Modeling Intergovernmental Collaboration: A System Dynamics Approach

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I. Introduction

This paper describes the development and testing of a system dynamics model of the collaboration, trust building and knowledge sharing processes in a complex, intergovernmental information system project. The model building and testing activity was an exploration of the feasibility of applying system dynamics modeling methods to this kind of process—a complex interorganizational one about which only qualitative data were available. The process to be modeled was the subject of qualitative field research studying processes of knowledge and information sharing in interorganizational networks. This research had produced a large volume of observational and interview data, partially analyzed, about the technology project. In the course of collecting and analyzing data from this project, the researchers noted evidence of what appeared to be important feedback effects. The feedback loops could be seen as substantial influences on how the collaboration and knowledge sharing developed and how the information system design and construction progressed. These observations led to conversations with colleagues who have extensive experience in dynamic modeling. All agreed that applying dynamic modeling methods to this process had considerable potential to yield valuable insights into collaboration and, as a novel application of the methods, could yield new modeling insights as well. The modeling was undertaken as a test of both propositions. The effort was judged a success. This will lead to continued exploration of these questions.

II. The Project Context

The system dynamics model was intended to capture dynamics of a project undertaken by the Center for Technology in Government between 1999 and 2001. The purpose of the project was to develop a new management information system that would assist the Bureau of Housing Services (State of New York) and state-funded homeless shelter providers better manage and evaluate programs.[1] New York State and its localities spend millions of dollars and devote substantial effort in providing both housing and services to homeless single adults and families. The Bureau of Housing Services (BHS), part of the New York State Office of Temporary and Disability Assistance, manages the temporary housing services program in New York State. The program is comprehensive in that it determines eligibility and need for services, provides case management, direct services, and referrals to outside service providers. The expenditure in federal, state, and local government programs for the homeless in New York State is estimated to be $350 million annually, of which $130 million is spent on service programs.

The operation and regulation of homeless shelters is a multi-government, interorganizational operation. BHS has regulatory oversight responsibility for all nonprofit and local government service providers that receive financial support from the State. In this role, BHS writes the regulations that govern the physical, financial, and program requirements for shelters. It certifies shelter programs according to these requirements and conducts periodic inspections of all shelters. Eighty percent of the homeless population in New York State resides in New York City, Westchester County, and Suffolk County. In New York City, BHS shares its regulatory role with the New York City Department of Homeless Services for those providers that also

[1] During the course of the innovation project described here the agency name was changed from Bureau of Shelter Services (BSS) to Bureau of Housing Services (BHS). The use of "BHS" in this paper refers to the same agency as the earlier BSS.

receive funding from the City. Although there are a few City-operated programs, the overwhelming majority of service providers are nonprofit organizations. Some are very small operations serving only a few people or families at a time. Others are major programs of large well-established organizations like the Salvation Army and the American Red Cross. Outside New York City, county social services agencies have similar responsibilities to oversee shelter and service programs.

The field research on which this modeling is based examined a collaborative project of the Center for Technology in Government (CTG) working with the Bureau of Housing Services (BHS). The purpose of the project was to devise an integrated system to help government and nonprofit providers make decisions about programs for the homeless population and evaluate their effectiveness. The outcome of this project was the creation of the Homeless Information Management System (HIMS), which is a prototype that draws upon data from multiple existing case management and financial systems. The HIMS data repository will allow decision makers at the state, local, and provider levels to assess temporary housing and service programs for homeless families and single adults. It will be used to conduct ongoing evaluation and refinement of service programs across providers for this population.

To be successful, the project required participants from the state agency responsible for shelter oversight to work in a highly collaborative way with managers from a wide range of homeless shelters in New York City, Westchester, and Suffolk counties. Over a 2+year period, the project participants were able to achieve the necessary collaboration and share highly detailed and complex operational knowledge. The result was the design and development of a successful prototype information system.

III. Perspectives on Knowledge Sharing and Collaboration

Interorganizational collaboration and knowledge sharing has been examined in research ranging from communication and direct relationships (Galbraith, 1973) to factors affecting knowledge exchange and learning (Cook & Brown, 1999). There has been some attention to collaboration that involves innovations in the operation of government, but knowledge sharing has received relatively little attention (Milward & Provan, 1998). The growing movements for government reforms and efficiency often involve combining innovations in information technology and sharing operational knowledge across agencies. The success of innovations involving such collaboration can depend heavily on effective knowledge sharing across organizational boundaries. Whether knowledge is tacit or explicit can affect the ease and effectiveness of sharing (Cook & Brown, 1999). Knowledge may be held by individuals or groups such as communities of practice (Wenger, 1998), as well as embedded in organizational procedures (Weick & Westley, 1996).

There is no consensus about how knowledge is shared in cross-organizational collaborations. Some views of knowledge locate it "in the heads (or brains) of an organization's members and take learning to be assimilation of information that is able to modify mental contents, behaviors, and actions" (Gherardi & Nicolini, 2000, p.10). Sharing of this kind of knowledge may be relatively easy. However, much of the knowledge of interest here is tacit, embedded in the social context, and much more difficult to transfer. The meaning of such knowledge cannot be separated from the work culture and the social construction of the work processes in the various organizations. This includes knowledge about how the work gets done and how that will change as a result of making the operational information available outside the organization. Just sharing the formal knowledge about work procedures and policies would not capture the necessary depth and nuance of knowledge embedded in practice needed for this particular innovation.

