Human and Organizational Risk Modeling*

CASOS Technical Report

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Abstract

This report describes a study of human and organizational risk within NASA's Team X, a conceptual mission design team. A grounded theory approach was used to develop computational models for risk analysis. Among the major findings in the analysis were identification of critical personnel, risk of turnover and performance tradeoff of differing leadership styles.

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Keywords: organization theory, organizational risk, computational analysis, social networks, multi-agent simulation, socio-cultural environment, socio-technical environment, critical personnel, turnover, leadership, concurrent engineering, aerospace mission design, NASA

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1. Progress Report

This report presents the progress on the NASA Organizational Risk Model (ORM), for HORM Milestone #1, KESS #2 and ECS #3 under the Engineering for Complex Systems Program (ECS).

1.1. Data Collection

Observations of Team X at JPL were made on two occasions: February 11-12, 2003 and April 22-25, 2003. The February observation was the CMU team only and met the objective of introduction to the Team X process. The April data collection effort was coordinated with Stanford University and the University of Illinois, Urbana-Champaign. All modeling was completed using the data collected from the April collaborative effort. The model data collection focused on the Team X CSSR mission design.

In addition to observation, interviews were conducted with several Team X members.

A follow-up survey was completed in June for the Team X CSSR mission design. The survey included questions from all three university modeling teams, see Appendix A. Previous efforts to gain completion of the survey in April and May were unsuccessful. This accounts for the time lag between the sessions and the survey results.

1.2. Computational Models and Tools

In order to meet the objectives of the Organizational Risk Model, the ORA tool was developed and the Construct model was extended. The ORA tool produces a static snapshot of the organization whereas the Construct model produces dynamic organizational analysis. ORA and Construct are designed so they can be docked. ORA input can be used to parameterize Construct and Construct output can be input into ORA. In this way, a full complement of social network measures can be obtained for temporal analysis.

1.2.a. ORA

ORA is the organizational risk analyzer. Its purpose is to assess the level of possible organizational risk and the factors that contribute to this risk. All measures are based on the meta-matrix and take in to account the relations among personnel, knowledge, resources and tasks. These measures are based on work in social networks, operations research, organization theory, knowledge management, and task management. For a full description of the ORA measures see Appendix B.

1.2.b. Construct

Construct is a multi-agent model for the co-evolution of agents and socio-cultural environments. Based on observation of the Team X process and the technological and human networks involved, the following changes in Construct were made:

- **publish/subscribe system**
- **large screen broadcast tech.**

- **past missions database**
- **sidebars**

In addition, the following changes are scheduled for phase II implementation:

- **interdependencies**
    - **human network**
    - **technology network**
- **pooled, sequential, reciprocal tasks**
- **multi-tasking**
- **error cascades**

The previous changes were implemented in phase I as these technologies and group interaction method are key to the team's strategic management of the interdependencies and tasks as well as being channels for error propagation. The phase I changes needed to be implemented first. For more description about the current changes see Appendix C.

2. Modeling CSSR Team X

Data for CSSR Team X was collected as described in the data collection section above. The following is a high level description of CSSR Team X based on this data collection.

CSSR Team
Team X, located at JPL, is a concurrent engineering design team specializing in unmanned space missions. The CSSR Team X was composed of 20 team members plus the proposal manager and a second facilitator who filled in for the lead facilitator's absence in session 3. Of the 20 team members, two were staffing the mission design position. The two mission design personnel were aggregated in to one position node and no distinction is made as to the two separate personnel. The aggregation brings the number of positions to 19 and data was collected from these 19 positions plus the program manager and the second facilitator

Functional Roles
Each member on the team is a functional expert and represents a unique functional area. The separation of the design team into functional areas forces knowledge distribution into specialized channels. Each functional expert is responsible for designing their particular subsystem of the spacecraft. The two exceptions to this responsibility are the systems engineer and the facilitator. The systems engineer is responsible for maintaining the central database for the group. The facilitator is responsible for overseeing the activities of the group and for assuring that design goals are accomplished.

Design process
The design process requires individually designed subsystems to be successfully integrated into one system. Team X accomplishes this by concurrently designing subsystems and iteratively integrating the system to meet scientific and fiduciary objectives. The concurrent integration task requires pooled, sequential and reciprocal activities. The concurrent engineering design is supported by concurrency and integration as well as a strong, well-established culture. Concurrency is supported by

warroom co-location of the design sessions and multifunctional team composition. Integration is supported by co-location, computer systems and analytic methods.

Interdependencies
High interdependencies exist between subsystems and are characteristic of the complexities of space missions. Changes in one subsystem cascade throughout the system and cause changes in other subsystems. Team members develop mental maps of the interdependencies. These mental maps help guide the members through the design process. The existence of high interdependencies requires frequent two-way communication with more complex interactions needing face-to-face discussion. Knowledge management and communication are key factors to the successful completion of a design with high subsystem interdependencies.

Warroom –integrated human and technological networks
The warroom is an open space room fitted with telecommunication technology to support the mission design process. Co-location affords frequent face-to-face communications and reduces response latency to very short time periods among the multifunctional experts. For example, as complex exceptions occur, small sub-groups called sidebars will form to handle the problem and manage the interdependencies. The computer systems help to manage the design process and communication. Computer systems are in two basic classes - engineering tools and information technologies. The engineering tools are specifically designed for each subsystem and used individually by each expert. The information technologies are used in three ways. The first use is to transfer information seamlessly between the individual engineering tools by way of a central database. This helps to manage the interdependencies and to alleviate human communication transfer of non-complex information. This allows for the human interactions to focus on complex problems. The second use is to broadcast information visually to facilitate group discussion. This is done via three large screen at the front of the warroom. Each screen displays different information. The last use is to guide the design process. The facilitator uses output from the central database to organize the design process and evaluate the state of the spacecraft design. The human and technological networks are integrated in the warroom environment. The interoperability of the human and technological networks is used to manage and coordinate the design process and subsystem interdependencies.

Facilitator
The facilitator is a key position as this position requires system-wide expertise. System-wide expertise is required to not only manage the interdependencies but to converge the specialized knowledge of the group to achieve an integrated design. The facilitator controls the flow of the design session and displays high situational awareness. This position is also responsible for assuring a common operational picture among the team members.

Design Accuracy
The accuracy of the mission design is mainly undeterminable. There is not an adequate testing environment on earth and space mission completion is temporally lengthy.

Additional information

Mark, G. (December, 2001). Extreme Collaboration. *Communications of the ACM.*

2.1. CSSR Team X MetaMatrix

Based on the data collection, a metamatrix framework for Team X was completed for use in computational analysis. The metamatrix framework is shown in Figure 1 and followed by a description of each matrix. Two distinct metamatrices were made because data was collected on two separate facilitators. The distinctions for these metamatrices are other team member's perception of each facilitator and the perceptions each facilitator has of the other team members and the engineering process. Each metamatrix represents the team when led by the respective facilitator. The metamatrices were input to both ORA and Construct.

Figure 1	People	**Technology**	**Knowledge**	**Tasks**
People Relation	**Social Network** *Who knows who*	**Technology Network** *Who uses which tech.*	**Knowledge Network** *Who knows what*	**Assignment Network** *Who does what*
Technology Relation		**Operability Network** *Which tech. interfaces with which tech.*	**Encoded Network** *What is in which tech.*	**Tool Network** *Which tech. helps perform which task*
Knowledge Relation			**Interdependency Network** *What informs what*	**Needs Network** *What is needed to perform which task*
Task Relation				**Precedence Network** *Which tasks must be done before which tasks*

Note: The project manager is considered exogenous to this network as this position provides occasional consultation on an as needed basis, is not directly related to interdependencies between the positions, and does not directly contribute to the knowledge network. Therefore, the total number of positions in the analysis is 19.

Social Network – There are 19 positions in this Team X design session. The positions and seating layout are shown in Figure 2. This figure includes the project manager position that is exogenous to the analysis. The co-location of the group allows for communication to occur between any pair of positions.

Technology Network – This network consists of the position nodes and the technology nodes.

- Engineering tools – each position has their own engineering tool except for the systems engineer, facilitator and proposal manager.
- Publish/subscribe system – this database connects to each of the engineering tools and the systems engineer is directly responsible for maintaining this system for pre-session and session work.

Note: each of these tools have the ability to be broadcast onto any of the three large screens at the front of the room so that the entire group may see the display at the same time. The publish/subscribe system is almost always displayed on the center screen throughout the entire session. The left-side screen is dominated, with a few exceptions, by the configuration graphics from that respective engineer's tool. The right-side screen is dominated, again with a few exceptions, by the trajectory visualization from that respective engineer's tool.

Note: There is a database of past missions but this database does not seem to be used during the actual sessions. It is used during the pre-session work and some values in the publish/subscribe database are set according to data obtained from this tool.

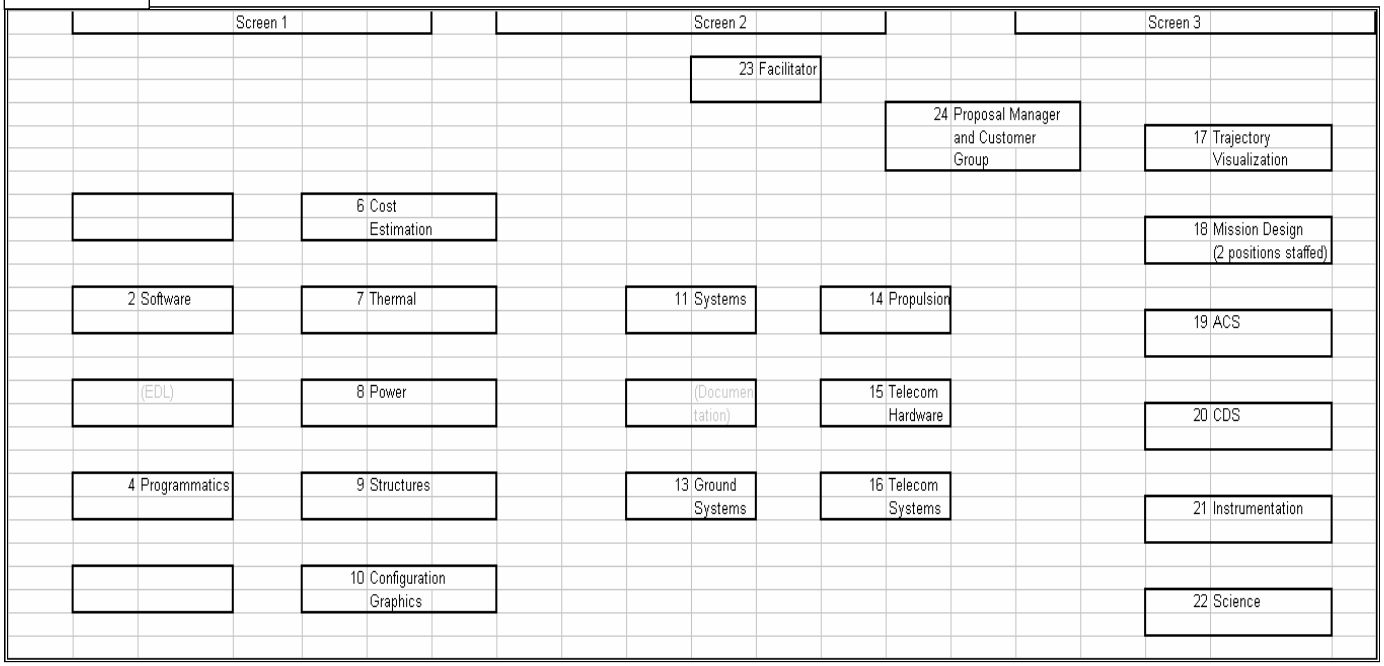
Operability Network – There are 17 engineering tools, the publish/subscribe system, database of past missions and 3 large screens for a total of 22 technologies. The engineering tools and the publish/subscribe system are in a star structure whereas the publish/subscribe database is the hub and each individual engineering tool is connected to the hub bi-directionally. Each of the engineering tools and the publish/subscribe system can send (one-way) to any of the 3 large screens. The database of past missions is stand-alone.

Knowledge Network – This network consists of the position nodes and the knowledge nodes. Knowledge is represented at a high level and is aggregated by position level because there is no low level detail on the knowledge breakdown within positions. The survey collects data on expertise level within 19 knowledge (position) areas. Expertise is rated on a four point scale (0 = none, 1 = beginner, 2 = intermediate, 3 = expert). Each knowledge area is represented by 3 bits. If a member was rated as having no knowledge of that area they receive 0's in all three bits. If a member was rated as either a beginner, intermediate or expert then they receive one, two or three 1's respectively.

Encoded Network – This network consists of the technology nodes and knowledge nodes. Each engineering tool has ties to its respective knowledge. The publish/subscribe system, database of past missions and the 3 large screens have access to all knowledge except for Proposal Mgmt. which is only in the database of past missions.

Interdependency Network – An approximation of the knowledge interdependencies was obtained from the survey data. Each knowledge area is represented by 3 bits and strength of dependency is shown by the number of bits receiving a 1. A strong dependency has a 1 in all three bits, a moderate dependency has a 1 in two of the three bits and so forth.

Figure 2



Assignment Network – This network consists of the position nodes and the task nodes Task is aggregated to the position level due to high level data. Each position is responsible for developing their respective subsystem and the facilitator has the task of overseeing the overall design.

Tool Network – This network consists of the technology nodes and the task nodes. Each subsystem position is linked to its respective engineering tool and all positions use the publish/subscribe system, database of past missions and the 3 large screens to accomplish their task.

Needs Network – This network consists of the knowledge nodes and the task nodes. An approximation of the interdependencies was obtained from the survey data. Each knowledge area is represented by 3 bits and strength of need is shown by the number of bits receiving a 1. A strong need has a 1 in all three bits, a moderate need has a 1 in two of the three bits and so forth.
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Precedence Network – There is no data in support of constructing this network.

2.2. ORA Analysis

The objective of ORA is to locate graph level and node level vulnerability. The following are high level interpretations of the results.

Graph level
The graph level measures indicate that Team X is optimally designed to perform their task.

Resource allocation risk
Team X has high congruency (resource = 1.0, knowledge = 0.7), low negotiation (resource = 0.0, knowledge = 0.9), low communicative need (0.0) and low redundancy (assignment = 0.0). These measures are characteristic of teams optimally designed around a particular task. A few of the high redundancy measures look to be anomalies and warrant explanation. Resource redundancy (4.9) is high due to many technological resources being shared – publish/subscribe system, broadcast screens and database of past missions. This redundancy is central to the communication and coordination of Team X and contributes to efficient performance. This measure is not considered detrimental. Access redundancy follows the same line of reasoning as resource redundancy. Knowledge redundancy (5.0) is high due to the understanding of other positions expertise and to the mental maps of the team and interdependencies. This is also essential to the performance of Team X and leads to the ability to integrate design. This measure is not considered detrimental.

Communication risk
Team X has small diameter (1.0), flat hierarchy (0.0), good efficiency (0.00) and high clustering (1.0). There is very minimal communication cost and information flow is rapid. These measures are characteristic of teams optimally designed around a particular task.

Task risk
The task risk measures are uninformative due to a lack of task definition and granularity.

Interpretation
Team X is tuned to high performance for their design task. Experience has shown that substantial improvements are difficult to realize when teams are so optimally designed. The cons to this type of design to task team is that these teams are usually not adaptive and do not perform well when faced with a new task. The tight clustering and rapid information flow mean that incorrect information can cascade through the network just as fast as correct information. Also, this type of team is prone to group think.

Overall Risk
It does not seem likely that Team X will be undertaking different tasks other than design so adaptability is not an issue. The structure of the group does promote information flow which can lead to increased error propagation if incorrect information is introduced and undetected.

Node level
The node level measures indicate several critical members of Team X. The following is a list of the top three members for each of the knowledge exclusivity, potential knowledge work load, actual knowledge workload and cognitive load measures.

knowledge exclusivity	potential knowledge workload	actual knowledge workload	cognitive load
4.5 (therm)	0.91 (therm)	0.048 (facil1)	0.23 (therm)
2.2 (facil1)	0.66 (system)	0.046 (therm)	0.20 (facil1)
1.8 (missn)	0.63 (facil1)	0.041 (system)	0.20 (system)

Interpretation
Thermal, facilitator 1 and systems consistently fall within the top three rankings of each measure. These three individuals are critical to knowledge acquisition and application. These results indicate that the team should protect against turnover of these individuals. Thermal is in the top ranking for three of the four measures. This indicates his unique and valuable expertise as well as the potential for this individual to emerge as a leader.

Traditional centrality measures
The traditional measures of centrality are not meaningful for this analysis due to the team being co-located and having the ability to directly communicate with each other.

Overall Risk
There is a critical employee turnover risk for Team X which has a reliance on key individuals. This turnover risk is associated with the risks of productivity and effectiveness as well as property and economic. This risk also poses a knowledge management challenge as loss of key expert knowledge or the inability to timely transfer knowledge due to only a few having the resource can impact performance negatively.

2.3. Construct Analysis

Two virtual experiments were run using the Team X revised version of Construct. The first experiment was motivated by observation of the Team X design sessions and tests to see if facilitator style has a tradeoff effect for point design and trade space exploration. The second experiment uses the ORA analysis of turnover risk as a basis for testing to see what effect the turnover of key individuals has on Team X.

