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Modeling and Analysis of Multidiscipline Research Teams at NASA Langley Research Center: A Systems Thinking Approach

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Abstract

Multidisciplinary analysis and design is inherently a team activity due to the variety of required expertise and knowledge. As a team activity, multidisciplinary research cannot escape the issues that affect all teams. The level of technical diversity required to perform multidisciplinary analysis and design makes the teaming aspects even more important. A study was conducted at the NASA Langley Research Center to develop a model of multidiscipline teams that can be used to help understand their dynamics and identify key factors that influence their effectiveness. The study sought to apply the elements of systems thinking to better understand the factors, both generic and Langley-specific, that influence the effectiveness of multidiscipline teams. The model of multidiscipline research teams developed during this study has been valuable in identifying means to enhance team effectiveness, recognize and avoid problem behaviors, and provide guidance for forming and coordinating multidiscipline teams.

Introduction

Effective multidisciplinary research requires several key components. Not only does it require good methods and efficient tools, it also requires exceptional teamwork and leadership. Multidisciplinary analysis and design is inherently a team activity due to the variety of expertise and knowledge required. As such, multidisciplinary research cannot escape the issues that affect all teams – vision and mission, communication, organization, interpersonal factors, etc. The level of technical diversity required to perform multidisciplinary research makes the teaming aspects even more important.

The majority of the research efforts involving multidisciplinary analysis and design have focused on

the challenging technical issues involved – optimization, sensitivity, and data interfaces. However, there have also been extensive studies of teams by organizational behavior researchers to identify the particular ways in which the various aspects of teaming influence the effectiveness and quality of multidisciplinary interactions.^[1,2,3] Research at the NASA Langley Research Center (LaRC) has focused on the technical issues. Team effectiveness research has not been addressed or exploited to any significant degree.

A study was conducted at LaRC to develop a model of multidiscipline teams to help understand their dynamics and identify key factors that influence their effectiveness. The study sought to apply the elements of Systems Thinking^[2] to better understand the factors, both generic and LaRC-specific, that influence the effectiveness of multidiscipline teams.

Systems Thinking

Systems thinking^[4,5] is one of five disciplines that Peter Senge has characterized as the core of a learning organization. A *learning organization* is a group of people continually enhancing their capacity to create what they want; an organization that taps the commitment and capacity for people at every level of the organization to learn. *Systems thinking* is a methodology for understanding and communicating key characteristics of the systems that underlie organizational decisions and behavior. It is based on the discipline of system dynamics developed in the early 1960's by Jay W. Forrester as a practical application of feedback control concepts to every day kinds of systems.^[6] System dynamics helps to describe how a system is interconnected with feedback loops that create the nonlinear behavior so frequently associated with modern day problems.

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A basic premise of systems thinking is that systems produce the results that they are designed (either intentionally or by default) to produce. The systems that characterize organizations can be influenced (via interventions) or even altered (via redesign) to more effectively produce the desired results.

The systems thinking approach starts by identifying key variables that affect a system and tracing their patterns over time. The patterns and trends exhibited by the key variables and the underlying structure affecting them (i.e., attitudes, beliefs, policies, procedures, rewards, etc.) are used to identify cause and effect relationships that form the feedback loops of the system. Diagrams of the causal relationships between variables provide a means for analyzing the response of the system to inputs and perturbations.^[3] The diagrams also serve as a basis for group decision making, scenario planning, and for modifying and designing new systems.

The analysis of systems thinking diagrams is facilitated by a collection of classic loop structures called *archetypes*.^[5] The archetypes characterize common system elements that often appear in complex systems and have been studied extensively. Each archetype has associated with it generic patterns of response and specific types of high leverage interventions that help to produce the desired results. The archetypes allow large complex systems to be broken down into simpler elements that can be dealt with in a systematic way.

Approach

The multidiscipline teaming model was developed by analyzing three LaRC teams. The objective was to select teams that were multidisciplinary in nature and had "rich" history. That is, the teams involved extensive interaction of several technical disciplines, operated over a significant period of time, were recent enough that the history could be accurately recounted, and characterized some positive and negative aspects of multidiscipline teaming. A representative cross-section of each team was interviewed to determine influential factors that affected their success and effectiveness. The interviews were used to identify key variables and structural elements that were related to team performance. The variables were grouped into two categories – those that affected the team from outside (external variables) and those that involved interactions among team members. The external and internal variables were treated somewhat independently and analyzed separately – one model was developed for internal team dynamics (described in this paper) and one model was developed for the dynamics that were external to the team and actually influenced the formation of multidiscipline

teams and multidisciplinary research in general (described in a companion paper, reference 7).

The key variables and other significant aspects of the interviews (e.g., prevalent attitudes and beliefs) were combined into simplified scenarios that characterize particular features of team dynamics. These scenarios were analyzed to find causal links between the key variables and a feedback (or causal loop) diagram was created. The resulting diagram was then related to common archetypes to provide a basis for developing a deeper understanding of the system and identifying potential interventions to enhance team effectiveness.

