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Singapore-U.S. Tactical All-Inclusive Navigation (SUSTAIN) collaborative innovation

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SUSTAIN International Science and Technology Collaboration: Methods & Best Practices for Non-Co-located Engineering Project Teams

Introduction: The purpose of this paper is to provide important information for others who undertake a non-co-located collaboration. This paper describes the experiences of and lessons learned by the Singapore-U.S. Tactical All-Inclusive Navigation (SUSTAIN) team in their effort to create innovative new navigation technologies for dismounted soldiers. Discussion will 1) highlight the issues that were important to address in SUSTAIN's attempts to effectively collaborate, 2) describe some of the tools used in the effort to facilitate the collaboration, and 3) suggest a set of best practices for future international research collaboration.

Literature Review: Dixon (2007)[1] reports on his experiences teaching project management in an international collaborative setting involving three universities, specifically highlighting the logistical hurdles and coordination challenges he experienced. He notes that "robust communications and communication systems" are vital for international collaborative teams to "survive and thrive." He also observes that the greatest hindrances to communication are often time zone differences, technology infrastructure disparities, and technical proficiency disparities among team members. He noted that the simple initialization of the project floundered due to lack of leadership and proactivity, but eventually was underway after the group established sub-team points-of-contact (POCs), established regular communication methods and times, and developed evaluation rubrics to judge the effectiveness of the collaboration. Dixon also noted that effective international collaboration in his effort hinged on two key technological requirements: international availability and cost. Dixon lists some "lessons learned" in regards to his international team collaboration involving three universities, noting in particular the importance of technological parity between partner, team communication, leadership buy-in and support for the project, cultural influences like time-of-work and interaction styles, and participant (and leadership) levels of interest in the project.

International "field trips" and temporary international "work placement" benefits engineers by providing first-hand knowledge of engineering work in a foreign country, as well as providing cultural insights into their methods of defining and solving problems while challenging conventional notions of problem definitions and solutions[2]. According to Downey et al. (2006)[2], it is "critically important" to gain educational and work experiences with people who were raised and trained in other cultures and countries, to understand dominant science and engineering images and patterns of work. Such exposure also helps develop future leaders and may improve the ability to anticipate, understand, and respect other perspectives, which may also improve conflict understanding and conflict management due to cross-cultural factors. Perhaps most importantly, such international collaborative work seems to provide development of non-technical expertise; i.e., the human, social, and cultural dimensions of engineering and scientific work[2].

The SUSTAIN Mission: The Singapore-U.S. Tactical All-Inclusive Navigation (SUSTAIN) initiative was a twelve month international research and development collaboration between military and academic scientists from both Singapore and the United States culminating in a final technical demonstration to U.S. and Singapore leadership. The concept for SUSTAIN came from a previous project model commonly used in Air Force Research Laboratory (AFRL) called

Commander's Challenge in which a high ranking military customer presents a current real world military problem, and a team of early-career engineers is assembled to rapidly produce an innovative technology solution. However, the SUSTAIN initiative took this project model one step further by including international collaboration with government research scientists from an allied nation. This gave the SUSTAIN initiative a dual purpose: 1) to advance technology in GPS-denied navigation and 2) to build long-lasting international ties, facilitating international collaboration between the two defense research organizations for years to come.

SUSTAIN's overarching mission statement was created based on mutual interests between the U.S. and Singaporean governments. It was agreed that SUSTAIN's mission was to create an innovative process, procedure, and/or technology for dismounted soldier navigation under GPS-degraded and GPS-denied situations. Products demonstrated by SUSTAIN were required to provide precise localization, precise orientation, precise timing, position marking, waypoint management and guidance and be highly portable and easily usable. The technology products presented at the final SUSTAIN technical demonstration were meant to provide innovative, unique solutions to a hard "challenge" problem with high interest from U.S. Department of Defense (DoD) and Singapore Ministry of Defense (MinDef). However, what use cases and specific technology areas were focused on in this effort depended heavily on the individual interests of the two countries. Singapore needed improved GPS–degraded navigation in urban canyon use cases while the U.S. needed improved navigation in triple canopy jungle environments for its special forces. Both countries had previous and ongoing research in different specialized navigation technologies, which influenced their choices of technologies to develop through SUSTAIN. U.S. and Singapore leadership compromised on the scope of the SUSTAIN mission. This agreement set the stage for the next year of collaboration.