2.3.a. Experiment 1 – Facilitator style tradeoff effect on point design and trade space exploration

Observations of the Team X design sessions indicate that facilitator management style varies greatly. The individual management styles may affect point design and trade space exploration differently.

Survey data collected from Team X was used to code to represent the individual management styles. The survey data used is as follows:

- Knowledge every team member has of each subsystem on a 4 point scale (none, beginner, intermediate, expert)
- Perception of the degree of task dependence each member has on other members. This is on a 4 point scale (none, little, moderate, enormous)

The network data on task dependency verifies that there is a difference in management style between the two facilitators. Figures 3 and 4 show the ties of strong (enormous) task dependence among Team X members when each facilitator is in charge. Figure 3 shows that team members have task dependency on facilitator 1 as the ties are directed to him. This demonstrates that facilitator 1 drives the Team X sessions and has a tighter control over the tasks and coordination. Figure 4 shows that facilitator 2 depends more on the team members as ties are directed to the team members. This demonstrates that facilitator 2 opens up the Team X sessions and decentralizes decisions more.

For purposes of the experiment the following two definitions are used:

– Point design – consensus decision making to converge knowledge and integrate design.
– Trade space exploration – exploration of an agents own position domain to make accurate decisions. This includes coordination with other position domains that are closely related.

Figure 3 – Task dependency network, Facilitator 1

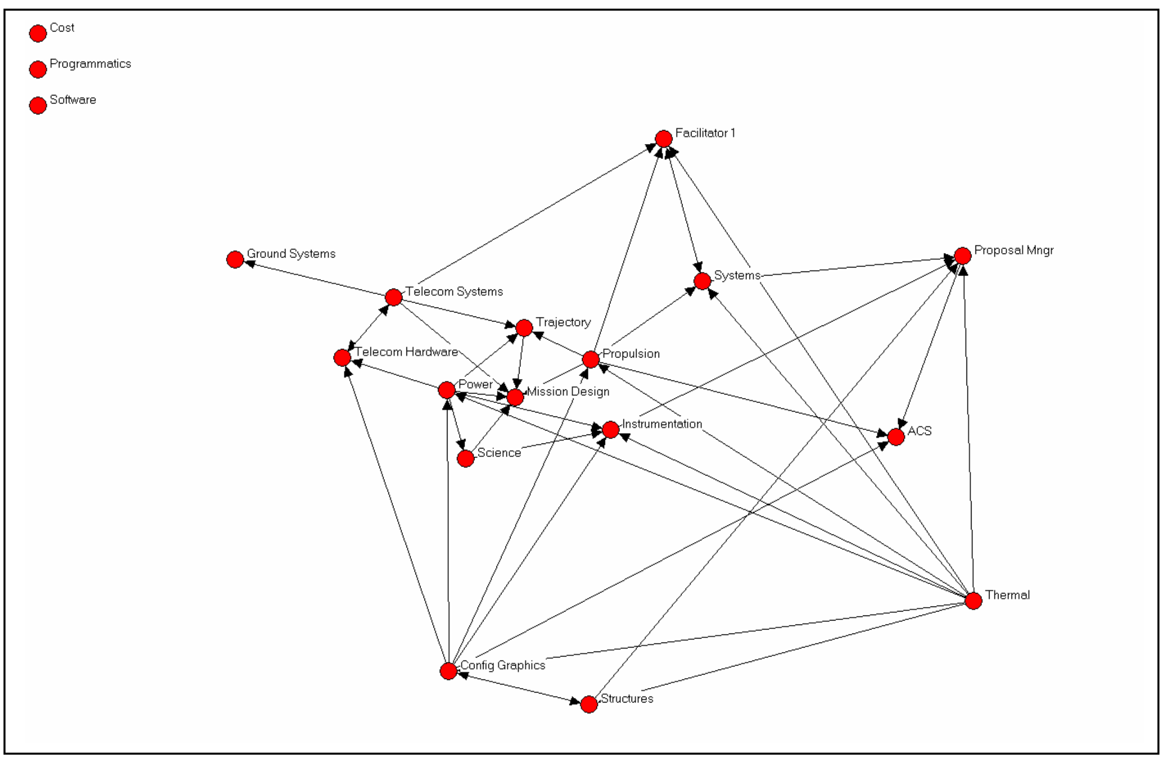


Figure 4 – Task dependency network, Facilitator 2

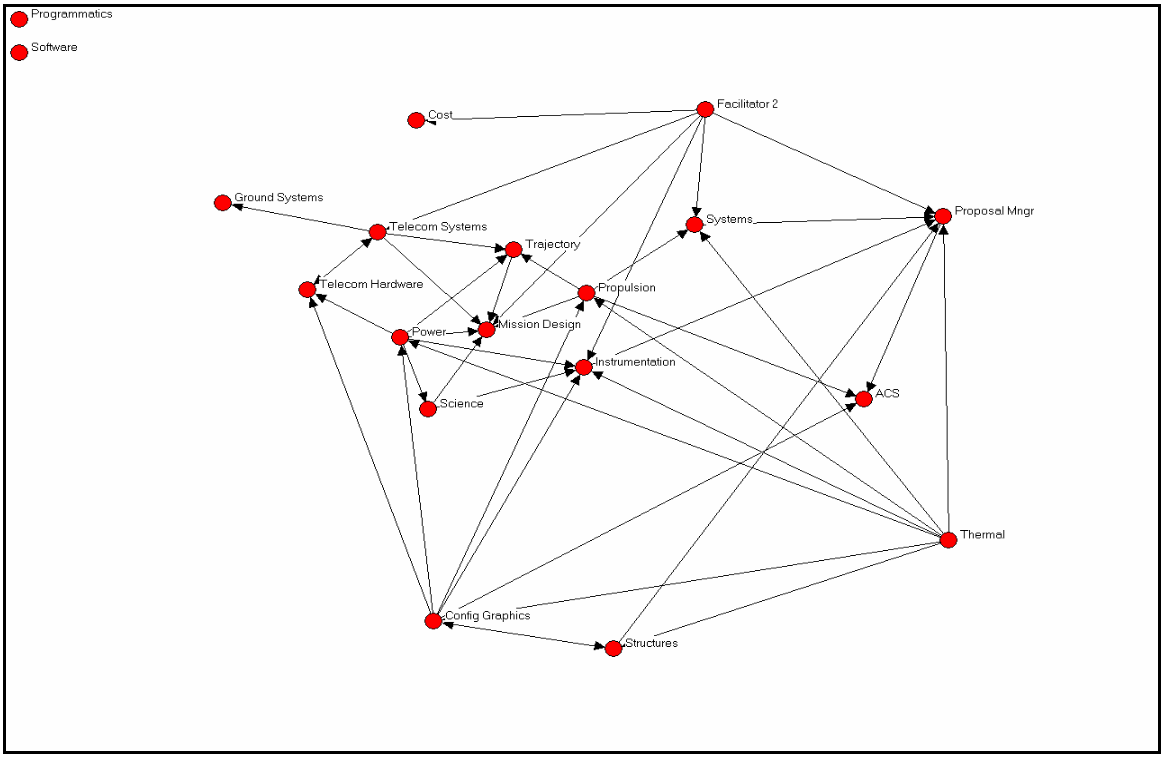


Figure 5

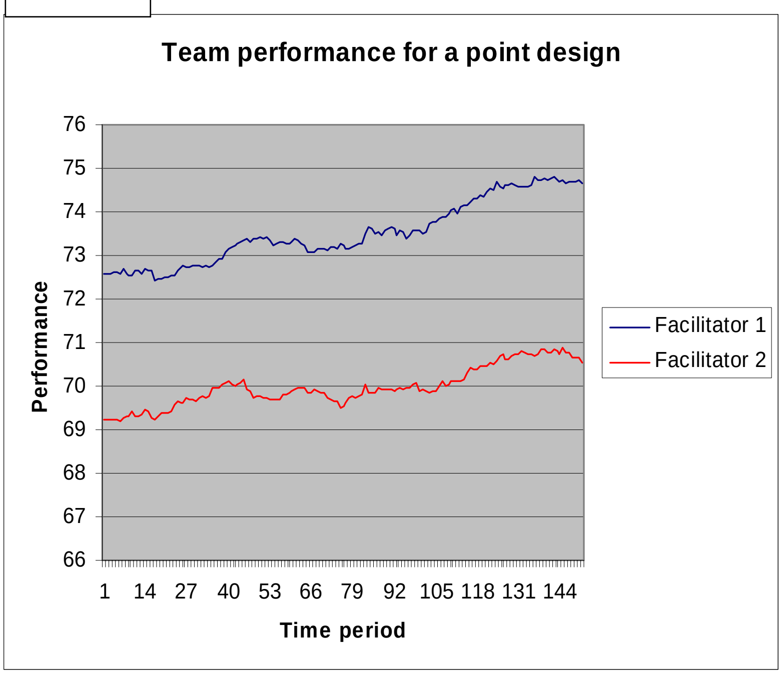
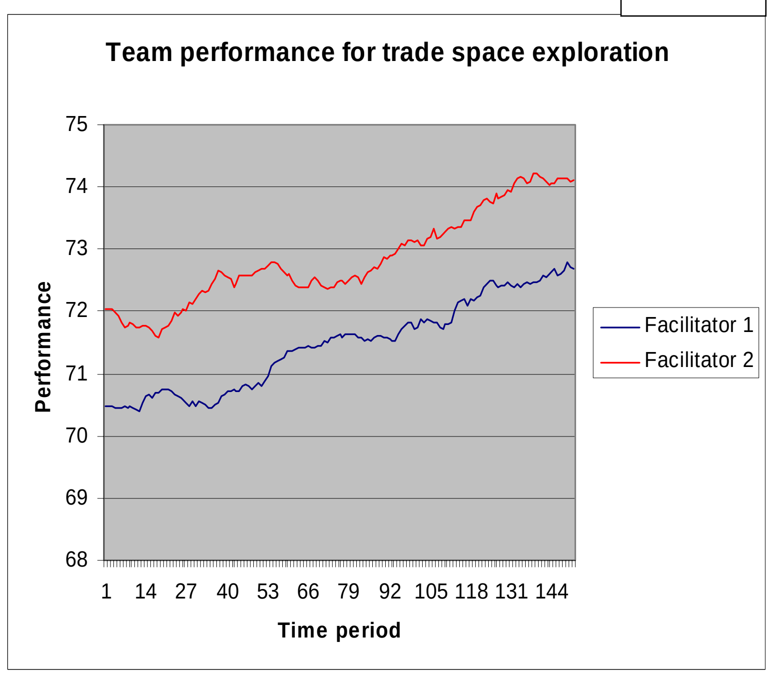


Figure 6



The knowledge and task dependency networks for each facilitator were input into construct and experiments run for the point design and trade space exploration objectives. Figure 5 shows the results for point design and Figure 6 shows the results for trade space exploration.

The results of the experiment show that facilitator 1 has a greater impact on the performance of a point design whereas facilitator 2 has a greater impact on the performance of trade space exploration. The management style of facilitator 1 drives the agents to come to consensus and converge the design. The management style of facilitator 2 lets the agents explore their space, which they are naturally inclined to do. The tradeoff here is productivity vs. effectiveness. From a risk perspective, management should be aware of this tradeoff and try to balance the two for optimal team performance that meets both time and safety goals. See Appendix C for additional information on experiment 1.

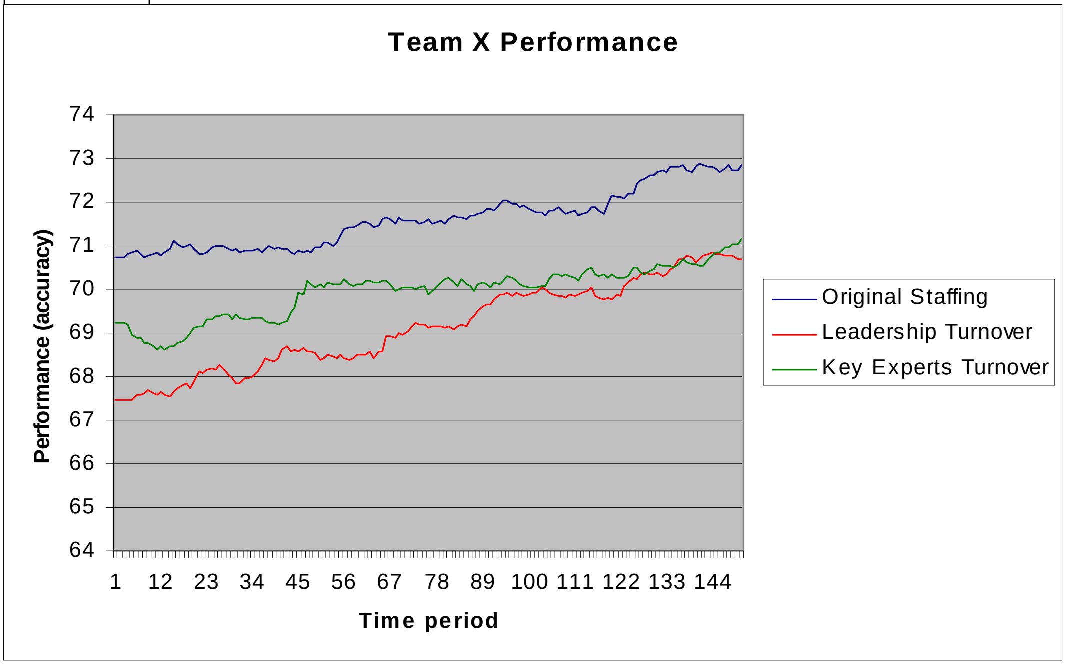
2.3.b. Experiment 2 – Turnover risk

A turnover risk experiment was run based in the identification of critical members from the ORA analysis above. The critical members are thermal, facilitator 1 and systems. Only facilitator 1 was used in these experiments. Facilitator 2 was not included. The survey data on the knowledge of every team member of each subsystem was used as input to Construct. Three conditions were run in this experiment:

1) Original CSSR staffing (baseline) – the exact knowledge base obtained from the survey was used.
2) Leadership change – the knowledge of the facilitator 1 reduced to average, lowering the expertise level. This represents someone with limited experience taking the role. All other staffing and knowledge base representations remained as they were for the CSSR staffing.
3) Key experts change – the knowledge of the thermal person and the systems person were reduced to average, lowering the expertise level. This represents people with limited experience staffing these positions. All other staffing and knowledge base representations remained as they were for the CSSR staffing including facilitator 1 – there is no leadership change.

Figure 7 shows the results of the experiment. Team X relies heavily on key expert personnel. The performance under conditions 2 and 3 are much worse than the baseline demonstrating that a leadership change or a key experts change will negatively impact the team. The loss of facilitator 1 poses the most risk to Team X performance. The decrease in performance for condition 1 was more than the decrease shown for condition 2. This is meaningful since there was a change in only one position for condition 1 as compared to a change in two positions for condition 2. It is also surprising given that thermal was highest ranking in three of the four knowledge measures in ORA. The results demonstrate the importance of leadership in this environment. As stated in the ORA analysis, the turnover of key members poses productivity, effectiveness, property and economic risk and a knowledge management challenge. See Appendix C for additional information on experiment 2.

Figure 7



3. General Observations and Recommendations for Team X

Recommendations are made based on general observation as well as ORA and Construct results. Appendix D contains more detail on the general observations and recommendations.

3.1. General Observations

Team X has created a successful concurrent engineering process. This team is optimally designed to perform the task of mission design. Team X uses a mixture of multifunctional teams, computer integration and analytic methods to achieve concurrency and integration. Integration methods such as co-location and information systems are appropriate as the environment has functional differentiation, cross-functional requirements, uncertainty, complexity and frequent two-way information flow. The matrix structure of the organization is congruent with a concurrent engineering team and the culture of Team X is highly supportive of the process.

3.2. Recommendations

- Create handover procedures
- Increase trade space exploration
- Increase documentation

- Develop a measure of risk based on design changes
- Create a mentoring program for the facilitator position
- Create publish/subscribe system error checking routine

3.2.a Create handover procedures

Observation concluded that hand-over to a position substitute in a member's absence is inadequate. The substitute spent a substantial amount of time gaining understanding of the situation. The Team X design session has a limited time frame. The lack of hand-over poses a productivity risk and effectiveness risk and is a knowledge management challenge.

Recommended procedures should include:

- Absentee spending extra time at the end of their last session preparing material for the substitute
- Material distribution to the substitute well prior to the session they will attend

3.2.b. Increase trade space exploration

Trade space exploration is limited to time constraint. Interviews indicate that design changes are often made in later phases and that cost differentials are a criticism. The lack of trade space exploration presents effectiveness and social risks.

Recommend increasing subsystem input into the pre-session phase to infuse knowledge and explore more space prior to the sessions. Pre-session phase is recommended because there is a productivity and effectiveness tradeoff within the session (see Construct results, Experiment 1).

3.2.c. Increase documentation

Interviews indicate that a large variance by position exists in the documentation of decision rationale. It is believed that documentation is open-ended. This can pose a risk at the team and individual level. The associated risks are productivity, effectiveness, professional and social. This is a major knowledge management challenge.

