Human Systems Integration: A 28,000 Foot View

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HUMAN SYSTEMS INTEGRATION: A 28,000 FOOT VIEW

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Human Systems Integration (HSI) is a discipline in which human capabilities and limitations across various dimensions are considered in the context of the design and evaluation of a dynamic system of people, technology, environment, tasks, organization, and other systems with the ultimate goal of achieving system resilience and adaptation, approaching joint optimization. An HSI perspective is described in the context of the Two Eagles mission, in which two pilots crossed the Pacific Ocean in a gas balloon. The two pilots set both the record for the longest duration and for the longest distance in a gas balloon. The system extended far beyond the balloon and the two pilots. It was complex and distributed around the world. There were many challenges associated with HSI issues, which are detailed in this paper and exemplify the value of a systems perspective.

HUMAN SYSTEMS INTEGRATION

Human Systems Integration (HSI) is a discipline in which human capabilities and limitations across various dimensions are considered in the context of the design and evaluation of a dynamic system of people, technology, environment, tasks, organization, and other systems with the ultimate goal of achieving system resilience and adaptation, approaching joint optimization (Boehm-Davis, Durso, & Lee, 2015; Pew & Mavor, 2007). Similar to systems engineering, interactions among system components are central to HSI. However, HSI also takes into account human dimensions and of that include human factors, manpower, training, personnel, health, safety, survivability, and habitability. These dimensions may also interact. It is due to these interactions that we often observe unintended consequences that result from a change to one part of the system.

Our research team had the opportunity to work on the science team of the exciting Two Eagles Mission – a record setting gas balloon project. This project provides a concrete example of HSI. In this paper we describe the project and then discuss it in terms of the larger system, human dimensions, and interactions.

TWO EAGLES GAS BALLOON MISSION

The Two Eagles gas balloon mission took two pilots from Japan across the Pacific Ocean to Baja, California. In doing so, they set two absolute world records: longest duration in a gas balloon and longest distance in a gas balloon (Hawatmeh, 2015, http://www.fai.org/records/news-of-records).

The Two Eagles Mission required extensive planning that occurred over the course of a decade. The balloon launched on January 24, 2015 from Saga, Japan and landed on January 30, 2015, approximately four miles offshore near La Poza Grande in Baja, California. The mission shattered prior distance records by 6,646 miles (27%) and prior duration records by 160.5 hours (17%), respectively.

The Two Eagles Mission was carried out by two experienced gas balloon pilots and supported by a large Mission Control team, as described in Table 1. Pilot, Troy Bradley, had over 6,000 hours of experience and nearly 60 world records in gas ballooning. The other pilot, Leonid Tiukhtyaev, led the "Russian Records Factory" ballooning project, was the President of Balloon Federation of Russia, and had set eight world records. Dr. Steven M. Shope led the mission control team that included the personnel listed in Table 1 as well as other support personnel and technical advisors. The mission control site was located in New Mexico and the team interacted with others distributed around the world including the Launch crew in Japan, weather experts located in the Middle East, and recovery teams distributed throughout the US and also in Canada and Mexico.

Table 1. Personnel involved in Two Eagles Mission Control

Role	Task
Mission Control Director	Design & lead Mission Control team
Meteorologist	Predict balloon trajectory
USAF Flight Surgeon (ret.)	Medical emergencies
Air Traffic Control	Coordinate with Air Traffic Control for air space permissions
Flight Scientist	Assess pilot cognitive readiness
Flight Director	Coordinate with pilots on flight decisions
Recovery Crew Coordinator	Organize recovery
Flight Tracker	Monitor balloon position
Media	Coordinate media requests
Capsule Communications	Communicate with pilots

The balloon system (Figure1) consists of an envelope and a capsule that is 7 ft. long, 5 ft. high, and 5 ft. wide. The capsule was designed to be very strong, yet light weight (approximately 220 lbs.) and is made from Kevlar/carbon-fiber composite. The capsule was also designed to survive a rough landing and provide shelter from harsh conditions. Because the capsule was unpressurized, the pilots were required to use oxygen above 12,000 feet. In addition to housing the two pilots, the capsule contained an array of communications and navigation equipment, and a high altitude heater. The envelope was custom made for the mission and was 350,000 ft^3, weighed 1,475 lbs., and could carry a ballast weight of 11,500 lbs. Because it has a lower molecular weight than the ambient atmosphere, helium gas was used. In ballooning helium is also preferable to hydrogen for stability reasons.

The Two Eagles mission was challenging for several reasons. First, the custom made balloon had never been flown prior to the mission. Second, most sport gas balloons that are 35,000 ft^3 and thus, the 350,000 ft^3 balloon was much larger and consequently more difficult to fly. Third, the pilots had no experience piloting together prior to the mission. Finally, weather and wind trajectories play a critical role in a successful gas balloon flight and low winds can result in a longer time in flight. The balloon is designed to fly for a maximum of ten days, so it was important that the flight did not exceed that time.