Collaboration and knowledge sharing also requires solving problems of trust, conflict, and risk among different communities of practice. These are largely matters of perception and beliefs about other participants in a network that can influence interactions and decision making (Elg & Johansson, 1997). Members' perceptions of power may also be related to the centrality of their organizations or community of practice relative to the others (Mizruchi & Galaskiewicz, 1994). These perceptions of power would also be likely to influence evaluations of risk and trust, since a more powerful participant in a network would be expected to shape positive or negative outcomes for itself or other members of the network.

Collaboration and knowledge sharing across organizational boundaries, with differing goals and competing interests, also involves considerable risks and potential conflicts. The strength and value of committed resources, including knowledge, influence those risks (Burt, 1997). Trust has also consistently been found to be a critical factor in interorganizational knowledge sharing relationships. Some level of trust is both an initial condition for the formation of the relationships as well as a result of positive interactions over time (Sheppard & Sherman, 1998). Interorganizational trust is also related to transaction costs (Williamson, 1991). The processes of social interaction through which these risk and conflict issues are resolved or mitigated are the main focus of the modeling described here.

Other environmental factors may limit the success of interorganizational collaboration in New York State (Cresswell, Pardo, Dawes, & Kelly, 2000). Turbulence or intense time pressures inhibit collaboration and effective key environmental factors limit the success of information systems that attempt to integrate work and information flow between state agencies and local governments. But incentives in the form of collaborative principles and practices can mitigate these problems.

Management's philosophy on sharing, as well as leadership and sponsorship of sharing relationships may also influence success (Larson, 1992; Pardo, 1998). Organizational capacity for innovation may facilitate creating new collaborative relationships and engage in knowledge sharing. Factors such as managerial support and leadership, availability of resources and infrastructure, and change orientation in the organizational culture have typically been shown to be related to an organizations innovative capacity (Cheng & VendeVen, 1996; Pardo, 1998). The intervention of CTG in this case was specifically designed to enhance this capability and was seen as a contributor to the formation of collaborative relationships.

IV. System Dynamics Modeling of Project Work and Knowledge Sharing

System dynamics is a methodology for studying and managing complex feedback systems, where feedback is understood as a closed sequence of causal relationships. That is to say, X causes Y, and eventually Y results affect X again. The field was envisioned by Jay Forrester in 1956 (Richardson, 1996). The basis of System Dynamics is that dynamic behaviors (performance over time) are closely linked to an underlying structure of feedback loops. Furthermore, in order to get a better understanding about linkages between behavior and structure a computer model is needed because the human mind has not the capability to manage the behavior of these complex structures (Forrester, 1971). In this way, a system dynamics computer model is the result of an iterative process of comparing and contrasting a set of assumptions about the system structure and the known behaviors of it (Figure 1).

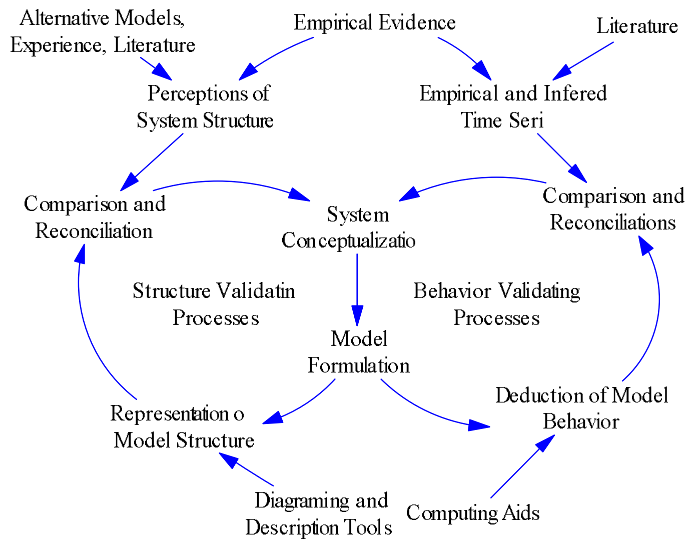


Figure 1 - The System Dynamics Modeling Process (Saeed, 1992)

Research employing system dynamics modeling has provided insights to several issues relevant to the project of interest. Cooper's (1980) study of change orders in a ship-building project and Abdel-Hamid's (1988) study of a software development effort explicitly portray the creation, identification, and resolution of problems during project work and their effect on the timeliness and quality of the completed project. They also demonstrate that assigning too-few resources to a project at its initiation can result in snowballing needs for resources in the final stages of project work. Repenning (2000) and Repenning, Goncalves, and Black (forthcoming) examine the allocation of resources to projects in product development when more than one project is underway. They conclude that observed biases toward allocating resources to projects whose deadlines are imminent can lead to systematic under allocation of people to early phases of projects. They further argue that a temporary increase in project workload can "tip" a project development organization to produce work at a permanently lower level of quality than potentially possible, even though the same number of resources are available before and after the temporary change in workload.