Recommend using a question format for documentation to provide a framework for increasing the input. Also, documenting the existence of unexplored trade space may help protect against later criticisms.

3.2.d. Develop a measure of risk based on design changes

Track the frequency and severity of design changes by subsystem and also aggregate the changes into a system measure. The measures are an indicator of risk and uncertainty by subsystem design and overall design, especially for effectiveness risk

3.2.e. Create a mentoring program for the facilitator position

ORA and Construct Experiment 2 results show that the facilitator is a critical member of the organization and there is a substantial turnover risk for this position. There are productivity, effectiveness, property and economic risks associated with facilitator turnover.

Recommend creating a mentoring program to develop experience and system-wide expertise. Carefully select people who have a potential for leadership, people skills and the ability to see the broader systems view. Certain subsystem positions have a propensity for developing system-wide knowledge – examples are Systems Engineer, Thermal.

3.2.f. Create a publish/subscribe system error checking routine

It was observed that many values were questioned for recency during the run-through of the systems worksheet at the end of each session. Assuming all design calculations are correct there are two errors that can occur – a member forgets to publish and a member forgets to subscribe. These errors may go undetected due to the high complexity of the task and the limits of human attention and memory. This poses an effectiveness risk.

Recommend creating a routine to compare the systems worksheets values to the respective subsystems values and report discrepancies. The computer can easily detect these errors and appropriate attention can then be given to correcting them.

4. HORM Next Steps

The modeling and analysis has mainly concentrated on Team X. Some preliminary information gathering has occurred on NASA ISS mission control by way of interview of an expert. Model changes made for Team X should be applicable to the other NASA teams, namely VIPeR and ISS mission control. For example, sidebars can occur in VIPeR and ISS mission control and the broadcast technologies are in use for ISS mission control. Modeling of the VIPeR and ISS mission control teams will provide secondary validation for the modeling changes already made. The next steps include expanding the Team X model as well as beginning the first iteration models for VIPeR and ISS mission control. Appendix E contains more information about the HORM next steps.

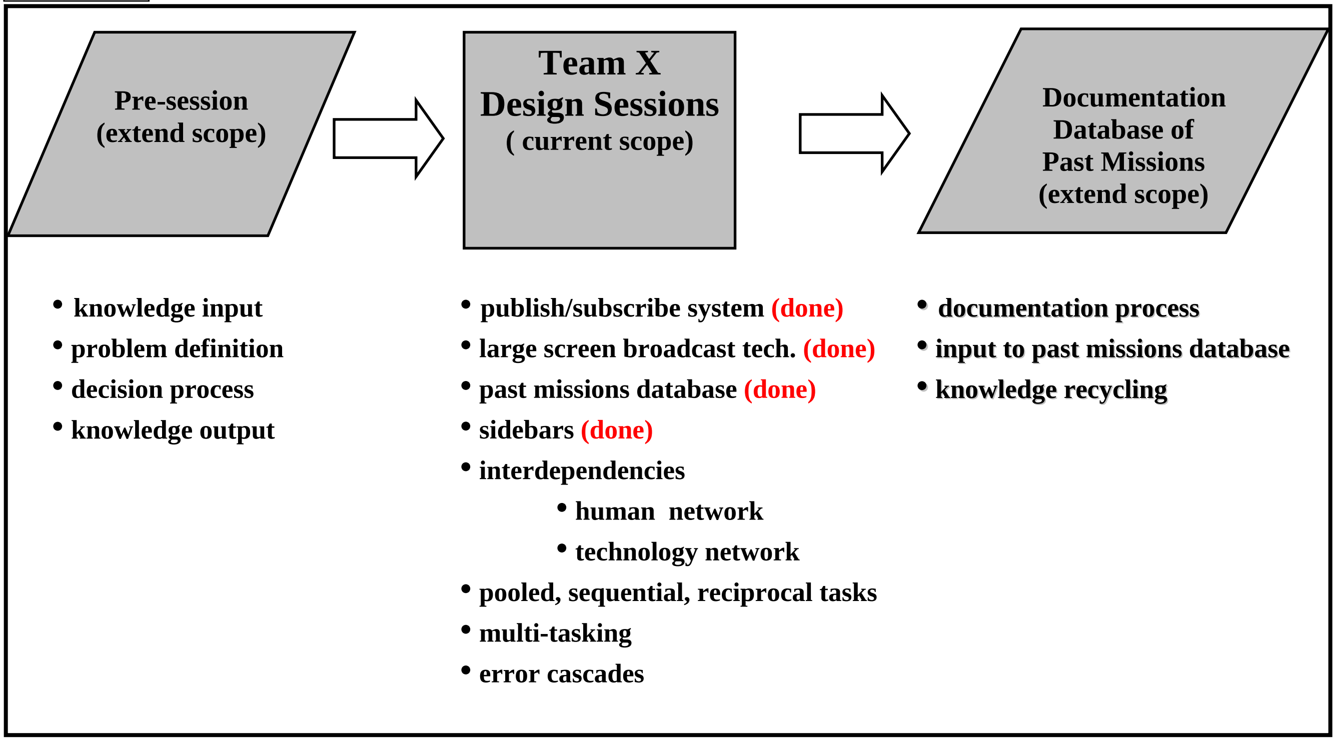
4.1. Expansion of the Team X Model

The next steps for the Team X representation include a more in-depth modeling of the design sessions as well as expanding the scope of the model to include pre-session and post-session analysis. Figure 8 provides an overview of the Team X modeling effort.

Team X Design Sessions

The phase II model design will implement representations of the human and technological network interdependencies, pooled/sequential/reciprocal tasks, multi-tasking and error cascades. This phase will add granularity to the model which allows for more specified analysis of organizational risk drivers. This will require additional interview, survey and observational data.

Figure 8



Pre-session
This expansion of scope will involve preliminary investigation and data collection to understand the pre-session process and how it feeds into the actual design session. Specific understanding of the pre-session inputs and outputs, problem definition and decision processes needs to be obtained. It is obvious that decisions made in the pre-session have an influence on the actual design sessions. Risk analysis would not be complete if it does not capture the pre-session process and the respective relationship to the design sessions. This expansion in scope will be best accomplished through observation, interview and survey data collection. The grounded theory approach worked well for the phase I data collection and design and is recommended here.

Post-session
The post-session is another expansion in scope and concentrates on the documentation process. The main objective is to understand how design session knowledge becomes archived and re-used in future design sessions (knowledge recycling). Modeling this piece of the knowledge management process is important to risk analysis. There may be organizational learning opportunities that are missed and existing knowledge that is not utilized. Again, the grounded theory approach is recommended.

4.2. Begin VIPeR Team Model

The following is an outline of the tasks to complete the first iteration of the VIPeR team model:

- Before SimStation introduction

    - Observation and Interviews – necessary to gain adequate understanding of the team and processes (team composition, knowledge distribution and transfer, coordination, etc…)
    - Demo of SimStation – understand:
        - Knowledge contained within
        - Interdependence mapping
        - Human interface and other methods of knowledge transfer
    - Data from SimStation and Risk surveys
- After SimStation introduction
    - Observation and Interviews – understand how the team processes have changed
    - Data from SimStation and Risk surveys
- Virtual Experiments
    - Simulate the effects of SimStation
    - Knowledge management experiments based on the team distribution of knowledge including system-wide experts
    - Team productivity and effectiveness
    - Collaboration and coordination strategies
- Use Before and After data to validate model

4.3. Begin ISS Mission Control Model

The following is an outline of the tasks to complete the first iteration of the ISS mission control model:

- Observation and Interviews – necessary to gain adequate understanding of the team and processes (team composition, knowledge distribution and transfer, dynamic and real-time environment, coordination, etc…)
    - Handover process is crucial
        - Change in team size and composition
        - Documentation process
        - Methods of knowledge transfer
    - Controller attrition rates
- Data from Risk survey
- Virtual Experiments
    - Reduced team and handover
    - Turnover
    - Knowledge management experiments based on the team distribution of knowledge
    - Team productivity and effectiveness
    - Collaboration and coordination strategies

Appendix A

Codebook information for Your Dependencies (udep)

Question 1 (of 22)

Your Work Dependency

Please indicate the degree to which you **directly depend on** Team X member(s) to complete **your work** by clicking in the circle and then responding to the questions in the pop-up windows.

When all questions have been answered, the pop-up window will disappear. If you would like to change any of your responses you can click on the person's name that you would like to adjust and then follow the new pop-up window.

There are 21 columns in matrix, labeled 'udep_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- No Response
2 -- I Don't Know
3 -- None
4 -- A Little Amount
5 -- A Moderate Amount
6 -- An Enormous Amount

Codebook information for Others' Dependencies (otdep)

Question 2 (of 22)

Others' Work Dependency

Please indicate the degree to which others directly depend on your work to complete **their work** by clicking in the circle and then following the pop-up windows.

When all questions have been answered, the pop-up window will disappear. If you would like to change any of your responses you can click on the person's name that you would like to adjust and then follow the new pop-up window.

There are 21 columns in matrix, labeled 'otdep_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- No Response
2 -- I Don't Know
3 -- None
4 -- A Little Amount
5 -- A Moderate Amount
6 -- An Enormous Amount

Codebook information for Group Use of Information (tm)

Question 3 (of 22)

The following items concern how knowledge is utilized in Team X.
Please indicate the extent to which you agree or disagree with each of the following statements.

There are 12 columns in matrix, labeled 'tm_x', where x is:
0 -- Most of my work is done independently.
1 -- Members of Team X have a lot of overlapping knowledge.

2 -- Each member has unique knowledge that they bring to our group.
3 -- I depend very much on the expertise of other members of Team X in order to do my job.
4 -- I depend very much on the expertise of other people outside Team X in order to do my job.
5 -- I work very closely with other Team X members.
6 -- I know a lot about the expertise of Team X members.
7 -- Team X members know a lot about my expertise.
8 -- Team X members know a lot about one another's expertise.
9 -- My group coordinates knowledge well.
10 -- Each member of Team X has a specialized role.
11 -- Members of Team X have interchangeable roles.

The range of each of these columns is:
0 -- No Response
1 -- I Don't Know
2 -- Strongly Disagree
3 -- Disagree
4 -- Neither
5 -- Agree
6 -- Strongly Agree

Codebook information for kndg1 (ko1)

Question 4 (of 22)

With respect to the CSSR mission, what level of knowledge do you think the members of Team X (including yourself) have in each of the Team X positions?

Click in the middle of the circle on the adjacent screen and a small window will pop up. Please respond to the questions in the pop-up window to select what level of knowledge each position in Team X has in each knowledge area. Click on the box you think represents that position's level of knowledge.

When you have responded for all positions, the pop-up window will disappear.

After this is completed, you will have the opportunity to change your answers. Select a token under the name of the position that you want to adjust such that the color corresponds to the knowledge area that you wish to change. Then, simply follow the pop-up window.

There are 84 columns in the matrix, labeled 'ko1_x_y', where x corresponds to the id of the actor being ranked, and y is:
0 -- ACS
1 -- Configuration Graphics
2 -- Cost Estimation
3 -- Facilitation

The range of each of these columns is:
0 -- -
1 -- I don't know
2 -- None
3 -- Beginner
4 -- Intermediate
5 -- Expert

Codebook information for kndg2 (ko2)

Question 5 (of 22)

With respect to the CSSR mission, what level of knowledge do you think the members of Team X (including yourself) have in each of the Team X positions?

After you complete this set, you will have the opportunity to change your answers. Select a token under the name of the position that you want to adjust such that the color corresponds to the knowledge area that you wish to change. Then, simply follow the pop-up window.

There are 105 columns in the matrix, labeled 'ko2_x_y', where x

corresponds to the id of the actor being ranked, and y is:
0 -- Ground Systems
1 -- Instrumentation
2 -- Mission Design
3 -- Power
4 -- Programmatics

The range of each of these columns is:
0 -- -
1 -- I don't know
2 -- None
3 -- Beginner
4 -- Intermediate
5 -- Expert

Codebook information for kndg3 (ko3)

Question 6 (of 22)

With respect to the CSSR mission, what level of knowledge do you think the members of Team X (including yourself) have in each of the Team X positions?

After you complete this set, you will have the opportunity to change your answers. Select a token under the name of the position that you want to adjust such that the color corresponds to the knowledge area that you wish to change. Then, simply follow the pop-up window.

There are 105 columns in the matrix, labeled 'ko3_x_y', where x corresponds to the id of the actor being ranked, and y is:
0 -- Proposal Management
1 -- Propulsion
2 -- Science
3 -- Software
4 -- Structures

The range of each of these columns is:
0 -- -
1 -- I don't know
2 -- None
3 -- Beginner
4 -- Intermediate
5 -- Expert

Codebook information for kndg4 (ko4)

Question 7 (of 22)

With respect to the CSSR mission, what level of knowledge do you think the members of Team X (including yourself) have in each of the Team X positions?

After you complete this set, you will have the opportunity to change your answers. Select a token under the name of the position that you want to adjust such that the color corresponds to the knowledge area that you wish to change. Then, simply follow the pop-up window.

There are 105 columns in the matrix, labeled 'ko4_x_y', where x corresponds to the id of the actor being ranked, and y is:
0 -- Systems
1 -- Telecom Hardware
2 -- Telecom Systems
3 -- Thermal
4 -- Trajectory

The range of each of these columns is:
0 -- -
1 -- I don't know
2 -- None
3 -- Beginner

4 -- Intermediate
5 -- Expert

Codebook information for Getting Information About ACS (cri_a)

Question 8a (of 22)

Getting Information About ACS

In your work for the CSSR mission, you may need information about **ACS** that you do not possess. Using the adjacent screen, please indicate one or more person(s) from whom you are likely to **retrieve information** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

These are the instructions for questions 8a-8s.

There are 21 columns in matrix, labeled 'cri_a_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Configuration Graphics (cri_b)

Question 8b (of 22)

Getting Information About Configuration Graphics

Please indicate from whom you are likely to **retrieve information** about **Configuration Graphics** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_b_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Cost Estimation (cri_c)

Question 8c (of 22)

Getting Information About Cost Estimation

Please indicate from whom you are likely to **retrieve information** about **Cost Estimation** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_c_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Facilitation (cri_d)

Question 8d (of 22)

Getting Information About Facilitation

Please indicate from whom you are likely to **retrieve information** about **Facilitation** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_d_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Ground Systems (cri_e)

Question 8e (of 22)

Getting Information About Ground Systems

Please indicate from whom you are likely to **retrieve information** about **Ground Systems** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_e_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -

1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Instrumentation (cri_f)

Question 8f (of 22)

Getting Information About Instrumentation

Please indicate from whom you are likely to **retrieve information** about **Instrumentation** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_f_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Mission Design (cri_g)

Question 8g (of 22)

Getting Information About Mission Design

Please indicate from whom you are likely to **retrieve information** about **Mission Design** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_g_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Power (cri_h)

Question 8h (of 22)

Getting Information About Power

Please indicate from whom you are likely to **retrieve information** about **Power** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_h_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Programmatics (cri_i)

Question 8i (of 22)

Getting Information About Programmatics

Please indicate from whom you are likely to **retrieve information** about **Programmatics** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_i_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Proposal Management (cri_j)

Question 8j (of 22)

Getting Information About Proposal Management

Please indicate from whom you are likely to **retrieve information** about **Proposal Management** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_j_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Propulsion (cri_k)

Question 8k (of 22)

Getting Information About Propulsion

Please indicate from whom you are likely to **retrieve information** about **Propulsion** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_k_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less

6 -- More than 20 times per day

Codebook information for Getting Information About Science (cri_l)

Question 8l (of 22)

Getting Information About Science

Please indicate from whom you are likely to **retrieve information** about **Science** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_l_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Software

(cri_m)

Question 8m (of 22)

Getting Information About Software

Please indicate from whom you are likely to **retrieve information** about **Software** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_m_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Structures (cri_n)

Question 8n (of 22)

Getting Information About Structures

Please indicate from whom you are likely to **retrieve information** about **Structures** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_n_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Systems (cri_o)

Question 8o (of 22)

Getting Information About Systems

Please indicate from whom you are likely to **retrieve information** about **Systems** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_o_x', where x is the id of the

user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Telecom Hardware (cri_p)

Question 8p (of 22)

Getting Information About Telecom Hardware

Please indicate from whom you are likely to **retrieve information** about **Telecom Hardware** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_p_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less

4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Telecom Systems (cri_q)

Question 8q (of 22)

Getting Information About Telecom Systems

Please indicate from whom you are likely to **retrieve information** about **Telecom Systems** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_q_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Thermal (cri_r)

Question 8r (of 22)

Getting Information About Thermal

Please indicate from whom you are likely to **retrieve information** about **Thermal** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_r_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Getting Information About Trajectory Visualization (cri_s)

Question 8s (of 22)

Getting Information About Trajectory Visualization

Please indicate from whom you are likely to **retrieve information** about **Trajectory Visualization** by clicking in the circle and responding to the questions in the pop-up window.

You will have the opportunity to change your answers by selecting the name of the position that you want to adjust and then, simply follow the pop-up window.