Collaboration Challenges: Collaboration efforts in SUSTAIN suffered from problems related to distance and time separating team members. Team members were geographically separated by over 15,000 kilometers and a 13-hour time difference. Co-located teams working during the same time have the ability to communicate verbally, see facial expressions, and exchange ideas in real-time. These luxuries were not available to the SUSTAIN team on a daily basis. Also, because Singapore team members were chosen from different organizations and universities, Singaporean team members could not be co-located on a daily basis. Team members in Singapore were located at three different offices: the National University of Singapore (NUS), the Singapore University of Technology and Design (SUTD), and Defence Science Organization National Laboratories (DSO). It proved difficult to coordinate team members' schedules because each member had additional professional responsibilities outside of SUSTAIN which occasionally took priority.

All teams collaborating remotely face challenges in communication, cohesion, and trust. However, distance and time issues increased these challenges, making international communication especially slow. Early in the project, this caused the SUSTAIN team to struggle with team decision making, problem identification, and problem solving. Eventually, the communication breakdown led to program management obstacles such as difficulties assigning tasks or simply deciding as a team what tasks were relevant and feasible to do. Sharing facilities and resources was also difficult, making collaborative testing of prototypes a rare occurrence.

Early efforts were made at a kick off meeting in Hawaii to bring the entire team and its leadership together for face to face collaboration and team building activities. However, as the project continued, distance and time also became barriers to team interpersonal relations, morale and cohesion, and trust. Motivating team members to complete tasks became difficult because often, the team wasn't able to sit together to agree on which tasks should be done and on what schedule. Such problems led to decreasing morale among team members. Trust was a major component in the ability of the team to function cohesively. Without explicit and consistent communication, team members were often wondered who was working on what task, and if members were actually accomplishing the work promised. As most members did not have prior relationships, there was also a technical trust issue: did teammates have the required expertise?

Other obstacles stemmed from political barriers to international collaboration. SUSTAIN was unique in this because it involved collaboration between the defense organizations of both countries. Team members from both the U.S. and Singapore each came in with their own national secrets and certain proprietary technologies that were not legally sharable with the other country. This meant that certain high level technologies and data were left unavailable to the SUSTAIN team. Because all team members came from military and government backgrounds, it was well understood and accepted that this was the case, and trust between team members did not suffer significantly as a result. Differences in national political focus had a significant effect on team composition, time allocated to project, and project goals. The U.S. and Singapore governments were each interested in different use cases for the navigation technology SUSTAIN was tasked to produce. This widened project scope combined with struggling international communications contributed to a very loosely defined set of goals for SUSTAIN at the beginning of the effort, which caused further program management difficulties later.

Work place structures, resources, and work habits also played important roles in affecting program management, execution, and communication. Multi-tasking, was a common work place habit between both Singapore and U.S. sides of the team. The organizations team members were sourced from often expected team members to continue maintaining their previous workloads along with the SUSTAIN workload. Team members were exposed to additional work commitment from their individual organization without consideration for the SUSTAIN collaboration. For example, two of the Singaporean team members were full-time professors at their universities. This led to team members needing to juggle between making progress for the SUSTAIN project or contributing to other work, which was at times more urgent. U.S. team members faced the same dilemma, however not to as much an extent, most likely because the American members of the team were provided a separate office space in which they could be co-located to focus solely on the SUSTAIN effort. These split motivations caused some rift in international collaboration and trust between team members.

Not only were the team members dispersed across countries, but so were their resources. Team members located at the universities in Singapore were able to delegate tasks to their students to generate and do initial prototyping of ideas for the project, and members from DSO had access to existing hardware resources to expedite the prototyping process. Sending prototypes or hardware across international borders was neither cost nor time efficient. Therefore, U.S. and Singapore sides of the team sometimes had to duplicate prototyping efforts in order to collaborate.