System dynamics modeling has also been used to explore the role of knowledge in creating collaborative patterns of interaction. Black, Carlisle, and Repenning (2001) draw on a case study by Barley (1986) documenting interactions between doctors and technicians during the implementation of computed tomography scanning to model how working with the new machine and its images affected expertise that doctors and technicians could bring to bear on the tasks at hand. The resulting model portrays changes in accumulated knowledge through time and suggests that relative expertise among doctors and technicians dynamically affects which group performs which task, which in turn affects who knows how to do what. These feedback dynamics play a significant role in whether the interactions between technicians and doctors unfold collaboratively or not.

If one subscribes to a socially constructed view of knowledge, then methods for representing who knows what when, and the ways in which relative expertise can change through time, can prove valuable to the study of knowledge sharing. Theories of structuration (Bourdieu 1980/1990; Giddens 1984) view social life as unfolding through a recursive process in which accumulated values and properties (sometimes called "capital") of institutions or individuals shape daily activities, which in turn can conserve or transform actors' accumulated capital. Often momentary activities and enduring properties reinforce each other as people choose to recreate the patterns and practices they have experienced in the past, but sometimes people draw differentially on accumulated experiences to create activities viewed as "new" or "changed." System dynamics modeling provides a particularly useful method for representing interactions between activities and actors' accumulations of capital through time. It moves from the researcher to computer simulation some of the burden of reasoning about outcomes of complex, recursive relationships; its stock-and-flow grammar is well suited to represent accumulations of capital (such as knowledge) and their effect on activities; and it is an inductive tool appropriate to building models beginning with salient elements of a field setting.

V. The Group Modeling Process

For more than 15 years, the modeling group at the University at Albany has been experimenting with techniques for building computer models directly with groups (Mumpower et al, 1998; Richardson et al, 1992; Rohrbaugh, 1992; Schuman and Rohrbaugh, 1991). More recently, these techniques have been used to construct system dynamic models (Richardson and Andersen, 1995 and 1997; Rohrbaugh, 2000). During these years of experience, researchers in the group have identified and described five distinct roles to be played during the modeling session: facilitator, modeler/reflector, process coach, recorder, and gatekeeper (Richardson and Andersen, 1995). The modeling team interacts with the client group to elicit, in the iterative way described above, the behavior and structure of the system to be modeled following a well-identified set of scripts (Andersen and Richardson, 1997). The work in group model building at Albany links to other similar efforts in the field (Vennix, 1996)

According to the scripts described in previous work, the modeling group prepared the sessions through several interviews with CTG researchers involved in the development of HIMS. During these preliminary interviews both groups made decisions about the schedule and the people to be involved in the modeling sessions. The participation and intervention of one of the authors of this paper (Cresswell) was particularly relevant to the modeling project. Because of his good understanding of the System Dynamics modeling methodology and its applications, he played the role of gatekeeper as described in Richardson and Andersen (1995).

Once the CTG research team a consented to the modeling experience, the modeling group designed two one-morning sessions. During the first of them, the CTG group was introduced to the System Dynamics ideas of stocks, flows, causal loops, structure and behavior through the discussion of a "concept model" (Figure 2) as proposed by Andersen and Richardson (1995, 1997). This session served as a fast introduction to System Dynamics concept models and constituted the starting point for the group discussion about the system to be modeled. During the first session the CTG group made several decisions about the purpose of the model, its boundaries, the key variables, the main reference modes, and the major loops of the model.

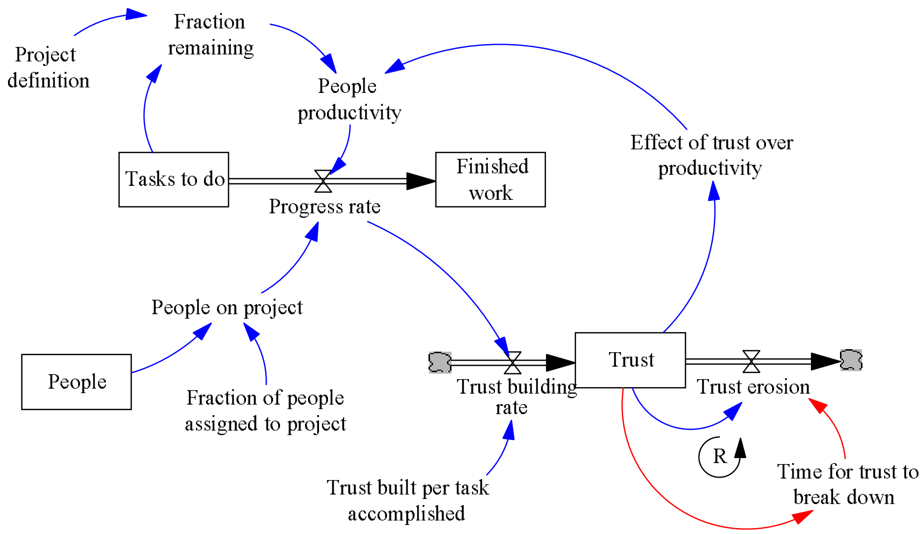


Figure 2 - Concept model used in the first modeling session

During the second modeling session, the group focused on the discussion of the preliminary model presented in the next section of this paper. After comparing and contrasting the formulated model with the set of conceptual maps developed in the first meeting, the modeling group ran some simple experiments with the model in order to get a better understanding of the feedback processes embedded in the model. Moreover, the team discussed the strengths and weaknesses of the model, enriching the initial model conceptualization.