There are 21 columns in matrix, labeled 'cri_s_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Incoming information (infu)

Question 9 (of 22)

Please indicate how frequently you **receive unrequested information** about each area.

There are 19 columns in matrix, labeled 'infu_x', where x is:
0 -- ACS
1 -- Configuration Graphics
2 -- Cost Estimation
3 -- Facilitation
4 -- Ground Systems

5 -- Instrumentation
6 -- Mission Design
7 -- Power
8 -- Programmatics
9 -- Proposal Management
10 -- Propulsion
11 -- Science
12 -- Software
13 -- Structures
14 -- Systems
15 -- Telecom Hardware
16 -- Telecom Systems
17 -- Thermal
18 -- Trajectory Visualization

The range of each of these columns is:
0 -- No Response
1 -- I Don't Know
2 -- Never
3 -- Seldom
4 -- Sometimes
5 -- Often
6 -- Very Often

Codebook information for Providing Information About ACS (cai_a)

Question 10a (of 22)

Providing Information About ACS

In your work for the CSSR mission, you may receive or create information about **ACS**. Using the adjacent screen, please indicate one or more group members to whom you are likely to **provide**

unrequested information about **ACS** by clicking in the circle and then responding to the questions in the pop-up window.

These are the instructions for questions 10a-10s.

There are 21 columns in matrix, labeled 'cai_a_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Configuration Graphics (cai_b)

Question 10b (of 22)

Providing Information About Configuration Graphics

Please indicate to whom you are likely to **provide unrequested information** about **Configuration Graphics** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_b_x', where x is the id of the user this relates to.

The range of each of these columns is:

0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Cost Estimation (cai_c)

Question 10c (of 22)

Providing Information About Cost Estimation

Please indicate to whom you are likely to **provide unrequested information** about **Cost Estimation** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_c_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Facilitation (cai_d)

Question 10d (of 22)

Providing Information About Facilitation

Please indicate to whom you are likely to **provide unrequested information** about **Facilitation** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_d_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Ground Systems (cai_e)

Question 10e (of 22)

Providing Information About Ground Systems

Please indicate to whom you are likely to **provide unrequested information** about **Ground Systems** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_e_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Instrumentation (cai_f)

Question 10f (of 22)

Providing Information About Instrumentation

Please indicate to whom you are likely to **provide unrequested information** about **Instrumentation** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_f_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know

2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Mission Design (cai_g)

Question 10g (of 22)

Providing Information About Mission Design

Please indicate to whom you are likely to **provide unrequested information** about **Mission Design** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_g_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Power (cai_h)

Question 10h (of 22)

Providing Information About Power

Please indicate to whom you are likely to **provide unrequested information** about **Power** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_h_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Programmatics (cai_i)

Question 10i (of 22)

Providing Information About Programmatics

Please indicate to whom you are likely to **provide unrequested information** about **Programmatics** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_i_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Proposal Management (cai_j)

Question 10j (of 22)

Providing Information About Proposal Management

Please indicate to whom you are likely to **provide unrequested information** about **Proposal Management** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_j_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never

3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Propulsion (cai_k)

Question 10k (of 22)

Providing Information About Propulsion

Please indicate to whom you are likely to **provide unrequested information** about **Propulsion** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_k_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Science

(cai_l)

Question 10l (of 22)

Providing Information About Science

Please indicate to whom you are likely to **provide unrequested information** about **Science** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_l_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Software (cai_m)

Question 10m (of 22)

Providing Information About Software

Please indicate to whom you are likely to **provide unrequested information** about **Software** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_m_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Structures (cai_n)

Question 10n (of 22)

Providing Information About Structures

Please indicate to whom you are likely to **provide unrequested information** about **Structures** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_n_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less

5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Systems (cai_o)

Question 10o (of 22)

Providing Information About Systems

Please indicate to whom you are likely to **provide unrequested information** about **Systems** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_o_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Telecom Hardware (cai_p)

Question 10p (of 22)

Providing Information About Telecom Hardware

Please indicate to whom you are likely to **provide unrequested information** about **Telecom Hardware** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_p_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Telecom Systems (cai_q)

Question 10q (of 22)

Providing Information About Telecom Systems

Please indicate to whom you are likely to **provide unrequested information** about **Telecom Systems** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_q_x', where x is the id of the

user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Thermal (cai_r)

Question 10r (of 22)

Providing Information About Thermal

Please indicate to whom you are likely to **provide unrequested information** about **Thermal** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_r_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Providing Information About Trajectory Visualization (cai_s)

Question 10s (of 22)

Providing Information About Trajectory Visualization

Please indicate to whom you are likely to **provide unrequested information** about **Trajectory Visualization** by clicking the middle of the circle and responding to the questions in the pop-up window.

There are 21 columns in matrix, labeled 'cai_s_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Frequency of Communication (fc)

Question 11 (of 22)

Communication

Other than for allocating and retrieving information, how often do you communicate with members of Team X either via telephone, email, or face-to-face?

Click in the middle of the circle and follow the prompts in the pop-up windows.

When all questions have been answered, the pop-up window will disappear.

If you would like to change any of your responses, please click on the name of the person and respond to the pop-up window.

There are 21 columns in matrix, labeled 'fc_x', where x is the id of the user this relates to.

The range of each of these columns is:
0 -- -
1 -- I do not know
2 -- Never
3 -- 5 times per day or less
4 -- 10 times per day or less
5 -- 20 times per day or less
6 -- More than 20 times per day

Codebook information for Minutes During (mndur)

Question 12 (of 22)

For all of the time you have spent on the CSSR mission, how much time did you spend in **scheduled project related discussions** (during design sessions) in groups with more than two Team X members?

There are 2 columns in matrix, labeled 'mndur_x', where x is:

0 -- Hours
1 -- Minutes (approximate)

The range of each of these columns is:
0 -- No Response
1 -- I Don't Know
2 --
3 -- 0
4 -- 1
5 -- 2
6 -- 3
7 -- 4
8 -- 5
9 -- 6
10 -- 7
11 -- 8
12 -- 9
13 -- 10
14 -- 11
15 -- 12
16 -- 13
17 -- 14
18 -- 15
19 -- 16
20 -- 17
21 -- 18
22 -- 19
23 -- 20
24 -- 21
25 -- 22
26 -- 23
27 -- 24
28 -- 25
29 -- 26
30 -- 27
31 -- 28
32 -- 29

33 -- 30
34 -- 31
35 -- 32
36 -- 33
37 -- 34
38 -- 35
39 -- 36
40 -- 37

Codebook information for Minutes Outside (mnout)

Question 13 (of 22)

For all of the time you have spent on the CSSR mission, how much time did you spend in **unscheduled project related discussions** (outside design sessions) in sidebars, email, or person-to-person conversations?

There are 2 columns in matrix, labeled 'mnout_x', where x is:
0 -- Hours
1 -- Minutes (approximate)

The range of each of these columns is:
0 -- No Response
1 -- I Don't Know
2 --
3 -- 0
4 -- 1
5 -- 2
6 -- 3
7 -- 4
8 -- 5
9 -- 6
10 -- 7

11 -- 8
12 -- 9
13 -- 10
14 -- 11
15 -- 12
16 -- 13
17 -- 14
18 -- 15
19 -- 16
20 -- 17
21 -- 18
22 -- 19
23 -- 20
24 -- 21
25 -- 22
26 -- 23
27 -- 24
28 -- 25
29 -- 26
30 -- 27
31 -- 28
32 -- 29
33 -- 30
34 -- 31
35 -- 32
36 -- 33
37 -- 34
38 -- 35
39 -- 36
40 -- 37

Codebook information for Direct Minutes (drect)

Question 14 (of 22)

For all of the time you have spent on the CSSR mission, how much time did you spend doing **direct work**. Direct work is any planned work outside of pre-sessions and design sessions that does not involve coordination with teammates?

There are 2 columns in matrix, labeled 'drect_x', where x is:
0 -- Hours
1 -- Minutes (approximate)

The range of each of these columns is:
0 -- No Response
1 -- I Don't Know
2 --
3 -- 0
4 -- 1
5 -- 2
6 -- 3
7 -- 4
8 -- 5
9 -- 6
10 -- 7
11 -- 8
12 -- 9
13 -- 10
14 -- 11
15 -- 12
16 -- 13
17 -- 14
18 -- 15
19 -- 16
20 -- 17
21 -- 18
22 -- 19
23 -- 20
24 -- 21
25 -- 22

26 -- 23
27 -- 24
28 -- 25
29 -- 26
30 -- 27
31 -- 28
32 -- 29
33 -- 30
34 -- 31
35 -- 32
36 -- 33
37 -- 34
38 -- 35
39 -- 36
40 -- 37

Codebook information for Rework Time (rewrk)

Question 15 (of 22)

For all of the time you have spent on the CSSR mission, how much time did you spend doing **rework**. Rework is direct work that you do a second (or subsequent time) because assumptions became invalid or new decisions were made by another position?

There are 2 columns in matrix, labeled 'rewrk_x', where x is:
0 -- Hours
1 -- Minutes (approximate)

The range of each of these columns is:
0 -- No Response
1 -- I Don't Know
2 --
3 -- 0

4 -- 1
5 -- 2
6 -- 3
7 -- 4
8 -- 5
9 -- 6
10 -- 7
11 -- 8
12 -- 9
13 -- 10
14 -- 11
15 -- 12
16 -- 13
17 -- 14
18 -- 15
19 -- 16
20 -- 17
21 -- 18
22 -- 19
23 -- 20
24 -- 21
25 -- 22
26 -- 23
27 -- 24
28 -- 25
29 -- 26
30 -- 27
31 -- 28
32 -- 29
33 -- 30
34 -- 31
35 -- 32
36 -- 33
37 -- 34
38 -- 35
39 -- 36
40 -- 37

Codebook information for Inside retrieval (insde)

Question 16 (of 22)

How frequently did you retrieve information from each of these sources **during** the Team X CSSR sessions?

There are 7 columns in matrix, labeled 'insde_x', where x is:
0 -- From other person(s) inside Team X (besides customer group)
1 -- From customer group
2 -- From other person(s) outside of Team X
3 -- From published and subscribed database
4 -- From database of past missions
5 -- From a public display
6 -- From other sources

The range of each of these columns is:
0 -- No Response
1 -- I don't know
2 -- Low
3 -- Medium
4 -- High

Codebook information for Outside retrieval (outsde)

Question 17 (of 22)

How frequently did you retrieve information from each of these sources **outside** of the Team X session for CSSR mission (that is, prior to or after design sessions)?

There are 7 columns in matrix, labeled 'outsde_x', where x is:
0 -- From other person(s) inside Team X (besides customer group)
1 -- From customer group
2 -- From other person(s) outside of Team X
3 -- From published and subscribed database
4 -- From database of past missions
5 -- From a public display
6 -- From other sources

The range of each of these columns is:
0 -- No Response
1 -- I don't know
2 -- Low
3 -- Medium
4 -- High

Codebook information for Years Worked, Company (jplyrs)

Question 18 (of 22)

How long have you worked at **JPL**?

There are 3 columns in matrix, labeled 'jplyrs_x', where x is:
0 -- Years
1 -- Months
2 -- Weeks

The range of each of these columns is:
-3 -- No Response
-2 -- I Don't Know

-1 --
0 -- 0
1 -- 1
2 -- 2
3 -- 3
4 -- 4
5 -- 5
6 -- 6
7 -- 7
8 -- 8
9 -- 9
10 -- 10
11 -- 11
12 -- 12
13 -- 13
14 -- 14
15 -- 15
16 -- 16
17 -- 17
18 -- 18
19 -- 19
20 -- 20
21 -- 21
22 -- 22
23 -- 23
24 -- 24
25 -- 25
26 -- 26
27 -- 27
28 -- 28
29 -- 29
30 -- 30
31 -- 31
32 -- 32
33 -- 33
34 -- 34
35 -- 35

36 -- 36
37 -- 37
38 -- 38
39 -- 39
40 -- 40

Codebook information for Years Worked, Dep (tmxyrs)

Question 19 (of 22)

How long have you worked for JPL in **Team X**?

There are 3 columns in matrix, labeled 'tmxyrs_x', where x is:
0 -- Years
1 -- Months
2 -- Weeks

The range of each of these columns is:
-3 -- No Response
-2 -- I Don't Know
-1 --
0 -- 0
1 -- 1
2 -- 2
3 -- 3
4 -- 4
5 -- 5
6 -- 6
7 -- 7
8 -- 8
9 -- 9
10 -- 10

11 -- 11
12 -- 12
13 -- 13
14 -- 14
15 -- 15
16 -- 16
17 -- 17
18 -- 18
19 -- 19
20 -- 20
21 -- 21
22 -- 22
23 -- 23
24 -- 24
25 -- 25
26 -- 26
27 -- 27
28 -- 28
29 -- 29
30 -- 30
31 -- 31
32 -- 32
33 -- 33
34 -- 34
35 -- 35
36 -- 36
37 -- 37
38 -- 38
39 -- 39
40 -- 40

Codebook information for Years Worked, Position (nasayr)

Question 20 (of 22)

If you have worked at other NASA centers, please estimate how long have you worked there?

There are 3 columns in matrix, labeled 'nasayr_x', where x is:
0 -- Years
1 -- Months
2 -- Weeks

The range of each of these columns is:
-3 -- No Response
-2 -- I Don't Know
-1 --
0 -- 0
1 -- 1
2 -- 2
3 -- 3
4 -- 4
5 -- 5
6 -- 6
7 -- 7
8 -- 8
9 -- 9
10 -- 10
11 -- 11
12 -- 12
13 -- 13
14 -- 14
15 -- 15
16 -- 16
17 -- 17
18 -- 18
19 -- 19
20 -- 20
21 -- 21
22 -- 22
23 -- 23

24 -- 24
25 -- 25
26 -- 26
27 -- 27
28 -- 28
29 -- 29
30 -- 30
31 -- 31
32 -- 32
33 -- 33
34 -- 34
35 -- 35
36 -- 36
37 -- 37
38 -- 38
39 -- 39
40 -- 40

Codebook information for Education (educ)

Question 21 (of 22)

What is the highest level of education you received?

There is a single column 'educ' in the matrix.

Values are:
0 -- Some college
1 -- Bachelor's degree
2 -- Master's degree
3 -- Doctorate degree

Appendix B

ORA Measures Document

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March 22, 2003

ORA is the organizational risk analyzer. Its purpose is to assess the level of possible organizational risk and the factors that contribute to this risk. All measures are based on the meta-matrix and take in to account the relations among personnel, knowledge, resources and tasks. These measures are based on work in social networks, operations research, organization theory, knowledge management, and task management. As ORA is a product in development, additional measures will be added.

ORA runs on a PC running windows 2000 or XP operating system. The system interface is in JAVA and the measures are a combination of C and C++.

ORA takes as input one or more matrices in the meta-matrix for an organization and then calculates the measures herein.

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Suggestions for additional measures should be sent to Kathleen M. Carley, kathleen.carley@cmu.edu

A **network** N consists of two sets of nodes, called U and V, and a set $E \subset UxV$. An element e = (i,j) in E indicates there exists a relationship or tie between nodes $i \in U$ and $j \in V$. A network where U=V and therefore $E \subset VxV$, is called a **square network**; otherwise the network is a **rectangular network**. In square networks, $(i,i) \notin E$ for $i \in V$, that is, there are no self-loops.

An **organization** is a collection of networks. A **measure** is a function that maps one or more networks to R^n. Measures are often either scalar valued (real or binary) or vector valued (real or binary with dimension |U| or |V|).

When defining or implementing measures, a network can be represented as (1) a graph or as (2) an adjacency matrix. To represent a *square* network as a graph, let G=(V,E), where V is the network's nodes, and E are the ties; *rectangular* networks will not be represented as graphs. Both square and rectangular networks are represented as adjacency matrices. Given a network N=((U,V),E), define a matrix M of dimension |U|x|V|, and let M(i,j) = 1 iff $(i,j) \in E$. Then M is the adjacency matrix representation of N. Note that since a square network has no self-loops, its adjacency matrix representation has a zero diagonal.

The adjacency matrices of an organization's networks is called the MetaMatrix for the organization. The following adjacency matrices for the most common networks are used throughout the measures documentation:

A = *Communication Network*: element (i,j) is the degree to which agent i communicates with agent j
AK = *Knowledge Network*: element (i,j) is the degree to which agent i knows knowledge j
AR = *Capabilities Network*: element (i,j) is the degree to which agent i owns resource j
AT = *Assignment Network*: element (i,j) is the degree to which agent i is assigned to task j
K = *Information Network*: element (i,j) is the degree to which knowledge i is connected to knowledge j
KR = *Training Network*: element (i,j) is the degree to which knowledge i is needed to use resource j
KT = *Knowledge Requirement Network*: element (i,j) is the degree to which knowledge i is needed to do task j
R = *Resource Substitute Network*: element (i,j) is the degree to which resource i can be substituted for resource j
RT = *Resource Requirement Network*: element (i,j) is the degree to which resource i is needed to do task j
T = *Precedence Network:* element (i,j) is the degree to which task i must be done before task j

The matrices **A**,**K**,**R**,**T** are square networks; the others are rectangular networks.