Differences in team members' skillsets and backgrounds resulting from work place structures also played a role in the collaboration. The AFRL focuses on program management and acquisition skills. U.S. team members, gravitated to organizing the SUSTAIN project based on the acquisition principles they were taught. Singapore team members came from research organizations and universities, where work place structures were more academic. They were more apt to focus on prototyping and experimenting than on program management. Individual culture challenges did not affect the team as significantly. All team members from Singapore spoke fluent English and had received a portion of their education in the United States. These team members, though from a foreign country, were already well adjusted to American culture and language. Also, the country of Singapore boasts an impressively diverse population both ethnically and culturally, which resulted in the Singaporean members of the SUSTAIN team being well accustomed to working with others of different nationalities. Members from the U.S. were generally less accustomed to international collaboration. However, one U.S. team member had been a Vietnamese immigrant and was already familiar with Asian culture. And one U.S. team member had already collaborated with members from Singapore on previous projects. These levels of familiarity, which were already in place at the beginning of the SUSTAIN effort paved the way for easy development of relations between team members.

Collaboration Tools and Methods Used: The first step in beginning the SUSTAIN project was building the team. Each country selected team members separately. Member selection on the U.S. side consisted of an advertisement for volunteers from junior force military and government employees in the AFRL and an interview process. Candidates were interviewed and accepted based upon their technical experience, program management skills, creativity, and personality. Specific experience in the field of GPS and navigation was not required. Five team members were selected: three government scientists and two Air Force officers. Singapore leadership selected team members on a non-volunteer basis, emphasizing expertise and research experience in GPS navigation, all four with military backgrounds. Both nations had senior leaders within their defense organizations who championed the project and access to military and technical subject matter experts (SMEs). The result was a diverse team with members from both military and civilian backgrounds and many different areas of expertise: GNSS navigation, electrical and mechanical engineering, psychology, computer programming, program management, etc.

At the start of this collaboration, the SUSTAIN team was made up of nine total strangers put together in a team. All team members and leadership attended a face to face kick off meeting to officially start the project. Tools based on concepts from industrial organizational psychology were used to analyze the make-up of the team and formally educate members about how to effectively work together at a face to face kick off meeting. Team members and leaders participated in a formal analysis of individual personalities and creative habits by taking a Meyers-Briggs personality test and a 6-Hats personality test. The results of these tests were collected, presented to the team, and discussed at length with advice provided on the how to understand and work together with members of different personalities. Initial team bonding and icebreaking exercises were used at the meeting to help members come together as a team. These activities included events such as mountain climbing and dining at local restaurants so team members could interact in a more relaxed environment. Spending time together outside work helped team members to understand the various personalities and areas of expertise in the group and to build trust and familiarity with each other. However, team cohesion activities could only be planned over short periods of time as members could not spend an extended amount of time away from their home organizations. In substitution for face to face time, chat groups (text and video) provided a good alternative for maintaining relationships between team members.

At the four month point in the project, the U.S. members of the team visited Singapore to work closely with their Singaporean counterparts for two weeks. Likewise, at the nine month point in the project, the Singaporean team members visited the U.S. for two to three weeks. It was during these key times that the most effective collaboration was achieved. During these weeks, normal business hours were spent in team meetings, in group efforts to tests and evaluate prototypes, and in touring the facilities each government organization had to offer. Face to face team meetings with all members in attendance provided a platform for vital team decision making. Group testing allowed for all team members to not only feel involved in the technical aspects of the project but also to learn from each other and gain expertise in fields they'd not studied in before. Exchanging laboratory tours allowed each country to showcase its scientific accomplishments, consider possible technical areas for future collaboration, and understand what tools were available for use by the SUSTAIN team. The team spent evening hours hosting each other at dinner and participating in team recreational activities to build cohesion.

The team needed ways to coordinate tasking, communicate ideas, and manage knowledge. The team also needed to accomplish coordinated software development. Because this project was entirely "unclassified" (the lowest level of government information security requirements), both nations permitted use of private cloud services. Due to the small budget and short twelve month time allotted for the project, it was important to find low cost and easy to use communication tools. No one tool could be found that perfectly integrated all necessary forms of communication. So, several separate software communication tools were chosen.

