeon office and the Safety office. These same representatives, or panel of experts, reviewed and approved the baseline publication and the Revision A to the SCSC. Rules in the SCSC include rationale to assist planning personnel in understanding the reasoning for the rules and to prevent any misinterpretation of the rules. So if one FAO determines a violation exists in a timeline, another FAO should make the same determination. The validity of the SCSC is taken as face validity due to the fact that the rules in it have been reviewed and approved by the subject matter experts at JSC.

Selection of Alpha

The SCSC violations that make up the data for this study were determined by personnel in the Flight Planning branch at JSC. The personnel were highly trained and experienced with the SCSC rules. Exception documentation that was submitted detailing SCSC violations was reviewed by Flight Planning branch management to ensure the accuracy of the exception prior to being presented to other operations and program boards for approval. With this rationale, the researcher selected an alpha of 0.05 for this analysis.

Statistical Process

In the study, the measurement scale that will be used is the nominal scale. The data was sampled once from the Flight Planning branch records. The data was grouped into two groups defined as violations caused by EVA activities and violations caused by non-EVA activities. The data is simplistic in nature and can be considered non-parametric. The data was analyzed using a chi-square goodness-of-fit test (Furlong, 2000, pp. 410-413).

Descriptive Statistics

The data for this study is made up of SCSC violations that have been recorded and approved in SCSC exception documents. If an FAO scheduled an activity for a Shuttle crew member that broke a scheduling rule in the SCSC, an SCSC violation would be created. Multiple violations could be caused by a single scheduling event. For instance, if the FAO was required to schedule an EVA activity that was a longer duration than the maximum allowed, it would be a violation to the maximum EVA duration. This could also cause changes to activities that occur after the EVA, possibly shortening an activity to below its lower allowed limit creating another violation. If the FAO could not reschedule the activities to resolve the violation, then the FAO would document the violation(s) in an SCSC exception.

Graphical Displays

The researcher will present the SCSC violation data in a tabular form. Table 1 reflects what missions had recorded SCSC violations and what activities caused the violations during each mission. Missions are listed in the order they were flown.

TABLE 1

SCSC Exception Data Violation Categories

Flt # STS-	Ascent	Assembly	RNDZ	EVA	Crew Rot.	Transfer	Undock	Cabin Stow	Total Per Flight
88	6	17	20	4					47
96	5	8	7	3			7		30
101	7	5	4						16
106	5		3	11			1		20
92	7	5	7	24					43
97	2	3	7	4					16
98		7	6	9					22
102	4	1	4	1		2			12
100	7		4				7		18
104	5	2	5	9			5		26
105		3	9	7	7	11	1		38
108			2	2			4	4	12
110	7	5	3	24		1			40
111	4	1	4	9			7	7	32
112				36					36
113		1	3	9					13
Total	59	58	88	152	7	14	32	11	421

Table 2 shows the distribution of violations related to EVA activities compared to violations caused by non-EVA activities

TABLE 2

SCSC Violation Data; EVA or Non-EVA

Flt #	EVA	Non-EVA	Total Violations
88	4	43	47
96	3	27	30
101		16	16
106	11	9	20
92	24	19	43
97	4	12	16
98	9	13	22
102	1	11	12
100		18	18
104	9	17	26
105	7	31	38
108	2	10	12
110	24	16	40
111	9	23	32
112	36	0	36
113	9	4	13
Total	152	269	421

Statistical Analysis

For the statistical analysis, a one-way chi-square goodness-of-fit test was used. The end product of the data collection and categorization are reflected in Table 3.

TABLE 3

SCSC Violation Data Category Totals

Category	EVA Violations	Non-EVA Violations	All Violations
Total	152	269	421

Chi-Squared Test (x^2)

The data in this study are placed in particular categories based on their value on the dependent variable so the data is on a nominal scale. The data have a single independent variable; violations that are due to an EVA activity or due to a non-EVA activity. This allows the use of a one-way chi-squared goodness-of-fit test. The frequency distribution that is observed is compared to the frequency distribution that is predicted by the null hypothesis. The null hypothesis predicts that if the differences between the groups are random then the distributions are equivalent. The alternate hypothesis predicts that the differences between the groups do not equal the expected frequency distribution. Ho: $\text{Significance}_{(EVA)} = \text{Significance}_{(non\text{-}EVA)}$, H_A: $\text{Significance}_{(EVA)} \neq \text{Significance}_{(non\text{-}EVA)}$.

For the analysis, the total number of scores is 421. There are two categories; EVA violations and non-EVA violations with scores of 152 and 269 respectively. The first calculation is to determine the cell frequencies (*E*) that would be expected with the null hypothesis. The equation $E = N/k$ where *N* is the total number of scores and k is the number of categories. The resulting equation is $E = 421/2$ so that $E = 210.5$. The null hypothesis predicts that the scores would be evenly divided.