The following matrix notation is used:

|Matrix| = dimension of a *square* Matrix (i.e. if Matrix has dimension r x r, then |Matrix| = r)
Matrix(i,j) = the entry in the i^{th} row and j^{th} column of Matrix
Matrix(i,:) = i^{th} row vector of Matrix
Matrix(:,j) = j^{th} column vector of Matrix
sum(Matrix) = sum of the elements in Matrix (also, Matrix can be a row or column vector of Matrix)
Matrix' = the transpose of Matrix
~Matrix = for binary Matrix, ~Matrix(i,j) = 1 iff Matrix(i,j) = 0.
Matrix@Matrix = element-wise multiplication of two matrices (e.g. C=A@B => C(i,j) = A(i,j)*B(i,j))

These mathematical terms and symbols are used:

card(Set) = |Set| = the cardinality of Set
sgn(x) = 1 if x >= 0, and -1 otherwise
$\Re$ denotes a real number
Z denotes an integer

These graph theoretic terms are used:

$d_G(i, j)$ is the length of the shortest directed path in G from node i to node j. Note that if there is a path from i to j in G, then $1 \le d_G(i, j) < |V|$. Therefore, let $d_G(i, j) = |V|$ if there is no path in G from i to j. Also, let $d_G(i, i) = 0$ for each $i \in V$.

The **Reachability Graph** for a square network N=(V,E) is defined as follows: let G=(V,E) be the graph representation for N. The Reachability Graph for N is the graph G'=(V,E') where E'= {(i,j)$\in$VxV | $\exists$directed path from i to j in G}.

The **Underlying Network** for a network N=(V,E) is defined as follows: N'=(V,E') where E'= {(i,j) | (i,j)$\in$E $\vee$ (j,i)$\in$E }. That is, an symmetric version of N.

Measure Name	Description	Reference	Formula
Access Index, Knowledge Based	Boolean value which is true if an agent is the only agent who knows a piece of knowledge and who is known by exactly one other agent. The one agent known also has its KAI set to one. **Type** Node Level **Input** AK:binary; A:binary **Output** Binary	Ashworth	The Knowledge Access Index (KAI) for agent i is defined as follows: let $S_i = \{s \mid AK(i,s) \wedge (sum(AK(:,s)) = 1) \wedge (sum(A(i,:)) = 1)\}$ Then $KAI_i = ((S_i \neq \emptyset) \vee (\exists j \mid S_j \neq \emptyset \wedge A(j,i) = 1))$
Access Index, Resource Based	Boolean value which is true if an agent is the only agent with access to a resource and who is known by exactly one other agent. The one agent known also has its RAI set to one. **Type** Node Level **Input** AR:binary; A:binary **Output** Binary	Ashworth	The Resource Access Index (RAI) for agent i is defined identically as Knowledge Access Index, with the matrix AK replaced by AR.
Actual Workload, Knowledge	The knowledge an agent uses to perform the tasks to which it is assigned. **Type** Node Level **Input** AK:binary; KT:binary; AT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Actual Workload for agent i is defined as follows: (AK*KT*AT')(i,i)/sum(KT) Note how Potential Workload is the first matrix product.
Actual Workload, Resource	The resources an agent uses to perform the tasks to which it is assigned. **Type** Node Level **Input** AR:binary; RT:binary; AT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Actual Resource Workload for agent i is identical to Actual Knowledge Workload, replacing AK with AR and KT with RT.
Boundary Spanner, Weak	A node who if removed from a network N creates one or more new weak components is a Weak Boundary Spanner. **Type** Node Level **Input** N:square, symmetric **Output** Binary	Cormen, Leiserson, Riverest, Stein, 2001 p.558	A weak boundary spanner is an *articulation point* of the Communication Network, as defined in the referenced book.

Centrality, Betweenness	The Betweenness Centrality of node v in a network N is defined as: across all node pairs that have a shortest path containing v, the percentage that pass through v. This is defined for directed networks.
	Type Node Level
	Input N: square
	Output $\Re \in [0,1]$
		Freeman, 1979	Let G=(V,E) be the graph representation for the network. Let n=|V|, and fix a node v$\in$V.
			For (u,w)$\in$VxV, let $n_G(u,w)$ be the number of geodesics in G from u to w.
			If (u,w)$\in$E, then set $n_G(u,w)$=1.
			Define the following:
			let $S = \{(u,w) \in VxV \mid d_G(u,w) = d_G(u,v) + d_G(v,w)\}$
			let between = $\sum_{(u,w)\in S}(n_G(u,v) * n_G(v,w)) / n_G(u,w)$
			Then Betweenness Centrality of node v = between / ((n-1)(n-2)/2).
			
			Note: if G is not symmetric, then between is normalized by (n-1)(n-2).

Centrality, Closeness	The average closeness of a node to the other nodes in a network N. Loosely, Closeness is the inverse of the average distance in the network between the node and all other nodes. This is defined for directed networks. **Type** Node Level **Input** N:square **Output** $\Re \in [0,1]$	Freeman, 1979	Let G=(V,E) be the graph representation of the square network. Fix v$\in$V. let dist = $\sum_{i\in V} d_G(v,i)$, if every node is reachable from v Then Closeness Centrality of node v = (|V|-1)/dist. If some node is not reachable from v then the Closeness Centrality of v is |V|.
Centrality, Degree	The Degree Centrality of a node in a square network N is its normalized out-degree. This is defined the same for directed networks. **Type** Node Level **Input** N:square **Output** $\Re \in [0,1]$	Wasserman and Faust, 1994 (pg 199)	Let G=(V,E) be the graph representation of a square network and fix a node x. let deg = $card\{u \in V \mid (x,u) \in E\}$, this is the out-degree of node x. The Degree Centrality of node x is deg / (|V|-1)

Clustering Coefficient, 1998	Measures the degree of clustering in a network N. **Type** Graph Level **Input** N:symmetric(?), square **Output** $\Re \in [0,1]$	Watts and Strogatz, 1998	let G=(V,E) be the graph representation of a square network. For each node i $\in$ V define the following: let $in_i = \{u \in V \mid (u,i) \in V\}$ let $out_i = \{u \in V \mid (i,u) \in V\}$ let $inconnect_i = \{(u,v) \in E \mid u,v \in in_i\}$ let $outconnect_i = \{(u,v) \in E \mid u,v \in out_i\}$ Then compute for each node i $\in$ V its Node Clustering Coefficient ncc_i. There are three ways to do this: based on (1) in-degree, (2) out-degree, or (3) freeman degree: If $\mid in_i \mid = 0$ or $\mid out_i \mid = 0$, then $ncc_i = 0$. Otherwise, compute ncc_i in one of the following three ways: (1) let $ncc_i = \frac{\mid inconnect_i \mid}{\mid in_i \mid^2 - \mid in_i \mid}$ (2) let $ncc_i = \frac{\mid outconnect_i \mid}{\mid out_i \mid^2 - \mid out_i \mid}$ (3) let $ncc_i = \frac{1}{2}\left(\frac{\mid inconnect_i \mid}{\mid in_i \mid^2 - \mid in_i \mid} + \frac{\mid outconnect_i \mid}{\mid out_i \mid^2 - \mid out_i \mid}\right)$ Then Clustering Coefficient = $\left(\sum_{i \in V} ncc_i\right) / \mid V \mid$.

Cognitive Load	A complex measure taking into account the number of other agents, resources, and tasks an agent needs to manage and the communication needed to engage in such activity. Note: Cognitive Load is defined if one or both of the following pairs of networks exists: {AR,RT}, {AK,KT}. **Type** Node Level **Input** A:binary; AT:binary; [AR:binary; RT:binary]; [AK:binary; KT:binary] **Output** $\Re \in [0,1]$	Carley, 2002	The Cognitive Load for agent i is defined as follows: let ATR = AT*RT' let ATA = AT*AT' let x_1 = # of agents that agent i interacts with / total # of agents $= \left(\sum_{j \neq i} A(i,j)\right) / (\lvert A \rvert - 1)$ let x_2 = # of tasks agent i is assigned to / total # of tasks = sum(AT(i,:))/|T| let x_3 = sum of # agents who do the same tasks as agent i / (total # tasks * total # agents) $= \left(\sum_{j \neq i} ATA(i,j)\right) / (\lvert A \rvert - 1)(\lvert T \rvert)$ Note that x_4, x_5, x_6 depend upon networks AR and RT; if the networks AK and KT exist, then three analogous terms for knowledge are computed and averaged. If only AK and KT exist, then only they are used. let x_4 = # of resources agent i manages / total # of resources = sum(AR(i,:))/|R| let x_5 = sum of # resources agent i needs to do all its tasks / (total # tasks * total # resources) = sum(ATR(i,:))/(|T|*|R|) let x_6 = sum of negotiation needs agent i must do for each task / total possible negotiations $= \left(\sum_{j} (AR(i,j) > 0 \neq ATR(i,j) > 0)\right) / (\lvert R \rvert \lvert T \rvert)$ Then Cognitive Load for agent i = $(x_1 + x_2 + x_3 + x_4 + x_5 + x_6)/6$
Communicative Need	**Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Carley, 2002	Let G = (V,E) represent a square network: Then the Communicative Need = (Reciprocal Edge Count of G) / |E|
Component Count	The number of connected components in an symmetric (symmetric) network N. **Type** Graph Level **Input** N:square, symmetric **Output** $Z \in [0, \lvert V \rvert]$	Wasserman and Faust, 1994 (pg 109)	Given a square, symmetric network represented by a graph G=(V,E), the Component Count is the number of connected components in G.

Congruence, Communication	Measures to what extent agents communicate when and only when it is needful to complete tasks. Hence, higher congruence occurs when agents don't communicate if the tasks don't require it, and do when tasks require it. Communication needs to be reciprocal. **Type** Graph Level **Input** AT:binary; AR:binary; RT:binary, T:binary **Output** $\Re \in [0,1]$	Carley, 2002	Communication Congruence = 1 iff agents communicate when and only when it is needful to complete their tasks. Agents i and j must reciprocally communicate iff one of the following is true: (a) if i is assigned to a task s and j is assigned to a task t and s directly precedes task t (handoff) (b) if i is assigned to a task s and j is also assigned to s (co-assignment) (c) if i is assigned to a task s and j is not, and there is a resource r to which agents assigned to s have no access but j does (negotiation to get needed resource). The three cases are computed as follows: (a) let H = AT*T*AT' (b) let C = AT*AT' (c) let N = AT*Z*AR', where Z(t,r) = (AT'*AR - RT')(t,r)<0 Then let Q(i,j) = [(H+C+N) + (H+C+N)'](i,j) > 0, and note that reciprocal communication is required - indicated by adding the transpose. let d = card{ (i,j) | A(i,j) != Q(i,j) }, which measures the degree to which communication differs from that which is needed to do tasks. Finally, d /= (|A|*(|A|-1)), normalizes d to be in [0,1] Then, Communication Congruence = 1 - d
Congruence, Knowledge	Measures the similarity between what knowledge is assigned to tasks via agents, and what knowledge is required to do tasks. Perfect congruence occurs when agents have knowledge when and only when it is needful to complete tasks. **Type** Graph Level **Input** AK:binary; AT:binary; KT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Knowledge Congruence = 1 iff agents have knowledge when and only when it is needful to complete their tasks. Thus, we compute the knowledge assigned to tasks via agents, and compare it with the knowledge needed for tasks. let KAT = (AK'*AT) let d = card{ (i,j) | (KAT(i,j)>0) != (KT(i,j)>0)} let d = d / (|K|*|T|), which normalizes d to be in [0,1] Then Knowledge Congruence = 1 - d
Congruence, Resource	Measures the similarity between what resources are assigned to tasks via agents, and what resources are required to do tasks. Perfect congruence occurs when agents have access to resources when and only when it is needful to complete tasks. **Type** Graph Level **Input** AR:binary; AT:binary; RT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Identical to Knowledge Congruence with AR replaced by AK and KT replaced by RT.

Connectedness	Given a square network N, the degree to which N's underlying network is connected. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Krackhardt, 1994	Let N be a given square network. The Connectedness of N is the Density of the Reachability Network for N.
Constraint	The degree to which an agent is constrained by its current communication network. **Type** Node Level **Input** A **Output** $\Re \in [0,1]$	Burt, 1992	This is the Effective Size of Network measure described by Equ. 2.4 on pg. 55 of Burt, 1992. Note that the Communication Network is used for the matrix Z.
Density	The actual number of network edges versus the maximum possible edges for a network N. **Type** Graph Level **Input** N **Output** $\Re \in [0,1]$	Wasserman and Faust, 1994 (pg 101)	Let M be the adjacency matrix for the network of dimension m x n. If the network is square, then M is square and has a zero diagonal, and therefore Density = sum(M)/(m*(m-1)). For rectangular networks, Density = sum(M)/(m*n).
Diameter	The maximum shortest path length between any two nodes in a square network G=(V,E). If there exist i,j in V such that j is not reachable from i, then the diameter is returned as |V|. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Wasserman and Faust, 1994 (pg 111)	The diameter of G=(V,E) is defined as: $\max\{d_G(i, j) \mid i, j \in V\}$ That is, the maximum shortest directed path between any two vertices in G. If there exists i and j such that j is not reachable from i, then |V| is returned.
Diversity	The distribution of difference in idea sharing. **Type** Graph Level **Input** AK:binary **Output**	???	Let w_k = sum(AK(:,k)), $1 \le k \le \|K\|$ Let d = $1 - \sum_{k=1}^{\|K\|} \left(w_k / \|A\|\right)^2$ Then Diversity = d / |A|
Edge Count, Lateral	Fixing a root node x, a lateral edge (i,j) is one in which the distance from x to i is the same as the distance from x to j. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Carley, 2002	Let G=(V,E) be the graph representation of a network. And fix a node x$\in$V to be the root node. Let S = {(i,j)$\in$E | $d_G(x,i) = d_G(x, j)$ } Then, Lateral Edge Count = |S| / |E|
Edge Count, Pooled	A pooled edge in a network N=(V,E) is an edge (i,j)$\in$E such that there exists at least one other edge (i,k) $\in$E, and k$\neq$j. **Type** Graph Level **Input** N **Output** $\Re \in [0,1]$	Carley, 2002	Let M be the adjacency matrix representation of the network. Let S = { (i,j) | M(i,j)=1 $\wedge$ sum(M(:,j))>1 } In other words: edge (i,j) is a pooled edge iff the indegree of node j > 1. The Pooled Edge Count = |S| / |E|

Edge Count, Reciprocal	The number of edges in a network N=(V,E) that are reciprocated; an edge (i,j)$\in$E is reciprocated if (j,i)$\in$E. **Type** Graph Level **Input** N **Output** $\Re \in [0,1]$		Let G=(V,E) be the graph representation of a network. Let S = card{(i,j)$\in$E | i<j, (j,i)$\in$E } he Reciprocal Edge Count = |S| / |E|
Edge Count, Sequential	The number of edges in network N that are neither Reciprocal Edges nor Pooled Edges. Note that an edge can be both a Pooled and a Reciprocal edge. **Type** Graph Level **Input** N **Output** $\Re \in [0,1]$	Carley, 2002	Let G=(V,E) be the graph representation of a network, and let X = set of Pooled edges of G, and let Y = set of Reciprocal edges of G. Then Sequential Edge Count = | E-X-Y| / |E|
Edge Count, Skip	The number of edges in a network that skip levels. **Type** Graph Level **Input** N **Output** $\Re \in [0,1]$	Carley, 2002	A skip edge in a network represented by G=(V,E) is an edge (i,j)$\in$E such that j is reachable from i in the graph G'=(V,E\(i,j)), that is, the graph G with edge (i,j) removed. Skip Count is simply the number of such edges in G normalized to be in [0,1] by dividing by |E|.
Effective Network Size	The effective size of an agent's Communication Network based on redundancy of ties. **Type** Node Level **Input** A **Output** $\Re \in [0,1]$	Burt, 1992	This is the Effective Size of Network measure described by Equ. 2.2 on pg. 52 of Burt, 1992. Note that the Communication Network is used for the matrix Z.
Exclusivity, Knowledge Based	Detects agents who have singular knowledge. **Type** Node Level **Input** AK:binary **Output** $\Re \in [0,1]$	Ashworth	The Knowledge Exclusivity Index (KEI) for agent i is defined as follows: $\sum_{j=1}^{\|K\|} AK(i,j) * \exp(1 - sum(AK(:,j)))$
Exclusivity, Resource Based	Detects agents who have singular resource access. **Type** Node Level **Input** AR:binary **Output** $\Re \in [0,1]$	Ashworth	The Resource Exclusivity Index (REI) for agent i is defined exactly as for Knowledge Based Exclusivity, but with the matrix AK replaced by AR.
Exclusivity, Task Based	Detects agents who exclusively perform tasks. **Type** Node Level **Input** AT:binary **Output** $\Re \in [0,1]$	Ashworth	The Task Exclusivity Index (TEI) for agent i is defined exactly as for Knowledge Based Exclusivity, but with the matrix AK replaced by AT.