V. The Preliminary Model

Model Overview

The preliminary model developed from the behavior and structure elicitation of the first modeling session is the four-sector model depicted in Figure 3 (*Trust1*; an equation listing is included as an appendix). The main sectors of the model are the Project Sector, the Providers Sector, the State and Bureau of Housing Services (BHS) Sector, and the CTG Sector. The Project Sector includes the prototype development tasks and the accumulation of prototype components. Some of these components are imperfect and have attached to them some problems caused by the lack of group agreement. Project progress, combined with the average problems per component, constitutes the demonstrated results of the HIMS prototype. These demonstrated results promote engagement by both the State and the Providers participants.

On the other hand, prototype development depends on the collaborative effort and level of involvement of the two groups, state agency and service providers, facilitated by the CTG research team. State agency has two feasible outputs. They could promote prototype component development, but they could prevent project progress if there is no collaboration or peoples' participant engagement in the project.

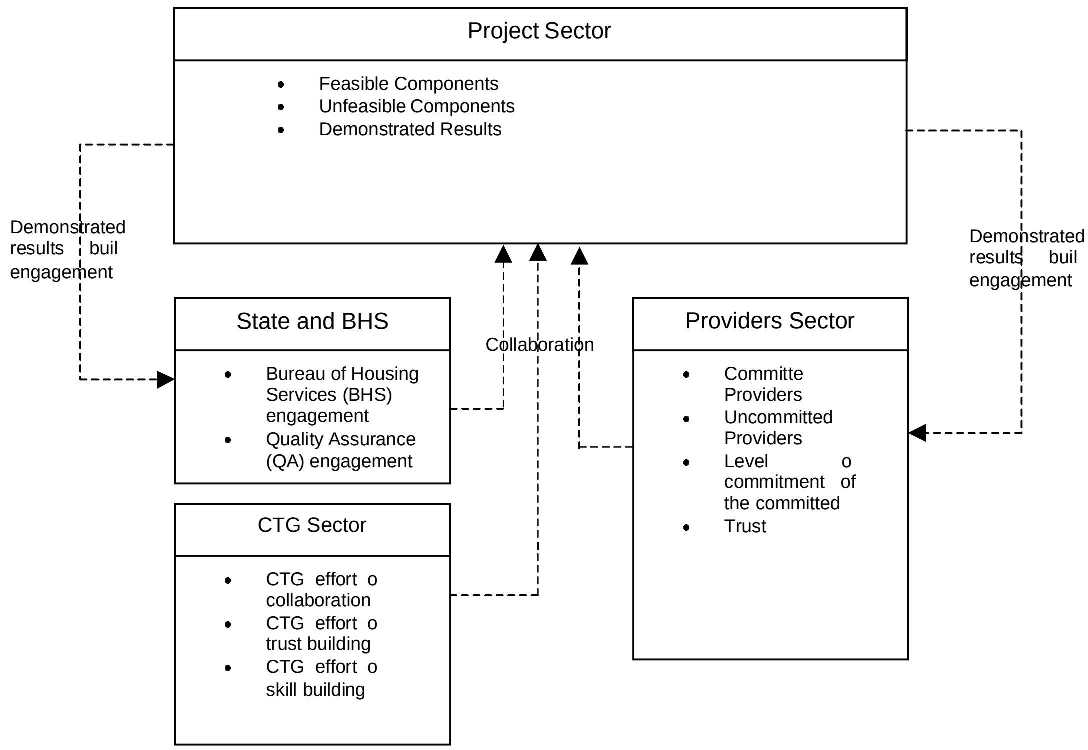


Figure 3 - *Trust1* model sectors

<u>CTG Sector</u>

This preliminary model considers the CTG research team as an exogenous factor. That is to say, CTG team activities are not involved in any feedback loop and they are considered as constants. As it is shown in Figure 4, the model assumes that CTG effort is divided between two main activities, project tasks and collaboration. The effort in project tasks represents people working in task development, and the effort on collaboration represents people working on tasks associated with the facilitation process and collaboration management (responsibility of collaboration). Some of the tasks associated with collaboration management and facilitation include making phone calls to service providers, facilitating meetings, and writing reports. Because of the nature of these activities, the model considers three different effects associated with this effort. The facilitation portion works to catalyze the collaborative efforts of servi ce providers and government. The collaboration management fraction promotes a higher level of contacts among providers by calling them to meetings and work sessions. On the other hand, the effort devoted to the responsibility of collaboration sustains participant engagement by reminding them of project progress and achievements through phone calls, progress reports, etc.