Figure 1. Two Eagles Balloon

THE TWO EAGLES SYSTEM

One could describe the Two Eagles balloon that includes the two pilots as a system. Indeed, it is a system of systems in that it includes flight, safety, and health equipment that are themselves systems. The humans themselves are systems of systems (circulatory system, nervous system, etc.). However, it is difficult to fully understand the balloon system without considering all of the other systems (each systems of systems) that are interconnected.

The Two Eagles mission involved an international team that was required to coordinate and collaborate through different time zones, different air traffic controls, and flight changes. The team had many functions, which included weather forecasting, flight strategy, and cognitive assessment (Figure 2). The system included the balloon, the two pilots, Mission Control, launch personnel, various media and weather personnel, helium suppliers, military and government participants, and more.

The pilots were not the only ones on the Two Eagles team that experienced stress and fatigue. The mission control team was staffed around the clock and was responsible for critical decision making throughout the mission. Adequate sleep was an issue for not only the pilots, but also the Mission Control team Poor decisions in mission control could definitely impact the mission and the balloon pilots.

It is important to understand the relations between the various sub-teams and how decisions made or actions taken by one unit can affect the operations of another. Such an understanding is needed to design, change, or predict performance of the system. Some examples of such system-wide interactions follow.

Example 1

By design, the balloon launched in the early evening. The first phase of flight is very difficult for the pilots, as the balloon is at maximum stress and the pilots are working to stabilize the flight level. Air traffic control needs to be able to communicate with the balloon, however, in most cases the controllers went through Mission Control to do so. The exception was Japanese Trans-Pacific air traffic controllers who insisted on having the satellite phone number for the capsule in order to authorize flight over the Japanese Trans-Pacific. One pilot was trying to sleep, the other was busy stabilizing the balloon and Japanese Trans-Pacific controllers called every five minutes to get position updates which woke up the sleeping pilot and distracted the other pilot from flight duties. It became serious and the pilots asked Mission Control to intervene and intercept the calls from the Japanese Trans-Pacific controllers. In short, because of the unusual nature of the flight, there was a higher volume of controller calls from Japan which potentially impacted flight safety of the balloon and required Mission Control to intervene.

Example 2

In a similar example, the US FAA center managers did not understand balloons and requested daily meetings between Mission Control and center managers across the US. Mission Control provided the managers with flight trajectories that were projected across seven days. One later trajectory in the flight showed the balloon going into Atlanta air space, which alarmed the managers. However, given the duration restrictions of the mission, the projected trajectory was not feasible that late in the mission. The constant communication requirements between Mission Control and the US FAA center managers took time away from Mission Control during the flight. Here the interactions between the FAA managers and Mission Control were also of high volume and distracting to the overall mission.

Example 3

The helium supplier in Japan required 48 hours' notice to provide the helium needed at launch. Nearly every helium tube truck in Japan was needed to fill this balloon. However, launch is critically dependent on weather on the ground which could not be reliably predicted within the 48 hour window. As a result, there were two false starts in which helium trucks had to be sent home, costing the project approximately $15, 000 per false alarm. In this case, weather impacted launch decisions which then impacted helium delivery and ultimate cost.

Overall, it is clear that in a complex system, issues that happen in one part can have cascading effects in other parts of the system. Of course not every interaction can be identified at the time of design, but resilient systems will have back-up plans in place (e.g., backup Mission Control personnel). In the remainder of this paper we describe the human dimensions as relevant to the Two Eagles mission.

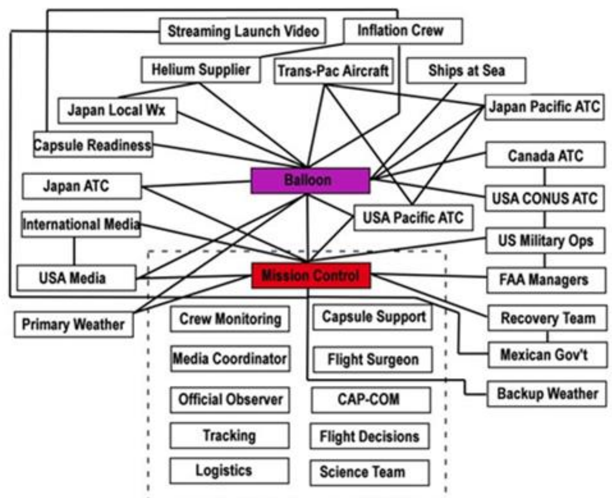

Figure 2. Two Eagles System

HUMAN DIMENSIONS

How do the human dimensions of human factors, manpower, training, personnel, health, safety, survivability, and habitability relate to the Two Eagles system? These dimensions will be discussed in terms of the balloon and Mission Control parts of the system.