Hierarchy	The degree to which a square network N exhibits a pure hierarchical structure. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Krackhardt, 1994	Let N be a given square network. The Hierarchy of N is the Reciprocity of the Reachability Network for N.
Interdependence	The percentage of edges in a network N that are Pooled or Reciprocal. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Carley, 2002	Let G=(V,E) be the graph representation of a square network. Let a = Pooled Edge Count and b = Reciprocal Edge Count of the network. Then Interdependence = (a+b)/|E|
Interlocker and Radial	Interlocker and radial nodes in a square network have a high and low Triad Count, respectively. **Type** Node Level **Input** N:square **Output** Binary	Carley, 2002	Let N=(V,E) be a square network. Let t_i = Triad Count for node i, $1 \le i \le \|V\|$. Let u = the mean of { t_i } Let d = the variance of { t_i } Then if $t_k \ge (u+d)$, then agent k is an *interlocker*. If $t_k \le (u-d)$ then agent k is a *radial*.
Load, Knowledge	Average number of knowledge per agent. **Type** Graph Level **Input** AK:binary **Output** $\Re \in [0,\|R\|]$	Carley, 2002	Knowledge Load = sum(AK)/ (|A|)
Load, Resource	Average number of resources per agent. **Type** Graph Level **Input** AR:binary **Output** $\Re \in [0,\|R\|]$	Carley, 2002	Resource Load = sum(AR)/ (|A|)
Negotiation, Knowledge	The extent to which personnel need to negotiate with each other because they lack the knowledge to do the tasks to which they are assigned. **Type** Graph Level **Input** AT:binary; AK:binary; KT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Compute the percentage of tasks that lack at least one resource: let Need = (AT'*AK) - KT' let S = { i | $1 \le i \le \|T\|$, $\exists$ j : Need(i,j) < 0 } Then Need for Negotiation = |S| / |T|
Negotiation, Resource	The extent to which personnel need to negotiate with each other because they lack the resources to do the tasks to which they are assigned. **Type** Graph Level **Input** AT:binary; AR:binary; RT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Identical to Knowledge Negotiation, replacing AK with AR, and KT with RT.

Network Centralization, Betweenness	Network centralization based on the betweenness score for each node in a square network. This measure is define for symmetric and non-symmetric networks. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Freeman, 1979	Let G=(V,E) represent the square network, and let n = |V| let d_i = Betweenness Centrality of node i let $\bar{d} = \max\{d_i \| 1 \le i \le n\}$ Then Network Betweenness Cent. = $\left(\sum_{1\le i\le n} \bar{d} - d_i\right)/(n-1)$.
Network Centralization, Closeness	Network centralization based on the closeness centrality of each node in a square network. This is not defined for unconnected or directed networks. **Type** Graph Level **Input** N:square, symmetric, connected **Output** $\Re \in [0,1]$	Freeman, 1979	Let G=(V,E) represent the square network, and let n = |V| let d_i = Closeness Centrality of node i let $\bar{d} = \max\{d_i \| 1 \le i \le n\}$ Then Network Closeness Cent. = $\left(\sum_{1\le i\le n} \bar{d} - d_i\right)/((n-2)(n-1)/(2n-3))$.
Network Centralization, Column Degree	A centralization based on the out degree of column vertices in a network N. **Type** Graph Level **Input** N **Output** $\Re \in [0,1]$	NetStat	Let M be the adjacency matrix representation of a rectangular network with n rows and o columns. let $d_j = sum(M(:, j))$ = out degree of column node j, $1 \le j \le o$ let $\bar{d} = \max\{d_j \| 1 \le j \le o\}$ Then Column Degree Network Centralization = $\left(\sum_{1\le j\le o} \bar{d} - d_j\right)/((o-1)*n)$.
Network Centralization, Degree	This centralization is defined on a square network N and is based on node out-degree. The scaling of the measure depends on whether the network is symmetric. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Freeman, 1979	Let M be the adjacency matrix representation of a square network. And let n=|M|. let $d_i = sum(M(i,:))$ = out degree of node i let $\bar{d} = \max\{d_i \| 1 \le i \le n\}$ Then Degree Network Centralization = $\left(\sum_{1\le i\le n} \bar{d} - d_i\right)/((n-1)(n-2))$. Note: if the network is not symmetric, then the scaling factor is $(n-1)^2$
Network Centralization, Row Degree	A centralization based on the out degree of row vertices in a network N. **Type** Graph Level **Input** N **Output** $\Re \in [0,1]$	NetStat	Let M be the adjacency matrix representation of a rectangular network with n rows and o columns. let $d_i = sum(M(i,:))$ = out degree of row node i let $\bar{d} = \max\{d_i \| 1 \le i \le n\}$ Then Row Degree Network Centralization = $\left(\sum_{1\le i\le n} \bar{d} - d_i\right)/((n-1)*o)$. Note: dividing by (n-1)*o normalizes the value to be in [0,1]

Network Levels	The Network Level of a square network N is the maximum Node Level of its nodes. **Type** Graph Level **Input** N:square **Output** $Z \in [0, \lvert V \rvert - 1]$	NetStat	Let G=(V,E) be the graph representation of a square network. Then the Levels of G = max { $d_G(i, j)$ | i,j $\in$ V; j reachable from i in G }
Node Level	The Node Level for a node v in a square network N is the worst case shortest path from v to every node v can reach. **Type** Node Level **Input** N:square **Output** $Z \in [0, \lvert V \rvert - 1]$	Carley, 2002	Let G=(V,E) be the graph representation of a square network and fix a node v. Node Level for v = max { $d_G(v, j)$ | j $\in$ V; j reachable from v in G }
Omega, Knowledge Based	The degree to which an organization reuses knowledge. **Type** Graph Level **Input** AT:binary; KT:binary; T:binary **Output** $\Re \in [0,1]$	Carley, Dekker, and Krackhardt 2000	Let TAT = TA*TA' Let N = ((T'@TAT)*KT')@KT' Then Knowledge Based Omega = sum(N)/sum(KT)
Omega, Resource Based	The degree to which an organization reuses resources. **Type** Graph Level **Input** AT:binary; RT:binary; T:binary **Output** $\Re \in [0,1]$	Carley, Dekker, and Krackhardt 2000	Identical to Knowledge Based Omega, replacing KT with RT.

Performance as Accuracy	Measures how accurately agents can perform their assigned tasks based on their access to knowledge and resources. **Type** Graph Level **Input** AK:binary; AT:binary; AR:binary; KT:binary; RT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Accuracy is computed based on the binary classification problem. It is computed in one of two ways: (1) Knowledge based: Let b be a binary string of length |K|, let N=KT', and let S=AK. Fix a task t. let answer = ($\sum_{1 \le k \le \|K\|} N(t,k) b_k$ / $\sum_{1 \le k \le \|K\|} N(t,k)$ > .5) , which is the correct classification of b with respect to task t. Now, let let I={ i | AT(i,t)=1}. let answer(i) = ($\sum_{1 \le k \le \|K\|} N(t,k) S(i,k) b_k / \sum_{1 \le k \le \|K\|} N(t,k) S(i,k)$ > .5), $i \in I$. This is agent i's classification of b with respect to t. The group of agents classify b using majority voting. That is, let group_answer = ($\frac{1}{\|I\|} \sum_{i \in I} answer(i)$ > .5). Then, if group_answer = answer, then the group was accurate, otherwise not. This is repeated multiple times for each task, and across all tasks. The percentage correct is Performance as Accuracy. (2) Resource based: let N=RT' and S=AR in the analysis of case (1). If the network has the knowledge and resource graphs to perform both cases, then Performance as Accuracy is the average of the two.
Potential Workload, Knowledge	Maximum knowledge an agent could use to do tasks if it were assigned to all tasks. **Type** Node Level **Input** AK:binary; KT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Potential Knowledge Workload for agent i = sum((AK*KT)(i,:))/sum(KT)
Potential Workload, Resource	Maximum resources an agent could use to do tasks if it were assigned to all tasks. **Type** Node Level **Input** AR:binary; RT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Potential Resource Workload for agent i is identical to Potential Knowledge Workload, replacing AK with AR, and KT with RT.
Reciprocity	The fraction of joined node pairs that are reciprocally joined in a square network N. **Type** Graph Level **Input** N: square **Output** $\Re \in [0,1]$	NetStat	Let G=(V,E) represent a square network. let S = {(i,j) | $(i,j) \in E \wedge (j,i) \in E$} let T = {(i,j) | $(i,j) \in E \vee (j,i) \in E$} Then the network's Reciprocity = |S|/|T|
Redundancy, Access	Average number of redundant agents per resource. An agent is redundant if there is already an agent that has access to the resource. **Type** Graph Level **Input** AR:binary	Carley, 2002	This is the Column Redundancy of matrix AR.

	Output $\Re \in [0, (\lvert A \rvert - 1) * \lvert R \rvert]$		
Redundancy, Assignment	Average number of redundant agents assigned to tasks. An agent is redundant if there is already an agent assigned to the task. **Type** Graph Level **Input** AT **Output** $\Re \in [0, (\lvert A \rvert - 1) * T]$	Carley, 2002	This is the Column Redundancy of matrix AT.
Redundancy, Column	Given a network N, the mean number of non-zero column entries in excess of one in the network's matrix representation. **Type** Graph Level **Input** N of dimension m x n **Output** $\Re \in [0, (m-1) * n]$	Netstat	Let M be the matrix representation for a network N of dimension m x n. let $d_j = \max\{0, sum(M(:, j)) - 1\}$, for $1 \leq j \leq n$; this is the number of column entries in excess of one for column j. Then Column Redundancy = $\left(\sum_{j=1}^{n} d_j \right) / n$
Redundancy, Knowledge	Average number of redundant agents per knowledge. An agent is redundant if there is already an agent that has the knowledge. **Type** Graph Level **Input** AK **Output** $\Re \in [0, (\lvert A \rvert - 1) * \lvert K \rvert]$	Carley, 2002	This is the Column Redundancy of matrix AK.
Redundancy, Resource	Average number of redundant resources assigned to tasks. A resource is redundant if there is already a resource assigned to the task. **Type** Graph Level **Input** RT:binary **Output** $\Re \in [0, (\lvert R \rvert - 1) * \lvert T \rvert]$	Carley, 2002	This is the Column Redundancy of matrix RT.
Redundancy, Row	Given a network N, the mean number of non-zero row entries in excess of one in the network's matrix representation. **Type** Graph Level **Input** N of dimension m x n **Output** $\Re \in [0, (n-1) * m]$	Netstat	Let M be the matrix representation for a network N of dimension m x n. let $d_i = \max\{0, sum(M(j, :)) - 1\}$, for $1 \leq i \leq m$; this is the number of column entries in excess of one for row i. Then Row Redundancy = $\left(\sum_{j=1}^{m} d_j \right) / m$

Relative Expertise	The degree of dissimilarity between agents based on shared knowledge. Each agent computes to what degree the other agents know what they do not know. **Type** Node Level **Input** AK:binary **Output** $\Re \in [0,1]$	Carley, 2002	The Relative Expertise matrix (RE) is defined as follows: RE(i,i) = 0 RE(i,j) = (~AK*AK') = # knowledge that j knows that i does not know Finally, normalize RE by its row sums: RE(i,:) /= sum(RE(i,:)) The Relative Expertise for agent i = $\left(\sum_{j=1, j\neq i}^{\|A\|} RE(i,j)\right)/(\|A\|-1)$, that is, the average of the non-diagonal elements of row i of RE.
Relative Similarity	The degree of similarity between two agents based on shared knowledge. Each agent computes to what degree the other agents know what they know. **Type** Node Level **Input** AK: binary **Output** $\Re \in [0,1]$	Carley, 2002	Let M = AK*AK' Let w(i) = sum(M(i,:)), $1 \le i \le \|A\|$ Then Relative Similarity (RS) between agents i and j is RS(i,j) = M(i,j)/w(i). The Relative Similarity for an agent i = $\left(\sum_{j=1, j\neq i}^{\|A\|} RS(i,j)\right)/(\|A\|-1)$, that is, the average of the non-diagonal elements of row i of RS.
Span of Control	The average number of subordinates per supervisor in the Communication Network. **Type** Graph Level **Input** A:binary **Output** $\Re \in [0,\|V\|-1]$	Carley, 2002	For each agent in the Communication Network who has 1 or more subordinates (a supervisor), sum the number of subordinates, then divide by the number of supervisors.
Speed, Average	The average communication time between any two agents who can communicate via some path. **Type** Graph Level **Input** A **Output** $\Re \in [0,1]$	Carley, 2002	let G=(V,E) be the graph representation of the Communication Network. let D={ $d_G(i,j)$ | i,j$\in$ V, i$\neq$ j; j reachable from i in G } Then Average Speed = $\left(\sum_{d\in D} d\right)/\|D\|$
Speed, Minimum	The worst case communication time between any two agents. **Type** Graph Level **Input** A **Output** $\Re \in [0,1]$	Carley, 2002	Minimum Speed = 1 / (Levels for the Communication Network)
Task Completion, Knowledge Based	The percentage of tasks that can be completed by the agents assigned to them, based solely on whether the agents have the requisite knowledge to do the tasks. **Type** Graph Level **Input** AK:binary; AT:binary; KT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Find the tasks that cannot be completed because the agents assigned to the tasks lack necessary knowledge: let Need = (AT'*AK) - KT' let S = { i | $1 \le i \le \|T\|$, $\exists$ j : Need(i,j) < 0 } Knowledge Based Task Completion is the percentage of tasks that could be completed = (|T|-|S|) / |T|

Task Completion, Overall	The percentage of tasks that can be completed by the agents assigned to them, based solely on whether the agents have the requisite knowledge and resources to do the tasks. **Type** Graph Level **Input** AR:binary; AT:binary; RT:binary; AK:binary, KT:binary **Output** $\Re \in [0,1]$	Carley, 2002	This is the average of Knowledge Based Task Completion and Resource Based Task Completion. If one of the two could not be computed, then the other is returned.
Task Completion, Resource Based	The percentage of tasks that can be completed by the agents assigned to them, based solely on whether the agents have the requisite resources to do the tasks. **Type** Graph Level **Input** AR:binary; AT:binary; RT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Find the tasks that cannot be completed because the agents assigned to the tasks lack necessary resources. Defined identically as Knowledge Based Task Completion, replacing matrix AK with AR and matrix KT with RT.
Transitivity	The percentage of triads i,j,k in a square network N such that if (i,j) and (j,k) are in the network, then (i,k) is in the network. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	NetStat	Let M be the adjacency matrix representation of the network. let I = {(i,j,k) $\in V^3$ | i,j,k distinct } let Potential = { (i,j,k) $\in$ I | M(i,j) = M(j,k) } let Empty = { (i,j,k) $\in$ I | M(i,j)=M(j,k)=M(i,k)=0 } let Complete = { (i,j,k) $\in$ I | M(i,j)=M(j,k)=M(i,k)=1 } Then Transitivity = (|Empty| + |Complete|)/|Potential|
Triad Count	The number of Communication Network triads that an agent is in. **Type** Node Level **Input** A:binary **Output** $Z \in [0, (\|A\|-1)(\|A\|-2)]$	NetStat	let Triad be an agent by agent matrix where Triad(i,i) = 0 Triad(i,j) = card{ k | k != i, k != j; A(i,j) $\wedge$ A(i,k) $\wedge$ A(k,j) }, i $\neq$ j Then the Triad count for agent i = sum(Triad(i,:))

Trust	The trust value for an agent is the average trust that exists between it and the other agents.
	Type Node Level
	Input AR:binary; AK:binary; AT:binary, A:binary
	Output $\Re \in [0,1]$
		Carley, 2002	let Trust be a matrix of dimension |A| x |A| defined as follows:
			Trust(i,i) = 0
			Trust(i,j) = (# triads with both i and j) +
			AR(i,:)' * AR(j,:) + // # resources i and j share
			AK(i,:)' * AK(j,:) + // # knowledge i and j share
			AT(i,:)' * AT(j,:) + // # tasks i and j share
			A(i,j) $\wedge$ A(j,i) + // reciprocal communication tie between i and j
			|A| / $d_P(i,j)$ // inverse communication time between i and j
			Trust is then normalized so that each entry is in [0,1].
			The trust value for agent i = sum(Trust(i,:)) / |A|

Under Supply, Knowledge	The extent to which the knowledge needed to do tasks are unavailable in the entire organization. **Type** Graph Level **Input** AK:binary; AT:binary; KT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Compute the average number of needed knowledge per task: let Need = (AT'*AK) - KT' let TaskNeed(i) = card{ j | Need(i,j)<0 }, for 1<=i<=|T| Then UnderSupply is sum(TaskNeed)/ |T|

Under Supply, Resource	The extent to which the resources needed to do tasks are unavailable in the entire organization. **Type** Graph Level **Input** AR:binary; AT:binary; RT:binary **Output** $\Re \in [0,1]$	Carley, 2002	Under Resource Supply is identical to Under Knowledge Supply, replacing AK with AR, and KT with RT.
Upper Boundedness	The degree to which pairs of agents have a common ancestor. **Type** Graph Level **Input** N:square **Output** $\Re \in [0,1]$	Krackhardt, 1994	