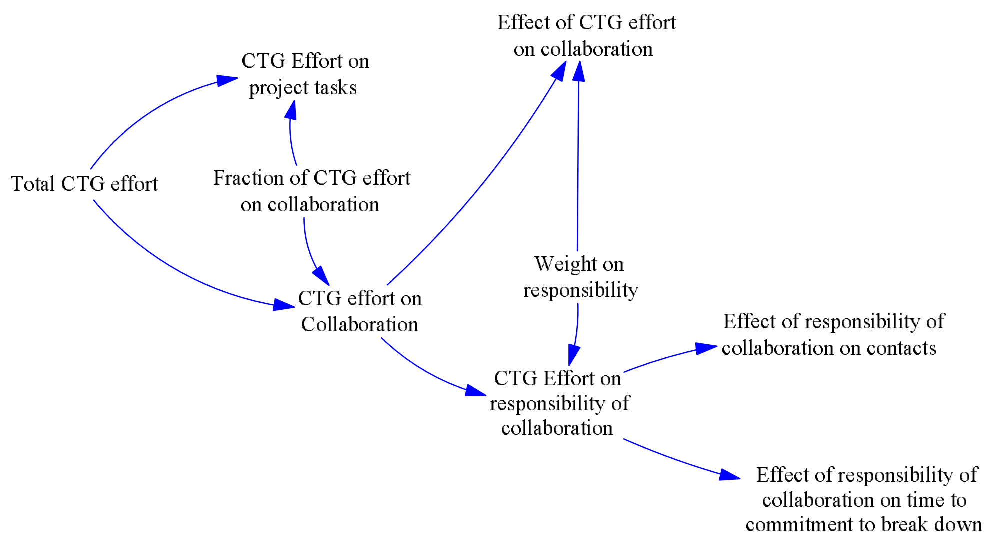


Figure 4 - CTG effort allocation in Trust1 (CTG Sector)

<u>State and BHS Sector</u>

The State Sector in Trust1 represents the BHS and QA effort committed and the level of engagement to the project (Figure 5). The level of engagement is influenced by the project perceived potential. As it was stated above, the perceived potential is one of the variables in the Project Sector that depends on project progress and the extent of agreement in project components.

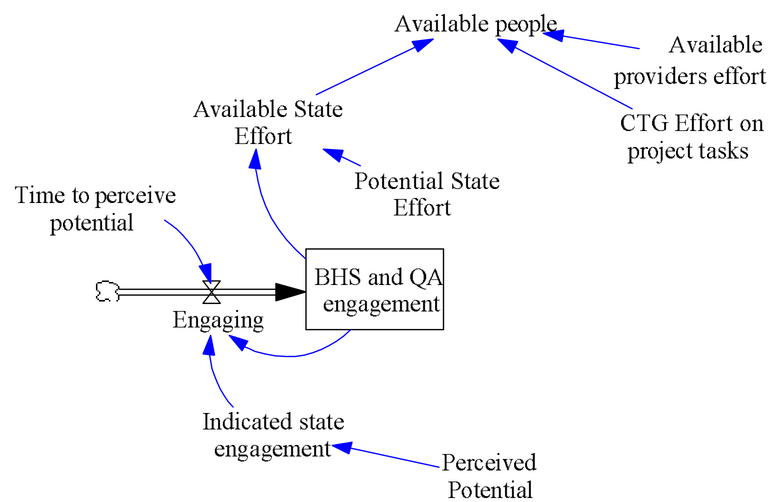


Figure 5 - BHS and State Sector

Engagement is defined in the model as a dimensionless value between 0 and 1. Thus, the effort allocated to the project is proportional to the level of engagement and the maximum effort that the State is willing to allocate to the project (Potential State Effort). State effort is added to CTG effort and providers' effort in order to get the available people to work on the project.

<u>Providers Sector</u>

Similar to the State Sector, the Providers Sector represents the quantity of providers committed to the project and the level of provider engagement to the project (Figure 6). Both, the level of engagement and the number of committed providers grow as functions of the perceived potential of the project. Both levels are drained in proportion to the average time for commitment to break down. The number of committed providers is modeled as an epidemic process, where the virulence of the commitment "infection" is a function of the average engagement per provider. The average engagement per provider is modeled as a weighted average of the engagement of the providers committed to the project. That is to say, providers join the committed group with a level of engagement based on the perceived potential of the project. This new engagement level is averaged with the engagement of the providers previously committed. As shown in the Figure 6, the number of contacts among providers and the time for commitment to break down depends on CTG effort on collaboration.