Efforts were made to perform program management through software tools widely used in business today. To coordinate tasking, the Atlassian JIRA software service was purchased. JIRA allows project managers to convert a work breakdown structure into individual tasks. Ultimately, JIRA was set aside because the amount of time required to operate JIRA made the tool less convenient. Also, many tasks in this basic research environment project were too small to warrant capturing in JIRA. To fulfil knowledge management and document and data sharing needs, Atlassian Confluence was chosen. Confluence is a wiki-format tool that permitted attaching external files, simultaneous group document editing, and file-change merging, and searching articles. One of the reasons a feature-rich wiki was successful was because both nations had experience using the tool and immediately saw benefit. Members' initial familiarity with the tool made consensus on its use easily attainable. The team hosted computer code written for the project in Bitbucket, a cloud-based repository from Atlassian.

In addition to written forms of communication, collaboration required frequent conversational communication. Brief daily team discussions were captured in an internet relay chat (IRC). The team used Slack for this service when computers were available but used the group messenger What's App for same-day logistical conversations. Both services are no-cost to send messages internationally. The team hosted a weekly video teleconference (VTC) to check in. At the time of this paper, Google Hangouts provided the best ability to allow personnel to call in from multiple locations with good video and audio quality at no monetary cost. While this method alone was insufficient to accomplish mission objectives, it did provide face to face time and an opportunity for team members to report on their individual activities and plan for future tasks. The U.S. was 13 hours behind Singapore, making both evening and morning video calls viable.

Due to the SUSTAIN project's bilateral military research aspects, the SUSTAIN project had unique security needs. The project required additional legal authorization. The project scope was restricted to basic research, which the U.S government generally considers as "unclassified". Military leadership from both nations signed an international agreement, authorizing personnel to collaborate. This required approval of the U.S. Foreign Disclosure office as well as editing portions of information so that important data, documents, and concepts were shareable without revealing sensitive military operational or technical details. When consulting experts from academia, industry, and both governments, it was important for SUSTAIN members to inform SMEs that the nature of SUSTAIN involved international partners, and that any information SMEs shared must either be: 1) shareable with foreign partners, or 2) clearly defined or noted as non-shareable. Establishing this policy up front and early allowed all parties to agree on how to manage information security.

One key technology area in which communication and collaboration proved challenging was collaborative computer software and hardware development in conjunction with the prototype technologies SUSTAIN produced. The team's software and computer code experts were located in separate countries and came with varying levels of software development experience. Due to the distance between members, it was impractical to integrate software and hardware components routinely or to do in-person identification of development problems. Team members collaborated on how to control versions of software and hardware as well as what commercially available tools and code libraries to use in order to manage system configurations. Software was shared on a joint repository. For simplicity, team members used the same integrated development environment (IDE) for code development. Builds were automated as much as possible using software package managers. The NuGet repository provided libraries in both C++ and .NET(C#). Similar repositories were available in Java and C#. The team decided what hardware would be duplicated at both U.S and Singapore work sites and what would be prototyped at only one site.

The SUSTAIN project officially began at the kick off meeting, and initial attempts were made to set in place traditional project management methods. Team project leaders were chosen. Roles of other team members were defined. A tentative schedule for the project was made using gantt charts. Collaboration tools were chosen, and a strategy for communication was developed. The scope of the project was left wide to leave room for innovative thought. However, it was assumed that the scope would later be narrowed once early background research and ideation efforts were accomplished. Most of these original plans were subject to change as the project went forward due to unforeseen communication, scheduling, and technological complications.

The nine members of the core SUSTAIN team chose from among themselves one project leader from Singapore and one project leader from the U.S. The responsibilities of these project leaders were to lead weekly video chat meetings, serve as an interface between the team and government leaders and subject matter experts, oversee the work of other team members, and conduct overall project management. One team member was tasked with managing budget and inventory. A sub team was created for computer software development, and other sub teams were formed as needed for smaller tasks within the project. These early attempts to assign team members to basic offices faltered as individuals' schedule conflicts surfaced and communication lapsed in the first months. Therefore, the team's organizational structure had to become more fluid. Tasks were assigned on a volunteer basis. Team members chose tasks they could complete based on their individual schedules and expertise. As time went on, new navigation solutions were thought of, and team members joined sub teams for prototypes at their leisure. Often, smaller prototyping efforts that failed to garner support from at least two or three team members did not continue to make progress. In other cases, multiple team members were able to unite around a prototyping effort, and progress on that prototype proceeded rapidly. If a member wished to champion a prototype, he or she had to first lobby for interest in that prototype with the rest of the team, receive feedback, and gain consensus on whether or not the proposed prototype was viable, and appealing to potential users. This interest-based method of prototype selection developed slowly, resulting from the absence of definitive technical direction from government leadership.