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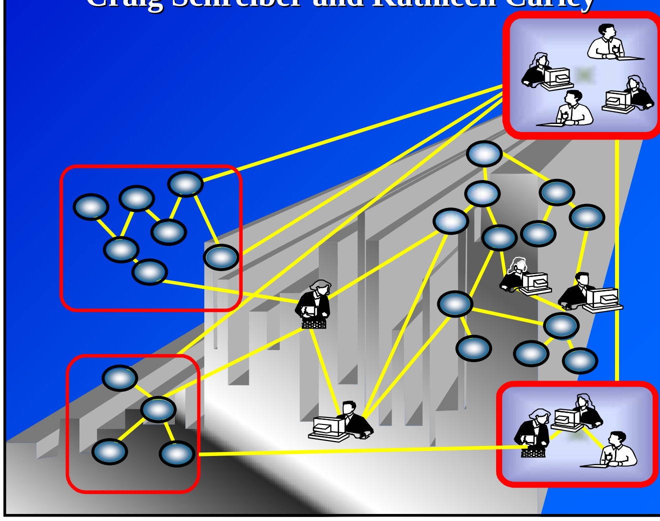
Appendix C

Team X Modeling and Experiments

Craig Schreiber and Kathleen Carley



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CASOS ISRI

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NASA

2003

Outline

- The model used – Construct-TM
- Team X modeling changes
- Experiment 1
  - The tradeoff btw point design and trade space exploration for different Facilitators
- Experiment 2
  - Turnover risk of key personnel
- Summary

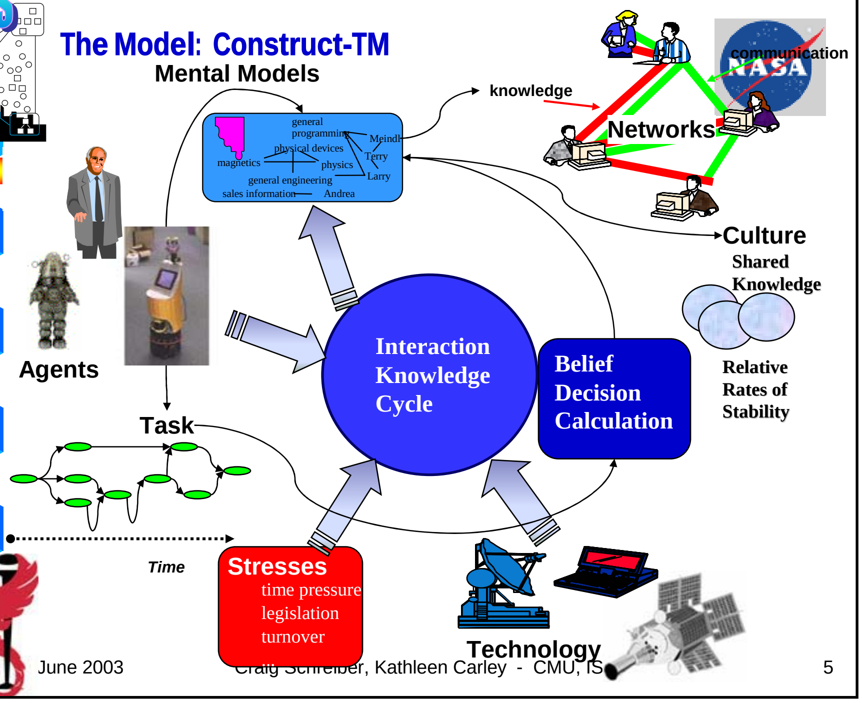
Construct-TM

- Construct-TM is a multi-agent model whereas agents communicate, learn and make decisions in a continuous cycle
  - Non-linear system – systems that generate complex temporal behavior due to variables that have dynamic relationships
  - Structuration – a theoretical perspective of construction and reconstruction of the social system through human interaction based on rules and resources
  - Social network analysis – defining and analyzing networks and relations

Construct-TM Validated

- Carley (1990)
- Carley and Krackhardt (1996)
- Carley and Hill (2001)
- Schreiber and Carley (2003)

The Model: Construct-TM



Team X Modeling Changes

Collected observational, survey and interview data on the CSSR mission design sessions of Team X. Based on these data the following changes to the Construct-TM model are suggested:

- **publish/subscribe system (done) ***
- **large screen broadcast tech. (done) ***
- **past missions database (done) ***
- **sidebars (done) ***
- **interdependencies**
  - **human network**
  - **technology network**
- **pooled, sequential, reciprocal tasks**
- **multi-tasking**
- **error cascades**

*** - These changes were implemented first because they are key to the team's strategic management of the interdependencies and tasks as well as being channels for error propagation**

Team X Modeling Changes Completed – Publish/Subscribe

Publish/Subscribe System

- Knowledge between subsystems is passed through a central database. The publishing of knowledge is not voluntary and transfer is forced. Subscribing ensures that only relevant knowledge is sent to each subsystem – only a fraction of the total knowledge available is obtained by each subsystem and the subsystems often receive different knowledge. The transfer of this knowledge is virtually transparent, seamless and immediate (low latency). This transfer mechanism alleviates the human agents from having to incur the time costs of lengthier transfer interactions.
- Modeled as an archival database whereas agents are forced to periodically publish and subscribe knowledge. Each agent publishes a subset of their knowledge and subscribes to a subset of the database's knowledge. Each agent subscription does not necessarily access the same subset of database knowledge and is often times accessing different knowledge.

Team X Modeling Changes Completed – Broadcast Technology

Broadcast Technology

- The three large screens at the front of the room broadcast knowledge to the entire team. Most information broadcast is archival, such as the systems worksheet. But some is non-archival, such as the customer presentation at the beginning of the session. This technology transfers the same knowledge at the same time to everyone on the team.
- Modeled as both archival and non-archival broadcast technology. The archival type is associated with an existing database. A subset of the database's knowledge will be broadcast to all the agents in a particular time period. The exact same knowledge is transferred to every agent. The non-archival type is similar whereas every agent receives the same knowledge in a time period. But it differs from archival in that once the broadcast (presentation) is done there is no way to retrieve the knowledge later unless it is re-broadcast.

Team X Modeling Changes Completed – Past Missions Database

Past Missions Database

- The past missions database contains archived knowledge of the designs for past missions. This database is not as central within the Team X design sessions as is the publish/subscribe system and the broadcast technologies. Team members can access this database on an individual basis as needed but actual use of this database is low as indicated by the survey. The past missions database seems to be used more in the pre-session.
- This is modeled as a combination task and referential database. The database contains prior task knowledge such as the systems worksheet and referential knowledge such as who worked on what subsystem. This database can be accessed by any agent at any time.

Team X Modeling Changes Completed – Sidebars

Sidebars

- Sidebars are when subgroups emerge within Team X to handle complex problems. These sidebars mainly coordinate through human interactions. Interdependencies are involved in the emergence of these subgroups.
- Modeled so that agents can either interact 1:1, 1:n or work alone in any given time period. The interaction choice is agent specific and not global within a time period. In other words, in a given time period some agents will be 1:n while other agents will be 1:1 while still other agents will be working alone.

Team X Modeling Changes
Items not completed

- Interdependencies
  - Human network – data was collected for this. The interdependencies are complicated and more time is needed to accomplish this change. Data on other mission designs would help to determine if this data can be generalized to overall Team X design.
  - Technological network – partial data was collected. Further data collection is needed as this network is central to knowledge transfer in the team.
- Pooled, sequential, reciprocal tasks – no data was collected. Observations conclude this to be an important model variable for future data collection.
- Multi-tasking – no data was collected. Observations conclude this to be an important model variable for future data collection.
- Error cascades – no data was collected. Observations conclude this to be an important model variable for future data collection.

Experiment 1
Facilitator Style Tradeoff

The tradeoff between point design and trade space exploration for different Facilitators

- Purpose – To test if facilitator styles impact point design and trade space exploration differently
- Definitions
  - Point design – consensus decision making to converge knowledge and integrate design.
  - Trade space exploration – exploration of an agents own position domain to make accurate decisions. This includes coordination with other position domains that are closely related.

Experiment 1
Variables

- Independent variables
  - facilitator knowledge
  - perception of dependencies on facilitator
  - perception of facilitator dependencies on others
  - design strategy (point design, trade space exploration)
- Dependent variable
  - performance

Experiment 1
Observations and Survey Data

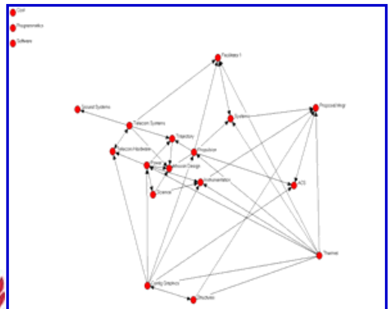
Observations indicate that facilitator management style varies greatly. This is the motivation for the experiment.

Survey data from Team X collected (data on 2 facilitators was obtained)

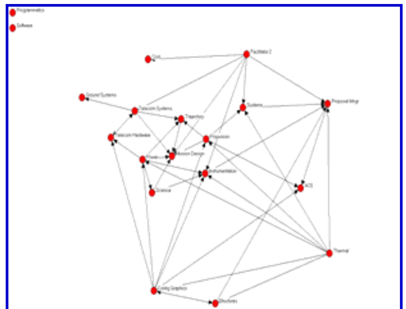
- the knowledge every team member has of each subsystem on a 4 point scale where 0 = none, 1 = beginner, 2 = intermediate, 3 = expert
- The perception of the degree of task dependence each member has on other members. This is on a 4 point scale where 0 = none, 1 = little, 2 = moderate, 3 = enormous

Experiment 1
Dependencies show style difference

The two network pictures of task dependencies show that there is a style difference for facilitators 1 and 2. Team members have task dependency on facilitator 1 whereas facilitator 2 has task dependency on the team members.

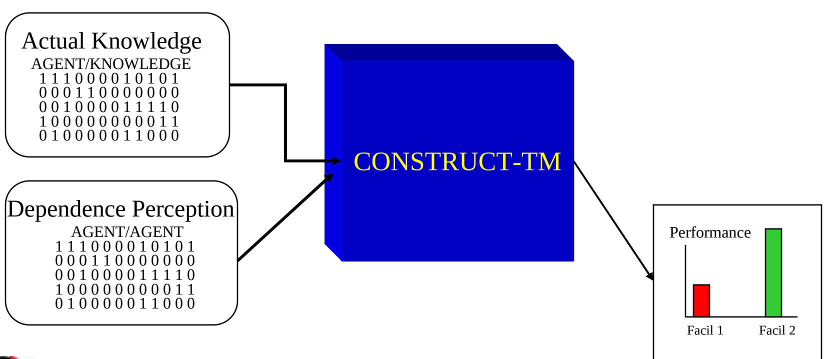


Ties are of strong task dependence

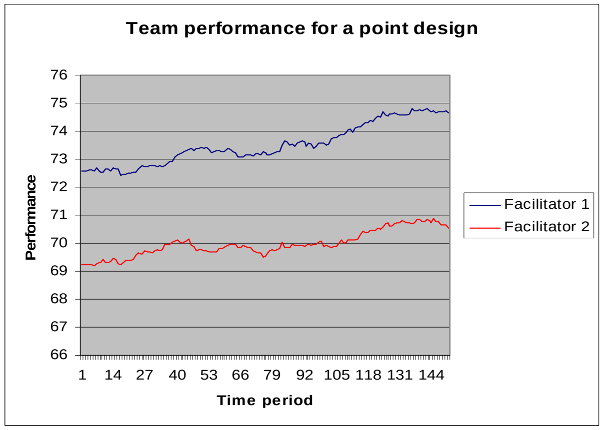


Ties are of strong task dependence

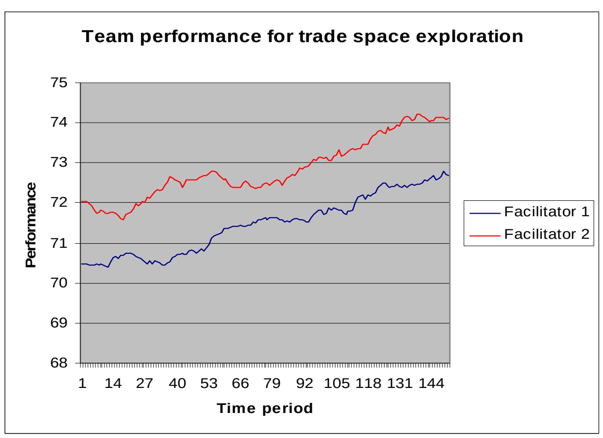
Experiment 1
Overview



Experiment 1
Results – Point Design



Experiment 1
Results – Trade Space Exploration



Experiment 1 Conclusion

The tradeoff between point design and trade space exploration for different Facilitators

- Better team performance
  - Point design - Facilitator 1's management style
  - Trade space exploration - Facilitator 2's management style
- Knowledge reported for each facilitator does not differ much
- Dependencies for work completion vary
  - Facilitator 1
    - Depends less on team members
    - Team members depend more on facilitator 1
  - Facilitator 2
    - Depends more on team members
    - Team members depend less on facilitator 2

Experiment 1 Conclusion

The tradeoff between point design and trade space exploration for different Facilitators

- Dependencies and simulation show that facilitator 1 drives the sessions
  - Tighter control over the interactions and tasks performed
  - Agents more engaged in consensus building and convergence of the system
- Dependencies and simulation show that facilitator 2 opens up the sessions and decentralizes
  - The system emerges from bottom up
  - Agents will naturally explore their trade space if given the opportunity to do so
- The tradeoff is for productivity and effectiveness

Experiment 2
Turnover Risk

Turnover of Team X key personnel

- Purpose – To test if the turnover of key Team X personnel have a negative impact on performance
- Independent variables
  - Team composition
    - CSSR staffing
    - key leadership change
    - key experts change
- Dependent variable
  - performance

Experiment 2
Team X Metamatrix used for ORA

	People	Technology	Knowledge	Tasks
People Relation	**Social Network** *Who knows who*	**Technology Network** *Who uses which tech.*	**Knowledge Network** *Who knows what*	**Assignment Network** *Who does what*
Technology Relation		**Operability Network** *Which tech. interfaces with which tech.*	**Encoded Network** *What is in which tech.*	**Tool Network** *Which tech. helps perform which task*
Knowledge Relation			**Interdependency Network** *What informs what*	**Needs Network** *What is needed to perform which task*
Task Relation				**Precedence Network** *Which tasks must be done before which tasks*

Experiment 2
Key Personnel

ORA identifies key personnel

knowledge exclusivity	potential knowledge workload	actual knowledge workload	cognitive load
4.5 (therm)	0.91 (therm)	0.048 (facil)	0.23 (therm)
2.2 (facil)	0.66 (system)	0.046 (therm)	0.20 (facil)
1.8 (missn)	0.63 (facil)	0.041 (system)	0.20 (system)

Experiment 2
Key Personnel

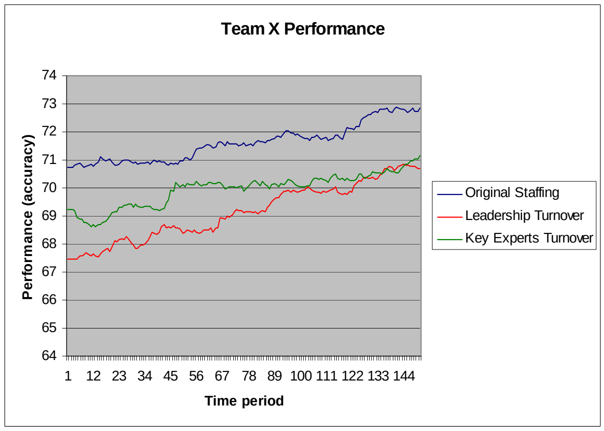
Top three personnel risks as identified by ORA

- Thermal
- Facilitator
- Systems

Experiments were run substituting less experienced personnel in key positions and comparing results to the original CSSR staffing:

- Facilitator – leadership change
  - All other positions retain the same CSSR staffing
- Thermal and Systems – key leader in charge but having less experienced staff in place of expert personnel
  - All other positions retain the same CSSR staffing

Experiment 2
Results



Experiment 2
Conclusion

Turnover of Team X key personnel

- Team X relies heavily on key expert personnel
  - Lost expert knowledge will have a negative effect on performance – loss in productivity and effectiveness
- Facilitator is the top key position and has the highest turnover risk
- The personnel staffing the Thermal and Systems positions also present a turnover risk
- The personnel are the expert turnover risk but particular positions may produce better experts due to increased exposure to system-wide interdependencies and effects
- This is a knowledge management challenge

Modeling and Experiments Summary

- Major changes have been made to the Construct-TM model to represent the Team X process
  - Publish/Subscribe system, Broadcast technology, Past missions database, Sidebars
  - Additional changes are planned to iteratively improve the representation of Team X
- Experiments conclude
  - Facilitator management styles have differing affects on point design and trade space exploration (productivity vs. effectiveness)
  - Team X has substantial risk for key personnel turnover (loss in both productivity and effectiveness)
    - Facilitator
    - Thermal and Systems