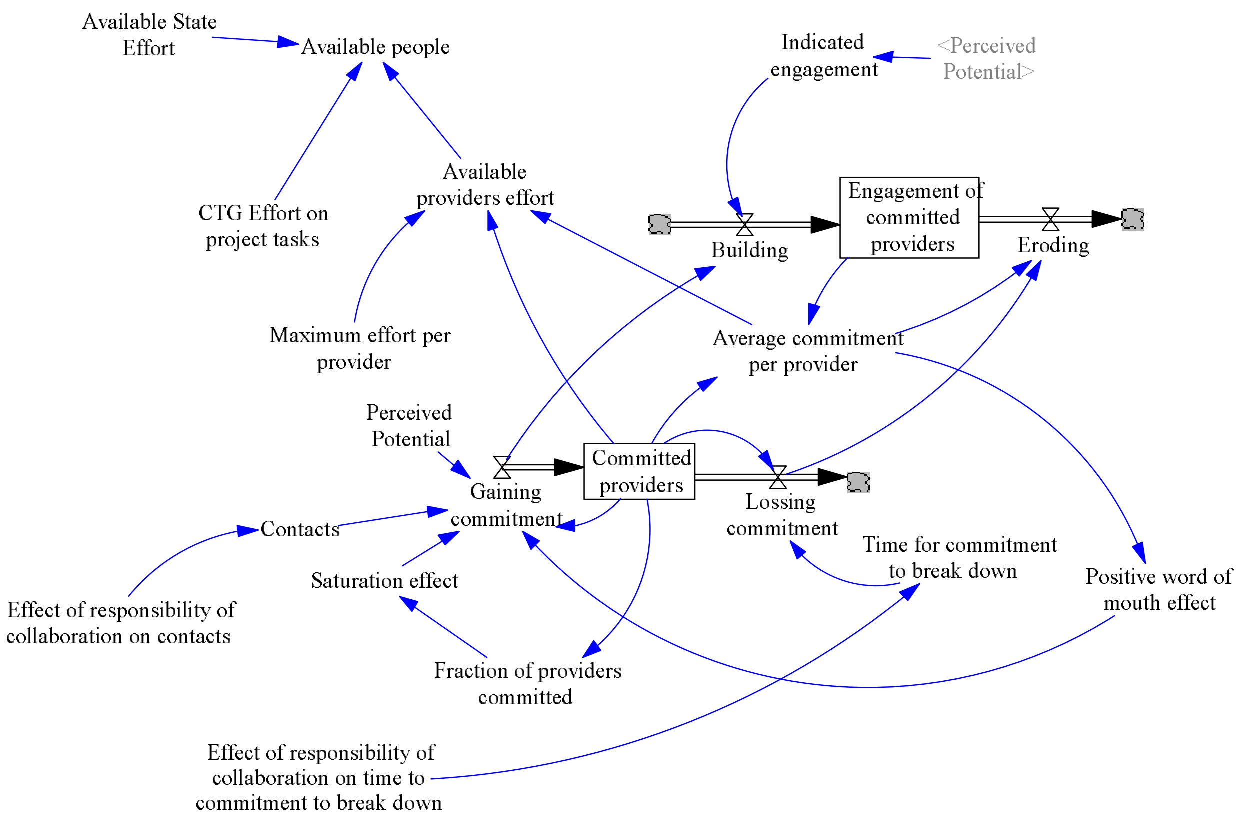


Figure 6 - Providers Sector in *Trust1*

Finally, the number of committed providers and the average engagement per provider determine the total provider effort on project development. This effort is added to State and CTG efforts on project development.

Project Sector

The core of the *Trust1* model is a simple project management model that tracks progress throughout the Homeless Information Management System (HIMS) project (Figure 7). The project is modeled as the accumulation of HIMS components developed through time. People dedicated to the project develop components in terms of their personal productivity. People on project development are the addition of CTG, providers and State efforts coming from the other sectors. Project Definition is the number of tasks in the HIMS project. Similar to other System Dynamics project models, when the fraction of components assumed to exist approaches to 1, the willingness to adjust the work force on task is reduced.

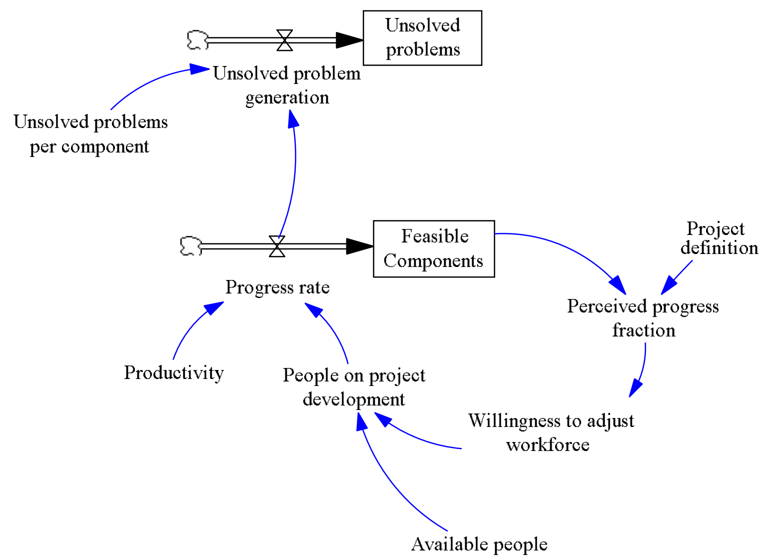


Figure 7 - Project progress in *Trust1*

However, each built component has a number of unsolved problems generated because of the lack of agreement inside the group. The number of unsolved problems per component is a function of the level of collaboration. When the level of collaboration is high, the unsolved problems per component are low (Figure 7). People's productivity is also proportional to the level of collaboration. When the collaboration level is high, the productivity is also high.

Collaboration is assumed to be a weighted average of providers and State involvement in the project. The model assumes that the state is willing to devote a maximum of 5 full time people to the project. The amount of effort actually committed to the project is proportional to the state level of engagement. On the provider side, the assumption is that each of the 118 potential providers is capable to commit a maximum effort equivalent to a half-time person. The amount of effort effectively committed is proportional to the average commitment per provider. CTG effort on collaboration (equivalent to a half-time person in the model) has a multiplier effect on collaboration.