The individual diagrams were combined to construct an integrated model of LaRC multidiscipline team dynamics. The model and the individual scenario diagrams were used to identify and analyze high leverage interventions that could be used to avoid problems and remedy those that might occur. High leverage interventions take advantage of the natural feedback characteristics of the system so that relatively small actions can have large impact. Once the action is taken the results are usually long lasting and self sustaining.

Results

The team interviews revealed six distinct scenarios. Each scenario is associated with a particular factor or set of factors that appear to have a strong influence on the effectiveness of multidiscipline teams. Most of the scenarios are representative of teams in general but they also incorporate several multidisciplinary and Langley specific elements. The multidisciplinary specific elements involve issues of technical diversity, i.e., interactions between people with different technical backgrounds. The Langley specific elements involve the predominant individual, organizational, and cultural beliefs and attitudes that affect the way in which the teams interact and respond to various situations.

The key variable in almost every scenario is *team effectiveness*, a term that is used to represent a variety of desired characteristics associated with highly successful teams. Some characteristics of highly successful teams include meeting milestones and deadlines, producing high quality products, producing results with long-term impact, exceeding expectations (sponsor, organization, customers, team members), and exhibiting effective communication, productivity, and efficiency.

Each of the scenarios address key factor(s) that tend to limit the effectiveness of multidiscipline research teams at LaRC. The individual scenarios were given names that suggest their key variables and how they are related to and influence team effectiveness. The six scenarios are –

- Clarity of Mission,
- Involvement of Key Experts,
- Multidiscipline Team Experience,
- Willingness to be a Team Player,
- Effectiveness of Team Processes, and
- Balanced Level of Technology.

Associated with each scenario is a story, a set of variables that change over time, and a causal loop diagram that includes the key variables, how the variables are related through cause and effect, and factors that influence how and why changes occur (e.g., external variables, mental models, and time delays). Note that, for the sake of brevity, some of the influential factors were omitted from this paper. However, these factors were important considerations during the modeling process and subsequent analysis.

Each scenario will be presented in sequence to establish the various components of the model. The scenarios will then be analyzed in the context of a common archetype called *Limits to Growth*. The analysis will identify a series of interventions with the potential to enhance team effectiveness by exploiting the dynamics inherent in the system.

Clarity of Mission

Focusing on a common goal was something that was evident in all the teams that were studied and is an essential feature of all teams. There was a time near the beginning of each team's life where the overall mission appeared to be clear to all the team members. This clarity of mission enabled each team member to see how they fit in and to work towards the common goal. However, once the mission was clear to all team members, the amount and quality of communication tended to drop off.

Initially, the lack of communication did not appear to hinder the team and actually appeared to some to be a good thing. The teams seemed to feel that it was best to go about their tasks and communicate on an "as needed" basis. However, as time passed people began to develop slightly different and individualized versions of the vision. As clarity of mission eroded, the effectiveness of the team fell. This caused one of two things to happen. One result was that people continued working on their own piece of the puzzle without worrying about how their piece was fitting in with the larger picture. However, the collection of pieces no longer fit together into the same picture. A second result was that people got frustrated with the team and either officially or unofficially quit because it was viewed as a waste of their time. In each case there was a negative impact on effectiveness.

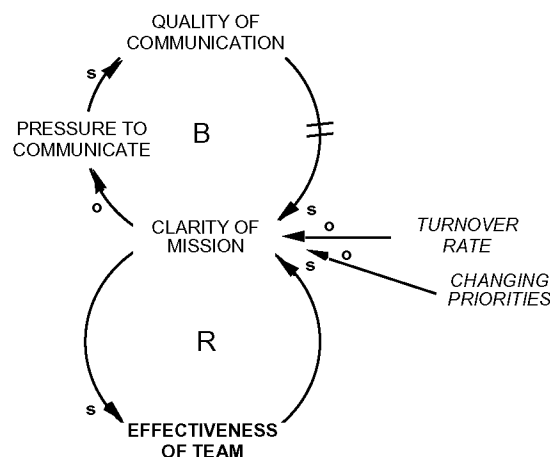


Figure 1 - Clarity of Mission.

Figure 1 depicts the causal loop diagram for Clarity of Mission. The key variables for the diagram include team effectiveness, clarity of mission, pressure to communicate, and the quality of communication. Initially the clarity of mission leads to increased effectiveness which helps to further focus on the mission which, in turn helps to further enhance team effectiveness resulting in a reinforcing cycle.*

With a high level of mission clarity the pressure to communicate is reduced which causes the quality of communication to decline which after some time† causes each team member to develop a slightly different understanding of the mission. The lack of mission clarity eventually becomes apparent and the pressure to communicate goes up. The effect is that over time clarity of mission oscillates and becomes balanced about some nominal value.

There are two other factors that help support this structure – turnover rate and changing priorities. Turnover rate, which will be discussed subsequently, has the effect of eroding mission clarity because as new members join the team they generally have an incomplete understanding of the mission. Similarly, changing priorities have the effect of decreasing mission clarity since changes in priority often change some aspect of the mission – for example, goals and objectives, roles of team members, schedule, or budget.