Modeling Lessons Learned

- Observation and interviews are essential
  - Modeling of the teams and process could not be done without it
- Survey data improves granularity
  - Augments the modeling from observation and interviews
  - Realistic group representation for experiments
  - Not essential for the first iteration of modeling
- Role of the information technology is not captured in the survey data
  - Additional data collection is needed to focus on the integration of the human and technological networks
- Need to model other NASA teams
  - Current changes should be applicable to other teams (VIPeR, ISS-MC)
  - Secondary validation

Acknowledgement

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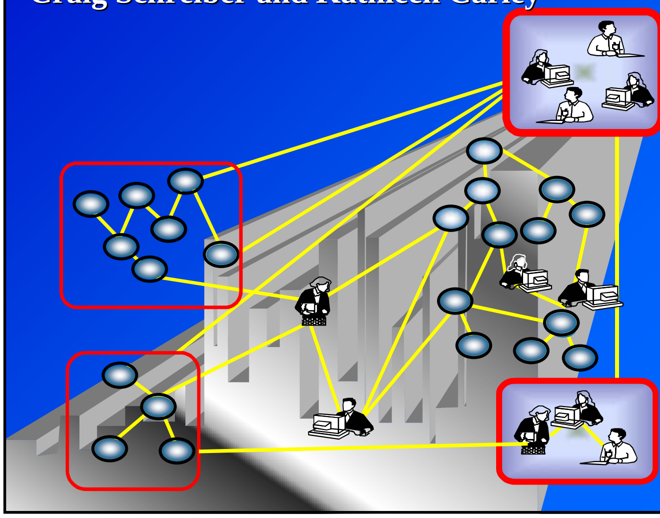
Appendix D

Team X - General Observations and Recommendations

Craig Schreiber and Kathleen Carley



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Outline

- Collaborative Project
- Team X – CSSR Mission
- Concurrent Engineering
  - Definition
  - Classes of Support
- Observations on Process Initiatives
- Observations on Computer Support
- Summary

Collaborative Project

- NASA Ames funded research on risk and safety
  - Engineering for Complex Systems
  - Knowledge Engineering for Safety and Success (KESS)
- Target group – JPL's Team X
- Collaborative data collection with Stanford and UIUC
  - Observations, interviews and on-line survey
- Goals
  - Understand Team X process
  - Build model of the process
  - Run computational analyses

Team X – CSSR Mission

- Scientific goal – rendezvous with comet, collect sample and return sample to earth
- Team goal – design spacecraft to meet scientific goal within cost constraint
- Project group consisted of a team leader (facilitator), 18 subsystems and customer team
- Concurrent engineering approach
- Complex process
  - Concurrent engineering
    - Mixture of pooled, sequential and reciprocal activities
  - Task complexity

Concurrent Engineering - Definition

Institute for Defense Analysis Report R-338 (1986):

Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirements

Concurrent Engineering - Classes of Support

There are four main classes of concurrent engineering support

- Process initiatives
- Computer support
- Formal methods
- Data interchange

Data collection efforts focused only on the first two classes – process initiatives and computer support

Components of Process Initiatives and Computer Support

Process initiatives – there are two central aspects
- Team composition and operation - which includes management and support
- Organizational structure and culture

Computer support – For Team X there are two categories
- Engineering design tools
- Information systems

Process Initiatives Observations - Team Composition and Operation

Team Composition and Operation
- Designed and managed very well
  - Multidisciplinary
  - Full responsibility for mission design
  - Warroom co-location
    - Effective communication
      - Short response latency
      - Synchronous and asynchronous communication
      - Computer support and visual displays
      - Position (subsystem) proximity within room based on communication frequency
    - Pooled, sequential and reciprocal activities
  - Documentation of decisions

Process Initiatives Observations - Organizational Structure and Culture

- Structural match and supportive culture
  - Matrix structure has congruence with project teams and concurrent engineering process
  - Culture is strong and supportive
    - High team commitment and team identity
    - Knowledge sharing norm
  - Evidence of convergent knowledge – the ability to synthesize specialized knowledge to successfully complete interdependent tasks
    - Well developed mental maps of the team, process and interdependencies

Process Initiatives Recommendations - Hand-over

Hand-over – there looks to be inadequate handover when a substitute fills in for a position member's absence

- Structures had a substitute on day 3
- Member spent roughly 45 minutes reviewing material
  - Large block of time considering the session is only 3 hours
- Knowledge management challenge – inadequate handover presents productivity and effectiveness risks
- Recommendations
  - Hand-over procedures should be established for absences known in advance
    - Absentee should spend extra time at the end of their last session preparing material to get the substitute up to speed quickly
    - Material should be distributed to the substitute prior to the next session so they have time to review the material.

Process Initiatives Recommendations – Trade space

Trade space exploration – observations conclude that trade space exploration is limited

- Time constraint
- Pre-session decisions and systems worksheet pre-session entries narrow the decision space
- Interviews indicate that the mission design often changes in later design phases. The subsequent change in cost is a criticism.
- Effectiveness and social risks
- Recommendations
  - Increase subsystem input (knowledge infusion) into the pre-session decisions
    - Pre-session recommended because there is a productivity and effectiveness tradeoff within the session (see virtual experiment 1)
  - Document the existence of unexplored space
    - Transfers knowledge to later phases
    - Protects against criticism

Process Initiatives Recommendations - Documentation

Documenting decisions and rationale – there seems to be a large variance in how well a position and/or individual documents decision rationale. It is believed that documentation is open-ended

- Importance of good documentation – a knowledge management challenge
  - Archiving
    - Research on variance between design phases
    - Use in future Team X designs
  - Knowledge transfer to teams in later design phases
- Productivity, effectiveness, professional and social risks
- Recommendations
  - Question format – develop questions that each subsystem must answer, provides framework for increasing documentation
  - Trade space limitations – documentation of exploration limits can explain comparative variance as well as protect against criticism

Process Initiatives Recommendations – Risk Measure

Measure of risk based on design changes

- Recommendation
  - Track the frequency and severity of design changes
    - By subsystem
    - Aggregate into a system measure
  - Measure is an indicator of risk and uncertainty by subsystem design and overall design
    - Estimator of effectiveness risk

Process Initiatives Recommendations – Turnover Risk

Turnover risk for Facilitator position – there is a lack of depth in personnel

- Facilitator is the key leadership position (see ORA and virtual experiment 2)
  - Influences the intensity and flow of integration and coordination through the different phases of the design process
  - Coordinates the process of knowledge convergence
  - Influences the initial path of the point-design
  - Influences the exploration of trade space
  - High situational awareness.
- Considerable experience and systems knowledge is needed to fill the role (see virtual experiment 2)
- Few team members have systems knowledge
- Knowledge management challenge, productivity and effectiveness risks (see virtual experiment 2)

Process Initiatives Recommendations – Turnover Risk

Turnover risk for Facilitator position – there is a lack of depth in personnel

- Recommendations
  - Create a mentoring program to develop experience and systems knowledge
    - Carefully select people who have a potential for leadership, people skills as well as the ability to see the broader systems view
      - Certain subsystem positions have a propensity for developing systems knowledge – examples are Systems Engineer, Thermal

Computer Support Observations

Engineering design tools (EDT)

- Every position has adequate subsystem tools – no criticisms of this support conveyed
- Less emphasis on this in data collection

Information systems

- Many systems used – publish/subscribe database, database of past mission designs, 3 large projected screens
- Publish/subscribe db is central to the design sessions
  - Organizational learning
    - Framework from which facilitator guides sessions
    - Task interdependencies between positions are captured within

Computer Support Observations

- Publish/subscribe db is central to the design sessions
  - Knowledge transfer
    - Values from one EDT are passed to another EDT through the db
    - Technological transfer of well established task interdependent knowledge allows human communications to focus on more complex interactions

Computer Support Recommendations – Error Checking

Technologically check for publishing/subscribing error

- Assuming all design calculations are correct there are two errors that can occur
  - Forget to publish
  - Forget to subscribe
- During the run-through of the systems worksheet at the end of each session it was observed that many values were questioned for recency
  - These errors may go undetected due to the high complexity of the task and limits of human attention and memory
- Effectiveness risk
- Recommendation
  - Create a routine to compare the systems worksheets values to the respective subsystems values and report discrepancies

Summary

- Team X has a successful concurrent engineering process
  - Uses a mixture of multifunctional teams, computer integration and analytic methods to achieve concurrency and integration
  - Integration methods such as co-location, information systems are appropriate as the environment has functional differentiation, cross-functional requirements, uncertainty, complexity and frequent two-way information flow
- Recommendations
  - Process initiatives
    - Create handover procedures
    - Increase trade space exploration
    - Increase documentation
    - Develop a measure of risk based on design changes
    - Create a mentoring program for the facilitator position
  - Computer support
    - Create publish/subscribe error checking routine

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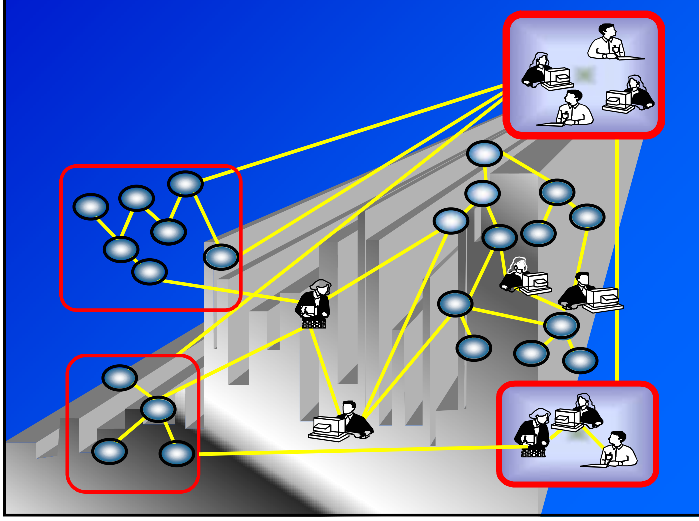
Appendix E

HORM Next Steps

Craig Schreiber and Kathleen Carley



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2003

HORM Background

The modeling and analysis has mainly concentrated on Team X. Some preliminary information gathering has occurred on NASA ISS mission control by way of interview with Valerie Shalin.

Model changes already made should be applicable to the other NASA teams, VIPeR, ISS mission control.

Modeling of the VIPeR and ISS mission control teams will provide secondary validation for the model.

The next steps include expanding the Team X model as well as beginning the first iteration model for VIPeR and ISS mission control.

Next Steps
Outline

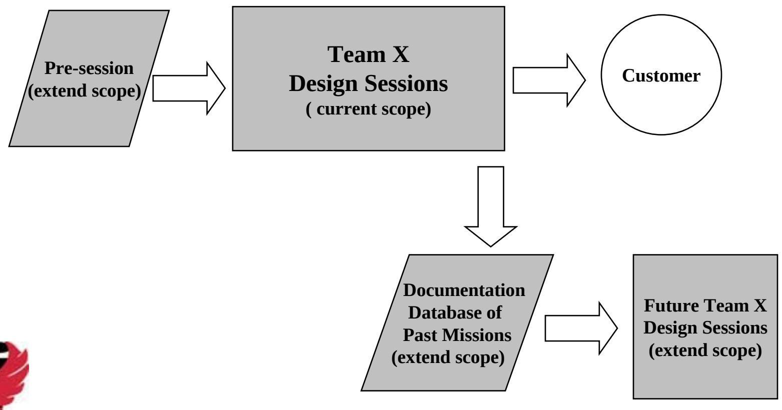
- Team X
  - Design Sessions
  - Pre-session
  - Post-session
  - Summary
- VIPeR
- ISS Mission Control
- Summary

Team X
Background

The modeling and analysis has concentrated on the processes within the Team X design sessions. The collection of data on the design sessions was completed for the CSSR mission.

The next steps include more in-depth modeling of the design sessions as well as expanding the scope of the model to include pre-session and post-session analysis.

Team X Background



Team X Model Expansion

- Team X Design Sessions
  - Model Interdependencies
  - Model Pooled, Sequential and Reciprocal Tasks
  - Model Multi-tasking
  - Model Error Cascades
- Pre-session
  - Knowledge input/output
  - Decision processes
  - Initialization of systems worksheet
- Post-session
  - Documentation
  - Database of past missions
  - Knowledge recycling

Team X Design Sessions Model the Interdependencies

Interdependencies

- The human interaction network
  - CSSR survey collected this data
  - Collect data for a different mission design
  - Compare to determine generality or contingency
- The technology network
  - Due to time constraint, a little less than ½ of the knowledge transfer between positions was collected during CSSR
  - Collect the rest of the data – should not differ among different design sessions
  - Determine correlation between human and technological networks
- Focus on integration of the human and technological networks

Team X Design Session Model Pooled, Sequential and Reciprocal Tasks

Pooled, Sequential and Reciprocal Tasks

- Observations of CSSR indicate pooled, sequential and reciprocal tasks are intertwined in the Team X process
  - Coordination and communication varies as to which task category is in effect
- Collect survey and interview data to break down activities into the task categories
- Understand the coordination associated with each task category

Team X Design Sessions
Model Multi-tasking

Multi-tasking

- Observation of the CSSR design sessions indicate that team members work on their subsystem task, receive visual and audible information and participate in sidebars
  - Survey, interview and observation data indicate that some positions have more tasks than others
- Collect survey data on the amount of multi-tasking by position
- Compute measures such as cognitive load

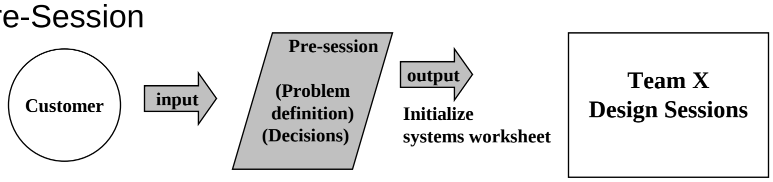
Team X Design Sessions
Model Error Cascades

Error Cascades

- Due to the fast-pace of the design sessions, the cognitive challenge of the task and the hidden transfer of knowledge through technology, errors can propagate through the system unnoticed.
- Collect survey and interview data on the types of error cascades that occur

Team X
Pre-Session

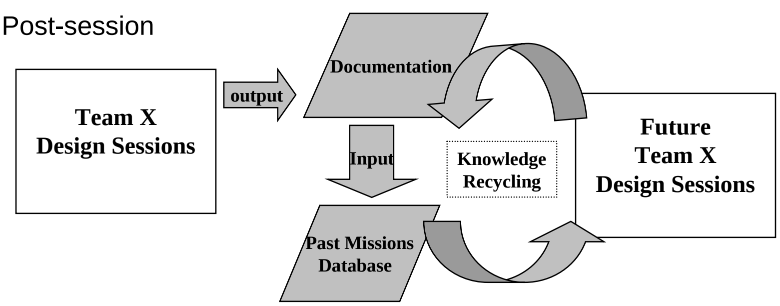
Pre-Session



- Collect data on the
  - Input of knowledge from the customer
  - Pre-session processes
    - Problem definition
    - Decisions
  - Output of knowledge to the Team X design session
  - How does this process affect the point design and exploration of the trade space in the Team X sessions?

Team X
Post-session

Post-session



- Collect data on the
  - Documentation process
  - Input to the Past Missions Database
  - Knowledge recycling

Team X Summary

- knowledge input
- problem definition
- decision process
- knowledge output

- publish/subscribe system (done) *
- large screen broadcast tech. (done) *
- past missions database (done) *
- sidebars (done) *
- interdependencies
  - human network
  - technology network
- pooled, sequential, reciprocal tasks
- multi-tasking
- error cascades

- documentation process
- input to past missions database
- knowledge recycling

* - *These changes were implemented first because they are key to the team's strategic management of the interdependencies and tasks as well as being channels for error propagation*

VIPeR
Modeling Steps – Data Collection

- Before SimStation introduction
  - Observation and Interviews – necessary to gain adequate understanding of the team and processes (team composition, knowledge distribution and transfer, coordination, etc…)
  - Demo of SimStation – understand:
    - Knowledge contained within
    - Interdependence mapping
    - Human interface and other methods of knowledge transfer
  - Data from SimStation and Risk surveys
- After SimStation introduction
  - Observation and Interviews – understand how the team processes have changed
  - Data from SimStation and Risk surveys

VIPeR
Modeling Steps - Experiments

- Virtual Experiments
  - Simulate the effects of SimStation
  - Knowledge management experiments based on the team distribution of knowledge including system-wide experts
  - Team productivity and effectiveness
  - Collaboration and coordination strategies
- Use Before and After data to validate model

ISS Mission Control
Modeling Steps – Data Collection

- Observation and Interviews – necessary to gain adequate understanding of the team and processes (team composition, knowledge distribution and transfer, dynamic and real-time environment, coordination, etc…)
  - Handover process is crucial
    - Change in team size and composition
    - Documentation process
    - Methods of knowledge transfer
  - Controller attrition rates
- Data from Risk survey

ISS Mission Control
Modeling Steps – Experiments

- Virtual Experiments
  - Reduced team and handover
  - Turnover
  - Knowledge management experiments based on the team distribution of knowledge
  - Team productivity and effectiveness
  - Collaboration and coordination strategies

Next Steps
Summary

- Expand the Team X model
  - Includes additional data collection
- Begin first iteration of the VIPeR team model
- Begin first iteration of the ISS Mission Control model

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