The next step is to compare the difference between the observed (O) and the expected (E) cell frequencies to find the obtained value of x^2 using this formula: $x^2_{obtained} = \sum [(O\text{-}E)^2/E]$. From Table 3, O for EVA violations = 152 and O for non-EVA violations = 269. Using this data, the formula for x^2 is:

$x^2_{obtained} = (152 - 210.5)^2/210.5 + (269 - 210.5)^2/210.5 = (- 58.5)^2/210.5 + (58.5)^2/210.5$

$x^2_{obtained} = (3422.5)/210.5 + (3422.5)/210.5 = 6844.5/210.5$

$x^2_{obtained} = 32.515$

This obtained value must be compared to the critical value of x^2 ($x^2_{critical}$) which is found in a table of critical values of chi squares (Furlong, 2000, p. B8). To perform this comparison, the degrees of freedom (df) for the data set must be determined. The equation used is $df = k - 1$, where k is the number of categories in the data set. In the data set for this analysis, $k = 1$, and the subsequent equation is $df = 2 - 1 = 1$.

Results

The alpha level for this study is 0.05. Using this alpha and the calculated $df = 1$ in the table of critical values of chi squares, the table provides $x^2_{\text{critical}} = 3.841$(Furlong, 2000, p. B8). So it is found that $x^2_{obtained}$ is greater than or equal to x^2_{critical} ($32.515 \geq 3.841$). The null hypothesis is rejected and is it found that the frequency difference observed in the data is not a random event as would be if the null hypothesis were true. The numbers of SCSC violations caused by EVA activities were a significant contributor to the total number of violations for Shuttle/ISS missions.

Variables Not Included in the Analysis

This analysis did not take into consideration the number of EVAs on each of the missions. The fewer EVAs on a mission the fewer chances of causing EVA violations. Another factor that might have an effect on the number of EVA violations is the presence of a crew on the ISS. The first 5 Shuttle missions listed in Table 1, STS-88 through STS-92, traveled to the ISS before a crew resided in the station. The first mission to have an ISS crew present was STS-97 (NASA, 2010b). Also, prior to STS-104, EVAs were conducted out of the Shuttle airlock. The ISS airlock was installed and first used during STS-104 (NASA, 2010c).

Conclusion

The hypothesis for this project was that the number of SCSC violations caused by EVA activities was a significant contributor to the total number of violations for Shuttle/ISS missions. The statistical analysis supports the hypothesis. The violation data in Table 1 lists only two missions out of sixteen that did not have any violations caused by EVAs. These were missions STS-101 and STS-100.

The Shuttle missions analyzed used the rules Revision A of the SCSC. Not all possible situations could be foreseen and violations to the constraints occurred. These violations were reviewed by operations and program managers. Considerations were made for crew safety and mission success and violations were approved or rejected based on these criteria.

Other aerospace occupations have found the need for scheduling constraints. The FAA used constraints to keep airline crews rested. Studies have been performed to help mitigate fatigue in airframe maintenance workers. Also, ground operators of space probes have found that operations schedules must take into consideration the health and efficiency of its workers.

Future missions led by NASA can build upon the experience learned from the SCSC. New private companies will need to have oversight by a governmental agency, possibly the FAA, to ensure that crews are rested and prepared for operating a spacecraft and that the passengers and public are kept safe.

Recommendation

Scheduling constraints for Shuttle missions evolved throughout the history of the program. Although with several updates made to the rules, it was still not possible to completely eradicate constraint violations. It fell upon operations and program management to decide what violations would be allowed. System upgrades on future vehicles could help prevent scheduling violations by off-loading the crew's schedule.

Future NASA missions may have scheduling constraints based on the type of mission being carried out. The Shuttle program carried out missions performing science, station assembly and satellite retrieval and servicing. Future NASA human programs should review the Shuttle missions and any scheduling violations from those missions to better understand how activities such as EVAs can affect the crew and their schedules. New systems designs such as new EVA suits should be considered to limit the amount of preparation time required to perform an activity.

With the introduction of private space companies beginning to operate in this unforgiving field, there needs to be government regulations and rules that ensure the safe operations for the vehicle, crews, passengers and the public. The FAA has taken a step in this direction but more work needs to be done. Crews aboard spacecraft do not experience the effects of gravity. The lack of gravity can cause crew to experience nausea and feelings of vertigo (NASA, 2011f). It would be advisable for commercial companies to send inexperienced crew members into space first as passengers to determine their ability to tolerate the lack of gravity.

It is clear by the statistical analysis that EVAs were difficult to plan in a Shuttle mission to the ISS without causing scheduling constraint violations. Additional investigations would need to be performed to determine the significance of the variables that were not considered in this study. Another study could be performed for Shuttle to ISS missions that were planned using the rules in the SCSC Revision B. The results could be compared to the results in this study to determine if the changes in the SCSC Revision B were effective.

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