Human Factors Issues

The piloting task was cognitively and physically demanding. Decisions had to be made about when to launch, change in direction, and releasing ballast. Situation awareness was important, as well as communications with Mission Control. In several cases, plans had to adapt to changing weather and winds. A significant amount of physically demanding work was necessary, such as cutting ballasts by climbing out of the capsule in high altitudes with temperatures as low as -10 degrees Fahrenheit. Fatigue and stress were expected to be issues. The pilots took turns sleeping or piloting.

Mission Control had similar cognitive tasks without the physical tasks. However, the 24/7 operation and communications with all of the other system components produced significant fatigue and stress. Mission Control also served as a cognitive back-up for the pilots. Teamwork was essential.

Manpower Issues

The balloon was limited to two people. This is because weight is a critical issue. More people would require a bigger capsule and additional supplies. Mission Control was staffed according to functional needs. There were two shifts a day and some people were cross trained for redundancy. There were 20 individuals in Mission Control. In retrospect, the team was completely unprepared for the amount of media attention that the mission received. During the event more than one billion media impressions were generated around the world. This created a huge tax on manpower and the need for more individuals to handle the media needs was apparent.

Training Issues

Although the pilots were skilled gas balloon pilots, they had never flown this particular balloon system. For the most part the equipment was very similar to other gas balloons, with the exception of the state-of-the-art satellite systems and tracking gear. Due to distractions surrounding finding a suitable launch window in Japan and high workload in other areas prior to launch, the two pilots had little time to train on this new equipment. As a result, Mission Control had to mitigate on occasion, thus increasing workload and diverting attention from other control tasks. The Mission Control team had regular phone meetings prior to the mission to familiarize each other with team roles. Most individuals in Mission Control had worked together before on similar projects.

Personnel Issues

The pilots self-selected, as they were also the organizers of the mission. The Mission Control director and pilots selected Mission Control personnel based on their previous experience working on a mission control team.

Health Issues

The pilots monitored their own consumables, fluid intake, sleep, and oxygen level (pulse oximeters). The data they entered were sent to Mission Control. However, in some cases they were unable to enter the data due to other temporal demands. The pilots also monitored the physical state of each other. There was a medical set (first aid, drugs) on board the capsule and a flight surgeon as a member of Mission Control. Both pilots reported getting good sleep, however, one pilot only gets four hours of sleep per night normally. Additionally, breathing oxygen at high altitudes could lead to fatigue and poor decision making and was a concern through the mission.

Safety Issues

Most of the flight trajectory was over the open water of the Pacific Ocean, creating very little risk for those on the surface. Measures were in place for pilot survivability in case of an emergency landing or crash as is explained in the next session. The trajectories took the balloon over some of most popular shipping routes in the Pacific and when the pilots dropped ballast they reported being able to see the water below. They also had marine radios to talk to ships in case of emergency.

Survivability Issues

In the event of a failure of the balloon envelope, it would act as a parachute to slowly lower the capsule to the surface. The capsule was designed to be sea worthy. In addition, the pilots had survival suits and a raft. They had enough provisions in the capsule to survive 2-3 weeks at sea.

Habitability Issues

The Two Eagles pilots lived for nearly a week in an unpressurized box the size of a king-size bed (Figure 3). They flew at altitudes between 18,000 and 28,000 feet, breathing oxygen through masks for 6.75 days. Temperatures were as low as -10 degrees Fahrenheit.

The pilots found the capsule to be very habitable. One pilot slept while the other worked at the control station. However, they could not stand up in capsule and would often climb out of capsule to release ballast bags or look at the view.

The Mission Control center was custom designed and constructed by the city of Albuquerque and located in the Anderson-Abruzzo Albuquerque International Balloon Museum. Viewing windows were available for the public. It also included rest areas and food was plentiful, much being donated by various persons in the public.

Figure 3. Two Eagles Pilots- Troy Bradley and Leonid Tiukhtyaev inside the unpressurized balloon cabin

INTERACTIONS ACROSS DIMENSIONS

Not only do different components of the system interact, but so do the human dimensions. For instance, in the case of the Two Eagles mission, personnel issues interacted with training issues. That is, because the pilots were also the organizers, it was difficult to enforce any training schedule. Workload prior to launch further complicated training, but the system was resilient due to the expertise regarding satellite and tracking equipment at Mission Control.

There were also initial concerns in the program about the interaction between personnel and safety. Specifically the pilots came from two different cultures and did not know each other very well. Putting two people in a small box for an extended period of time could result in conflict that may compromise safety. Fortunately for the mission, this was not the case.

CONCLUSION

The Two Eagles mission across the Pacific Ocean provides an interesting platform on which to showcase Human System Integration issues. The system was certainly larger than the balloon, highly complex, and distributed world-wide. In addition, each of the HSI dimensions are relevant to this complex system. Fortunately, there were no major failures or unexpected consequences. The examples of relatively minor unexpected consequences were quickly resolved by the team. This is largely due to the extensive planning that went into this mission by experienced personnel to make the system effective, safe, and resilient with the human components of that system being of central importance.

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