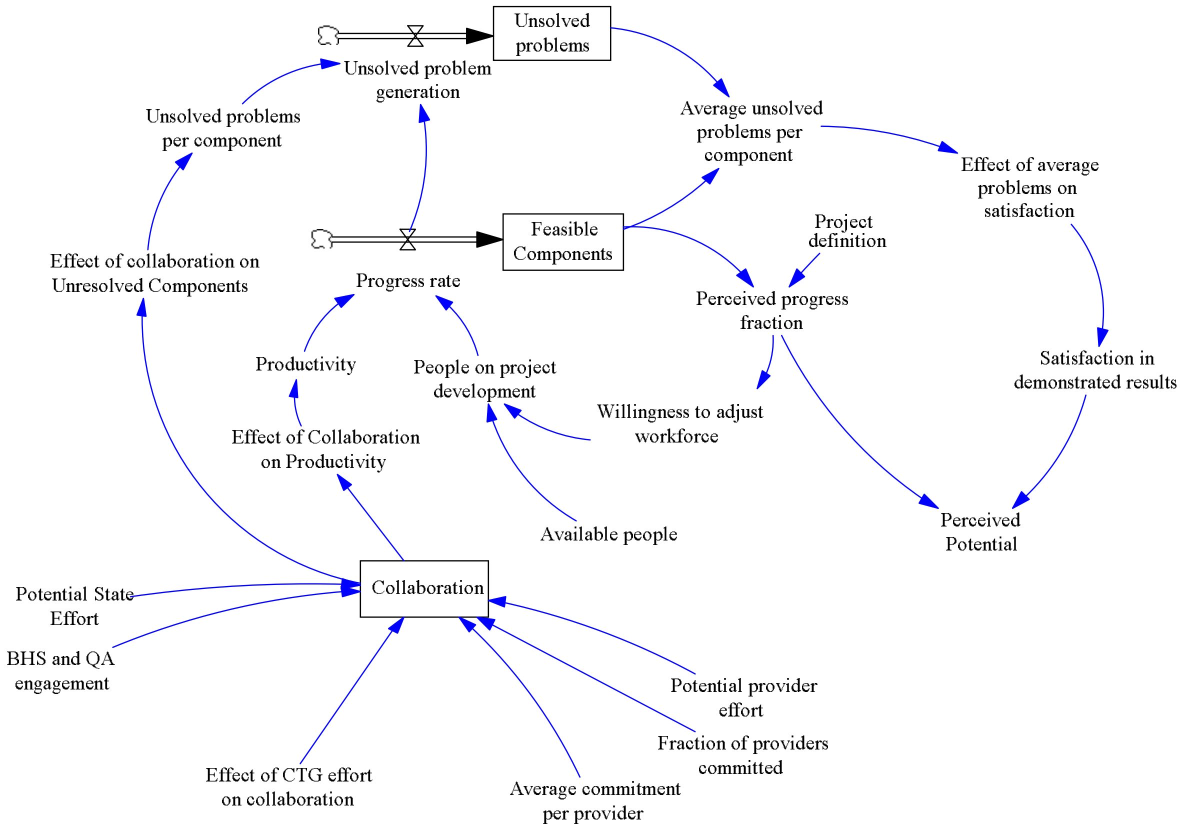


Figure 8 - Project Sector and collaboration structure in the model

Finally, the right side of Figure 8 shows the perceived potential structure as an average of the project progress and the satisfaction in demonstrated results. This satisfaction depends on the average unsolved problems per component. Perceived potential, project progress and satisfaction in demonstrated results are designed to be values between zero and 1.

VI. Results (Model Behavior)

<u>Base Run</u>

Once a model is developed, it is possible to experiment in a safe way with different parameters in order to analyze different scenarios. However, in order to have a reference point it is useful to have a base run with the basic model behavior (Figure 9). Figure 9 presents the base run of *Trust1* model.