* The arrows indicate the causality relationship between variables. The symbol "s" on the links between variables indicates changes in the variables are in the same direction (an increase in one variable causes and increase in the other). An "o" indicates that the changes are in opposite directions. An "R" in the center of a loop corresponds to a reinforcing cycle and a "B" corresponds to a balancing process.

† Double hash marks on a link between variables indicates time delay.

Involvement of Key Experts

A major factor that influenced the performance of one team in the study was the lack of involvement of certain key discipline experts during the early stages of the project. Due to competing activities and the lack of multiple individuals with the required skills there was a lack of availability of a key skill when the team was initiated. The effectiveness of the team was negatively affected by the lack of key experts. As time passed, however, the competing activities were completed and the key skills became available. After a time the new member was brought up to speed (by developing understanding of the technical and organizational issues) and the effectiveness of the team began to improve.

The loop diagram for this scenario is shown in figure 2. The main engine for growth in effectiveness is driven by the development of commitment by the team members and the subsequent involvement of those with needed expertise. As the team members increase their level of commitment they begin to apply their expertise to complete key tasks. As tasks are completed and the level of experience grows, the effectiveness of the team increases, the team becomes more committed to the effort, and the cycle continues. However, the level of involvement of key experts is determined by their availability. As the experts' capabilities are utilized the availability of that expertise decreases (assuming that there is a limited supply) which reduces the potential for any additional involvement of that expert. The effect is to limit the maximum level of involvement.

There are several external factors that tend to limit availability of key expertise. Key factors that were in effect for the team described above are technical diversity, line management and sponsor support, and the presence of competing activities that require the scarce skill. Had there been somebody else with the needed skills or had a competing activity not received higher priority, the constraint would not have been in effect and team effectiveness would not have been adversely affected (due to lack of key skills). There are several other factors that also affect allocation of scarce resources – rewards (this could be personal or organizational rewards) and visibility associated with working on one team versus the alternatives, the availability of funds and facilities (for example, one option could be to hire somebody with the requisite skills), and the rate of turnover within the team. A factor that affects the ability to develop commitment is the technical challenges associated with the mission. Technical experts are often more easily motivated when the needed tasks require the solution of challenging technical problems.^[8]

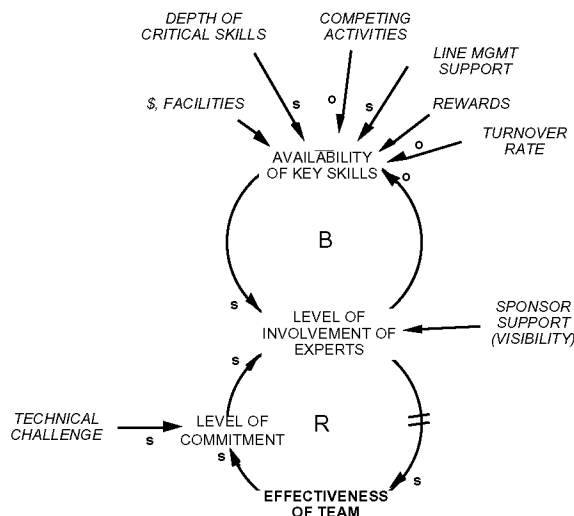


Figure 2 - Involvement of Key Experts.

Multidiscipline Team Experience

This scenario describes how technical diversity can influence team effectiveness. The effectiveness of multidiscipline research teams is very strongly influenced by the understanding each team member has of all the disciplines involved in the project. The development of interdisciplinary understanding depends on the biases discipline experts have in favor of or against the other disciplines. An appreciation of other disciplines tends to reduce biases against those disciplines but usually takes time to develop. As the biases against (or for) the various disciplines involved in a project are eliminated, the level of understanding continues to increase (because the willingness to learn is improved) which feeds back into further reducing discipline bias.

However, as discipline bias decreases, the tendency to feel that sufficient understanding has been achieved increases which tends to reduce the level of creative tension needed to further develop experience in integrating the various disciplines. This is understandable given that most technical experts have spent many years acquiring their expert knowledge and that developing new understanding in another field is a difficult and time consuming endeavor. As the creative tension wanes, the level of interaction between those with different technical backgrounds also wanes thereby slowing the development of interdisciplinary understanding and increasing the tendency for disciplinary bias. These interactions are illustrated in the diagram shown in figure 3.

There are a variety of other factors that influence interdisciplinary understanding as well. The team leader

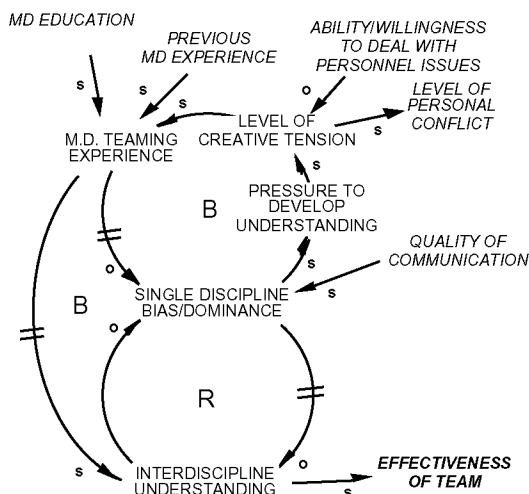


Figure 3 - Multidiscipline Team Experience

is usually an individual with a particular technical expertise (often associated with a discipline that is key to the success of the project). It is also common to have a particularly influential team member. These facts can result in one discipline being particularly dominant with an effect similar to discipline bias.