A critical step in the research and prototyping process was to narrow and completely define the scope of the SUSTAIN project. Early in the project, background research both inside and outside the field of navigation was encouraged in order to promote creative thought. However, the need for a well-defined problem space and purpose quickly became apparent as team focus lapsed without specific direction. Thus, considerable collaboration time was spent defining scope of problem while identifying problems of individual interest and mutual interest to both nations.

Best Practices for International Collaboration: The SUSTAIN team identified many best practices for international collaboration that other teams should consider. Future teams would benefit from a longer face to face kick off meeting to begin their project. Key tasks accomplished at this meeting should be as follows. 1) Arrange time for team bonding activities and introductions to all cultures and nationalities present in the group. 2) Train team members in using online communication tools, project management skills, and other specific skills necessary for the effort. 3) Establish a communication strategy which includes consistent, regulated communication. It can be concluded that the most effective collaboration will be achieved if all team members agree on what communication tools to use and a strategy of how to use those tools in a uniform way. 4) Create the initial budget plan and schedule for the effort, which should include major milestones and performance measurements as well as scheduled face to face meetings and reviews by leadership. 5) Leadership and upper management should fully define the scope of the effort. If the effort is meant to be an innovative technology effort like SUSTAIN, leadership should clearly define a customer base for the technology to be produced.

Best communication practices as international collaborative projects continue are as follows. 1) Use online chat tools which allow hyperlinks, attachments, and images to be sent as well as text. These should be used to enhance daily conversation between team members. 2) Create knowledge and data repositories for team use. Knowledge management software in the form of a wiki has potential to greatly enhance a team's collaboration ability. For data and document sharing and daily conversation, these written communications were found far superior to email methods. 3) When co-location isn't possible, team members should make use of online video chat tools for regular communications. Weekly video chat meetings with all team members in attendance are highly encouraged. These weekly meetings provide a way for team members to report on the progress of individual tasks, assigned new tasks, and achieve group consensus on team decisions.

Other advisable collaboration practices include maximizing face to face collaboration time, efficiency of workflow, and leadership involvement. If team members are located in separate countries, arrange for all members to exchange visits to each other's countries. This helps team members to gain an appreciation for the different cultures on the team and maximizes face to face collaboration time. Leadership should make the best use of resources provided by their organizations to make these visits cost efficient. Avoid duplicating work due to lack of co-location. If a team member is an expert in a certain area of knowledge or the performance of a certain task, that team member should be tasked to lead that particular portion of the effort, and if necessary, a sub-team should be formed around that person. This will permit the rest of the team to move other tasks forward, promoting efficient workflow. Leadership should ensure the team is provided with its own workspace (with separate sites in different countries if necessary) outfitted with all essential office tools, where team members can be co-located as much as possible, better communicate, and avoid distractions arising from outside workloads. It is recommended to have a member of leadership present at each work site on a regular basis to review team progress and provide accountability, motivation, and guidance.

Conclusion: The success of the SUSTAIN international collaboration depended heavily on new technology in online communication, the expertise of the SUSTAIN team members in both scientific research and program management, and continuous support from high ranking leadership. Not only was the SUTAIN project an effort to bring innovative technology to its customers but the project was also an exploration of new methods and best practices to implement when collaborating internationally on scientific research and engineering efforts. One of the goals of the SUSTAIN project was to pave the way for future international science and technology collaborations between the U.S. and other nations. Teams wishing to undertake collaborations similar to that of SUSTAIN should consider the benefits of global engineering competency to be gained as well as the difficulties of bringing together a multinational team.

Possible language and cultural barriers must be addressed before the project begins with training for team members in order to ensure that the collaboration is feasible. Distance and time between team members must be overcome using methods that are agreeable and usable by all parties. Teams should take advantage of face to face interactions wherever possible. Consensus must be achieved on communication tools used and how to use them to create a uniform communication strategy. Especially if the time frame of a project is short, leadership must give early guidance to form a project management strategy and must remain available to team members throughout the project. Detailed planning, leadership involvement, and cohesive, motivated team members will ultimately decide the success of international collaboration.

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