The development of creative tension is necessary to achieve the team goals.^[8] However, the creative tension can sometimes result in personal conflicts, especially between technical experts in highly interdependent yet fundamentally different disciplines (with little shared understanding between them). These conflicts can be very detrimental to team effectiveness, especially if they are not dealt with quickly and decisively.

Two other factors, previous multidisciplinary experience and training, can have a significant impact on the ability of the team to develop interdisciplinary understanding. A higher level of experience and training that members of the team have in dealing with the integration of multiple disciplines enhances the further development of understanding and helps to eliminate discipline biases within the team.^[9]

Willingness to be a Team Player

The effectiveness of a multidiscipline team is directly related to the willingness of the team members to be team players. Although this may seem obvious, the motivation for being a team player is, surprisingly, not necessarily clear. At least two of the multidiscipline teams studied were significantly affected by the willingness of their team members to be team players. For one team, the apparent reluctance of certain team members to work within a team environment negatively affected the project schedule.

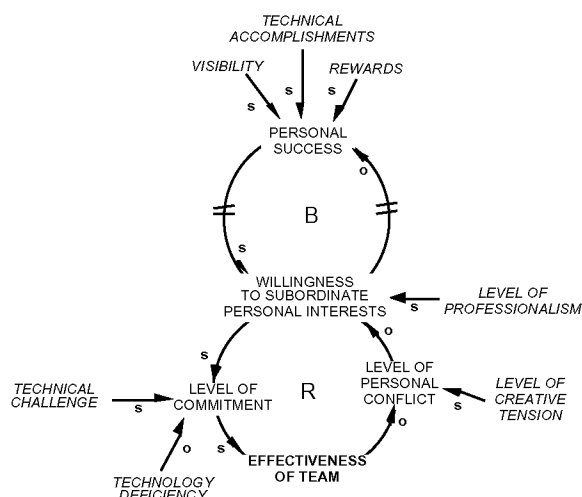


Figure 4 - Willingness to be a Team Player.

The major variables involved in this scenario are willingness to subordinate personal interests, level of commitment, level of conflict, and personal success. These variables characterize two types of phenomena – one is related to the individual's relationship to the team and the other is related to the individual's perception of individual benefits/rewards. When team members are willing to subordinate their personal interests to those of the team the level of commitment increases which, as seen previously, also enhances team effectiveness. Increased effectiveness tends to result in fewer conflicts and creates more cohesiveness and harmony within the team which is reflected in increased willingness to support the needs of the team. This reinforcing process is illustrated in the diagram in figure 4.

However, the mechanisms that help individuals to keep dedicating themselves to the team goals are not necessarily explicit in the organization. In fact, the measures of personal success are often at odds with being a team player. Traditionally, the reward system is designed to benefit those who advance the state-of-the-art of a particular discipline. In multidiscipline teams, however, the goal is to develop efficient multidisciplinary tools and methods that are not necessarily based on the state-of-the-art of a given discipline. Therefore, when a multidiscipline team activity is being formed, some experts may feel that they will not be able to work at the state-of-the-art level that they are used to which might limit their potential for promotion or other rewards. As a result, they decline to participate in the activity. If participation is mandatory, the result can be a less-than-enthusiastic team member. The end result is that the perceived inconsistencies between personal benefits and team effectiveness tend to limit team effectiveness by moderating the degree to which the team members are

willing to subordinate to the team goals. Note that there are delays between personal success and willingness to subordinate. This represents the tendency for people to continue to do the things that brought them success until a new pattern of action is well established.

Additional factors that contribute to this scenario include several mentioned previously (i.e., technical challenge and level of creative tension), factors that contribute to personal success (rewards, accomplishments, and organizational visibility), and factors such as level of professionalism that influence people's desire to contribute to the team despite the disincentives.

Effectiveness of Team Processes

The performance of one of the teams that was studied was strongly influenced by understanding and flexibility of team processes and the impact of turnover of team members. In the early stages of the project there was a lack of shared understanding regarding the manner in which the team would conduct business. The team primarily consisted of the combination of two disciplines which had not previously worked closely together. There was a conscious effort from the outset to involve every member of the team in the formulation of objectives and tasks and to do so by consensus. Team meetings were used to discuss and arrive at key decisions together and electronic mail was used to keep the entire team apprised of project status. A result of this strategy was frequent, often vocal, disagreements among team members. There was also considerable fluctuation in team membership and member involvement during the early stages of the project. Over time a crisis level was reached and the team sponsor was brought in to assist in conflict resolution. Subsequently team membership stabilized and the team structured itself in a manner that, while reducing the level of team-wide involvement in meetings and decision making, allowed it to arrive at consensus regarding the project objectives and tasks.

The loop diagram for this scenario is shown in figure 5. Note that the structure of the diagram is an interconnection of several reinforcing loops. A key factor in this system is the effect turnover has on team effectiveness. Turnover directly reduces effectiveness by the reduction in capability and expertise.^[9] It also reduces effectiveness indirectly by holding the entire team back while new capabilities and expertise are secured and new members are assimilated into the team.

There are several external factors that help to support this structure. Personal and organizational commitment has a significant role on the degree to which a shared understanding of team processes is developed. For

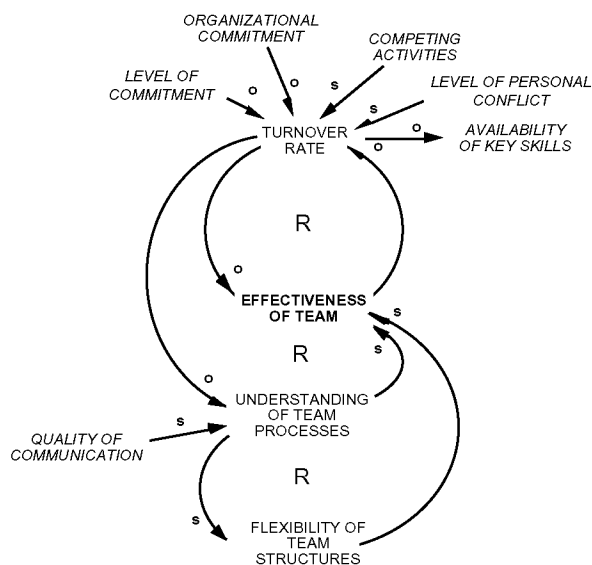


Figure 5 - Effectiveness of Team Processes.

example, less committed members may elect to skip meetings and so miss key interactions and decisions. When commitment is low the tendency to quit also increases. Commitment and turnover are strongly influenced by the level of personal conflict. As conflicts arise people are less willing to participate fully and seek opportunities associated with competing activities.

Another factor that affects effectiveness is a lack of clear understanding of team processes particularly due to the need for working across discipline and organizational lines. Effective, high quality communication can help to develop better shared understanding. However, when each team member is not clear about how they are expected to contribute to the team there is an increased likelihood of confusion, personal conflict, and frustration. As a result, the team is unable to make effective and timely decisions and effectiveness suffers. In addition, the lack of a shared understanding of how the team is to conduct its business decreases the team's ability to alter ground rules and other structures to adapt to changing circumstances.

Balanced Level of Technology

The last scenario identified during the study really involves two closely related scenarios. The first addresses the challenge of working below the single discipline state-of-the-art within a multidiscipline activity and the second addresses the challenge of raising the level of technical sophistication within multidiscipline teams. These two scenarios are related through a gap between the level of sophistication necessary for the multidisciplinary activity and that desired for the single discipline components.

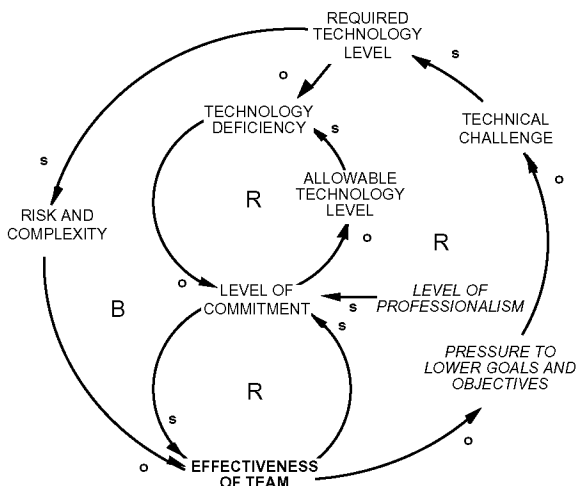


Figure 6 - Balancing the Level of Technology.

A key aspect of accomplishing multidisciplinary research is the combination of appropriate technologies from a variety of disciplines to achieve greater synergy in the results. In a research organization such as LaRC there are a variety of factors that encourage researchers to consistently seek to push the state-of-the-art in their respective disciplines. As a result, the *acceptable technology level* for most researchers involved in multidisciplinary activities is quite high.

Conversely, demands of multidisciplinary research (e.g., schedule, cost, cycle time), often require that the technologies associated with the various individual disciplines, the *required technology level*, be somewhat (often significantly) below the state-of-the-art. The difference between the acceptable technology level and the required technology level is termed the *technology deficiency*. When the technology deficiency increases, the effect is to reduce the level of commitment of the team members. The reduced commitment has the effect of making the team members even less open to working below the state-of-the-art which causes the technical deficiency to further widen. The lower level of commitment among the team members leads to reduced effectiveness as described previously. The diagram for these dynamics is shown in figure 6.

The required technology level for the multidisciplinary activity is determined by the technical challenge associated with the project goals and objectives. If the level of technical challenge is increased, then the required technology level is also increased which reduces the technology deficiency and leads to enhanced team effectiveness through increased commitment. However, increasing the required technology level (in order to reduce the technology deficiency) also increases risk and complexity. Added risk and complexity reduces the effectiveness of the team by a variety of mechanisms.

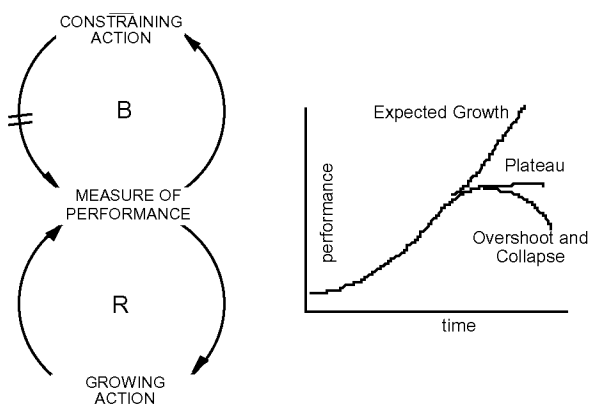


Figure 7 - Limits to Growth Archetype.

With consistently low levels of team effectiveness there is pressure to lower project goals and objectives which reduces the technical challenge which reduces the required technology level and the cycle continues.

The Complete Model

The complete model consists of the interconnection of all six scenarios by way of the common variables (e.g., level of commitment, quality of communication). It reveals the complex interdependence of the many factors that influence team effectiveness. Note that this model is like all models in that it is only an approximation of the true system. There are certainly many other scenarios that can be postulated. However, those presented here reflect the most significant aspects of the multidiscipline teams identified in the study.

Analysis

The analysis of the model consists of recognizing the fundamental nature of the dynamics that have been identified and developing interventions to remedy the problem or to better achieve the desired results. This involves comparing the scenarios to system archetypes. Archetypes are very powerful in that they allow a complex system to be modeled as a collection of generic dynamic structures with well known properties. The archetypes also have characteristic highly effective interventions for altering the behavior. These interventions are not always intuitive and many of the more intuitive interventions are actually ineffective in the long run and sometimes even make things worse.

A dozen or so archetypes have been identified.^[5] The archetype which is most prevalent in this study is called Limits to Growth. Figure 7 presents the loop diagram for this archetype along with a typical time history for the performance variable. The desired action is growth through the reinforcing loop. However, a constraining

action through the balancing loop limits the growth in such a way that performance either slows and levels off or even reverses the reinforcing process (from virtuous to vicious).

The loops shown in the figures generally characterize the dynamics that tend to constrain or suppress improvements in team effectiveness. The common occurrence of the limits to growth archetype provides a basis for identifying high leverage interventions and actions that can be taken to improve team effectiveness.

There are a variety of ways to react when the growth rate declines. Often the first inclination is to work harder or do more of what has worked already. The problem with this solution is that the constraint doesn't go away and even if it did there are almost certainly many other constraints waiting to happen.

When the desired growth shows signs of slowing or is stalled the balancing action has taken precedence over the reinforcing action. The highest leverage interventions for the limits to growth archetype, therefore, involve responding in the early growth stages before the constraints become active; anticipate the latent constraints and develop capacity to grow beyond them.

There are many ways to break or weaken the constraining action. The most effective interventions have some common attributes – they have impact throughout the system and are politically feasible. Because each scenario is part of a larger interconnected system, an intervention at one point in the system will have some effect beyond the immediate scenario. The most effective interventions take advantage of the interconnections. Because interventions inherently involve people making different choices and decisions, the interventions should be chosen so that they are consistent with the culture and core philosophy of the team/organization so that people are not asked to do things that are contrary to their values and principles. It is also easier to change procedures and policies than to change mental models and organizational culture, and therefore to use procedure and/or process changes to initiate the development of permanent change.^[10]

In the remainder of this section each of the scenarios will be viewed from the context of the limits to growth archetype and effective high leverage interventions. The assessments and potential interventions will provide a way for a sponsor, team leader, or team member to intervene in a team situation to effectively enhance team effectiveness.

Clarity of Mission

The key factor in maintaining clarity of mission is to keep the quality of communication among team

members high by breaking or at least weakening the link between clarity of mission and pressure to communicate. The team should endeavor to keep the pressure to communicate high even as people feel they have a clear understanding of the mission. The best way to accomplish this is by avoiding the problem in the first place. Once mission clarity has been lost a significant amount of energy will be needed to regain it.

One way that this can be accomplished is by developing team processes that maintain a focus on priorities and mission. This involves continually, or at least periodically, reassessing the ongoing efforts and tasks in the context of the overall goals and objectives. This is especially difficult when the team gets involved in detailed technical tasks.

Another way to keep the pressure to communicate high is to develop team processes that adapt to changing needs of information content. As the team progresses through the various stages of the project it is important to recognize the nature of the necessary information and tailor the forms of communication in an appropriate way. Information can be communicated in many ways (e.g., meetings, telephone, electronic mail). Each mode of communication has advantages and disadvantages that should be understood and exploited. In addition, different people communicate differently and the team processes should take this into account as well.

It is also important to monitor the quality of information being communicated and avoid the trap of equating quality with quantity and/or frequency. Too much information can be just as bad as too little. Information overload is a common complaint among technical professionals.

Involvement of Key Experts

Increasing the level of involvement of key experts is a very difficult problem because it is constrained by the availability of experts with key skills. The obvious intervention is to increase the availability of the key skills, but the availability of key skills is typically a fixed quantity over the life of a team. Another intervention is to increase the level of commitment of those already involved.

Increasing the availability of key skills (i.e., enhancing core competency) can be accomplished by various means: (1) maintain and develop expertise in key skills within a continuing education and development program, (2) sacrifice short-term effectiveness on a given team to develop and enhance skills and expertise "on the job," and (3) develop mechanisms by which key skills not readily available can be secured rapidly.

The first intervention is a long term solution and commitment to it should be reflected in the

organization's vision and strategy. The impact of such an intervention will probably not help teams currently experiencing the problem. However, the leverage associated with this solution over the long term is substantial, though the investment is substantial as well.

The second intervention is also a long term solution and is not likely to help in the short run. In fact, the development of such an intervention can adversely effect individual teams. In order to develop skills on the job the expertise is developed at the expense of the team. The negative impact on team effectiveness must be recognized and accepted by all those involved – team members, team leaders, line management, and sponsors. The success of this intervention also depends on the willingness and ability of the available experts to be mentors.

The third intervention in effect increases the available pool of available experts through, for example, temporary hires and contractors. It provides a way to directly benefit a given team but the added expertise does not benefit the organization permanently or over the long term and requires resources that could otherwise be used for more sustainable benefit.

Another type of intervention is to increase the involvement of key experts by attracting those already involved in competing activities. A variety of means can be used to accomplish this, particularly those based on addressing the factors that motivate the prospective team members (e.g., rewards, technical challenge). A longer term approach is to change the prevailing mental models and reinforcing structures to make team participation more attractive and flexible resource reallocation more acceptable.

The last type of intervention addresses developing additional commitment from those with key skills who are already on the team. The effort required to build and sustain commitment artificially (i.e., without having evidence of success) can be quite high. If commitment is attained it can be particularly tenuous. Therefore, this type of intervention does not have the leverage of the others.

Multidiscipline Team Experience

The key factor in reducing single discipline biases and/or dominance is to maintain the pressure to develop interdisciplinary understanding. This must be accomplished while maintaining very high levels of disciplinary expertise and therefore results in conflict that can be manifested as creative tension or personal conflict. The interventions for this scenario revolve around maintaining the creative tension and resolving personal conflicts.

Multidisciplinary research cuts across the research organizations at LaRC so there is no organizational structure dedicated or focused on cross-discipline activities. Therefore, interventions that develop opportunities and infrastructure to enhance cross-discipline understanding and appreciation have a lot of leverage. One type of intervention involves increasing the number of opportunities for research and development involving multiple disciplines. Another type involves clearly communicating the expectation for multidisciplinary skills.

Developing infrastructure to support multidisciplinary research and reduce the tendency for single discipline focus is also beneficial. Programs and goals that encourage multidiscipline interaction are included in the NASA strategic plan for the Aeronautics Enterprise.^[11]

Because a byproduct of creative tension is personal conflict, it is important that interventions include anticipation of conflicts and prompt response when they arise. Failure to do so is very damaging to team effectiveness.

Willingness to be a Team Player

A potential difficulty with this scenario is the misalignment of personal success and team success. This is the result of emphasis on individual versus team efforts and associated reward processes. If an organization recognizes and values multidiscipline team efforts, it needs to reward dedicated and effective team members appropriately.

The proper alignment of personal success with team success is the best and primary intervention for this loop. Unfortunately, redesigning reward systems has a long delay, both in the implementation and in the development of visible patterns that can affect behavior.

Another type of intervention with less delay seeks to appeal to other motivating factors. Professionalism, challenge, stimulation, excitement, and creative spirit are aspects of team work that can be used to motivate people to participate and commit to an endeavor.^[8] Building enthusiasm around these aspects of team work can help to establish willingness to be a team player.

Effectiveness of Team Processes

The most influential variable in this scenario is turnover rate. Interventions should result in reductions in turnover. This is especially true in areas where expertise is key or scarce since losses in these areas have the largest impact on effectiveness. Some ways to reduce turnover are to (1) staff the team with compatible and complementary individuals, (2) maintain strong sponsor and organizational support, (3) maintain quality communications to allow every team member to

develop a clear and consistent understanding of objectives, processes, and functions, and (4) deal promptly and directly with conflicts that can be detrimental to the team.

Another way to avoid turnover is to develop a shared understanding of the teams goals, objectives, and processes and develop processes that are able to adapt to the changing needs of the team (communication is one example). In this way each member of the team will understand their role and the role of others and develop a realistic set of expectations. The resulting team effectiveness will reduce the likelihood of conflicts and turnover.

Since some turnover is inevitable it is also important to anticipate and prepare for turnover by identifying and developing alternative sources for key expertise.

Balanced Level of Technology

The key factor in balancing the level of technology utilized within a multidiscipline team is technology deficiency (i.e., the difference between the level of technology acceptable to the discipline experts and that needed to accomplish the project objectives). Interventions therefore focus on reducing the technology deficiency.

There are only two ways to reduce the deficiency – raise the level of technology required or lower the acceptable technology level. However, there are several ways to approach the two options but with associated implications that should be considered.

Raising the goals and objectives of the project can require that more sophisticated technologies be employed. This lowers the technology deficiency but also raises the level of risk and complexity. The end result may or may not result in improved team effectiveness because the added commitment associated with more aggressive goals and objectives may be offset by the reduced effectiveness resulting from unforeseen schedule slips or personal conflicts associated with added risk and complexity. If added time and/or resources can be secured simultaneous to raising the technical challenge then the consequences of reduced effectiveness from added risk could be ameliorated and in the longer term effectiveness could be raised significantly.

Another approach is to lower the level of technical sophistication that is deemed acceptable by the discipline experts or to enhance the level of commitment by alternate means. This involves overcoming some fairly strong attitudes and established structures that serve to motivate people. An alternative is to select team members who may not be the most accomplished discipline experts but who have the necessary skills and capabilities to perform the work and

are more tolerant of lower levels of technical sophistication.

A more long term approach is to develop competence and expertise in the critical skill areas to reduce the risk associated with a given level of technology. However, this intervention will probably not benefit a team currently experiencing a technology deficiency problem.

High Leverage Interventions

The assessment of each of the six scenarios provides a basis for the development of interventions for particular problems. However, each scenario is only part of the whole story. Interventions in one part of the system will introduce effects in other parts of the system due to the interconnections between scenarios.

The most effective interventions involve taking advantage of the feedback inherent in the system. In that way, a small, subtle intervention could have large impact due to the way the system amplifies some signals. The key to selecting interventions is to identify points in the system with a high degree of connectivity, exploit areas where change will be accepted and the potential for compliance is high, and potential for sustainable change exists. For the LaRC multidiscipline team model developed herein the highest leverage points in the system involve *level of commitment*, *interdisciplinary understanding*, and *turnover rate*. Interventions that influence these variables are likely to be amplified within the system.

Successful interventions also require people to accept and comply with the changes because all interventions involve some level of choice. At LaRC, the areas in which people seem most receptive to change involve exhibiting leadership and decisiveness, enhancing freedom, control and independence, streamlining processes (e.g., reduce bureaucracy, reporting, and oversight), and developing opportunities for reward and advancement.

It is important to note that every intervention also has the potential for unintended consequences due to interconnections, feedback, and unmodeled effects within the system. It is advisable to assess the potential unintended consequences of any intervention and be prepared to respond if and when they occur.

Sustainable change requires the assimilation of new and better ways of working into the organizational culture. But beliefs, attitudes, and culture are difficult to change. Large scale change can be initiated through procedures and processes, creative tension, and limiting conflict with established culture and principles. Interventions with these characteristics can serve as a basis for permanent change within the organizational culture.^[10]

When implementing interventions it is important to do so gradually and with patience. Select only a very few interventions and give them time to work. Too many interventions can cause confusion and resistance and determining the impact of the various interventions will be difficult if not impossible. It can also take some time for the intervention(s) to produce the desired results. Because the interventions take advantage of the feedback inherent in the system, they are also dependent on the inherent delays.

The types of interventions that will most likely lead to substantial sustainable improvements in multidiscipline team effectiveness cross all levels – team sponsors and line management, team leaders, and team members. Team sponsors should seek to enhance level of commitment for multidisciplinary activities by emphasizing and strengthening the benefits of team participation and by establishing challenging individual objectives and goals within a multidisciplinary context. They should also seek to enhance opportunities for developing cross-discipline understanding. Team leaders should seek to maintain flexible and adaptive team management processes and exploit and/or develop the skills and expertise needed for multidisciplinary research. Team members should seek to contribute to the development of the processes and skills mentioned above and to exploit all of the benefits of multidiscipline teaming.

Concluding Remarks

The multidiscipline teaming model has many potential applications. Systems thinking provides a structured method to develop a shared understanding of the systems that govern team effectiveness. The model building process based on systems thinking is very valuable in that it allows the team to separate symptoms from causes and clarifies underlying issues. The diagrams serve as simple visual representations of the complex relationships between key variables and factors. Once developed, the model can be used to identify potentially high leverage interventions that could be employed to address multidiscipline team related issues and problems. The interventions can also be played out through the model to assess their likely impact and reduce the number of unintended consequences.

The model developed during this study has been valuable in identifying means to enhance multidiscipline team effectiveness, recognize and avoid problem behaviors, and provide guidance for forming and coordinating multidiscipline teams in the future. A collection of potential interventions have been identified and are the basis for continued analysis and research. The model has been used at LaRC on several occasions

to provide team leaders with some insight into how their teams are functioning and how they might address problems that have occurred or are likely to occur in the future.

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