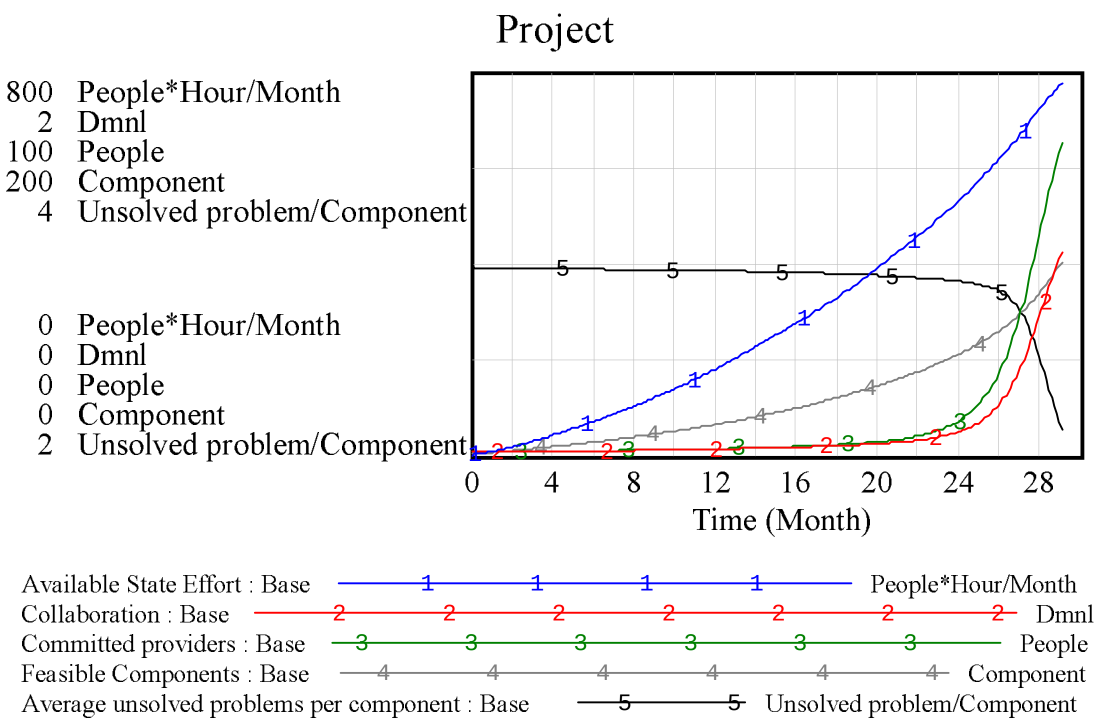


Figure 9 - Base behavior of *Trust1*

The base run shows the HIMS project ending in 29 months, with a sustained increase in the state effort on the project. Actually, state effort grows following the same qualitative behavior of the number of feasible components. The epidemic nature of the committed providers (a positive feedback structure), prevents provider involvement during the early project stages, but promotes a fast growth once the demonstrated results are enough to accelerate the contagious process. Collaboration follows the same qualitative behavior of committed providers. Finally, the average unsolved problems per component remains high until the level of collaboration starts to grow.

<u>Experiment 1: No CTG Effort</u>

The first experiment eliminates all CTG effort from the project, by setting Total CTG effort to zero. The behavior obtained from this experiment is shown in Figure 10.

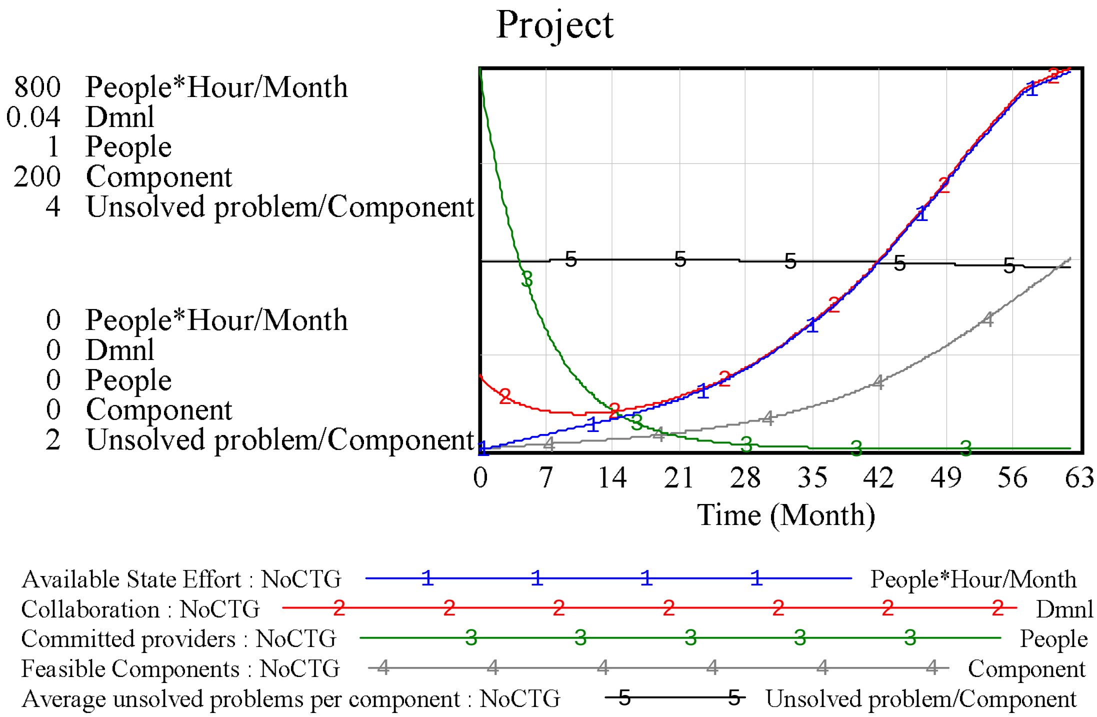


Figure 10 - Model Behavior without CTG intervention

With no involvement by CTG, the project is completed in about 63 months. The number of providers committed to the project is zero at the end. Project progress is advanced mainly by the state effort. The lack of providers' commitment causes collaboration never to reach a significant level, ending in a 0.04 value. No collaboration leads to high average unsolved problems per component. In other words, this experiment reflects a government project without user involvement. The result is a system with which people are not committed, and with a lot of potential problems left for implementation.

<u>Experiment 2: No facilitation Effort</u>

The second and last experiment eliminates CTG effort in collaboration. In this scenario, the project is finished in about 34 months, faster than in the No-CTG experiment because of the sustained CTG effort on task development. CTG effort is added to the state effort ending the project sooner. However, provider involvement declines in a manner similar to that seen in experiment 1, collaboration never increases and unsolved problems per component remain high (Figure 11).

The second experiment represents a project in which the government hires the services of an external agency to work in the project, but without considering user involvement. The project ends faster than without the external help. However, the level of commitment and the number of implementation potential problems remains similar to the previous experiment.

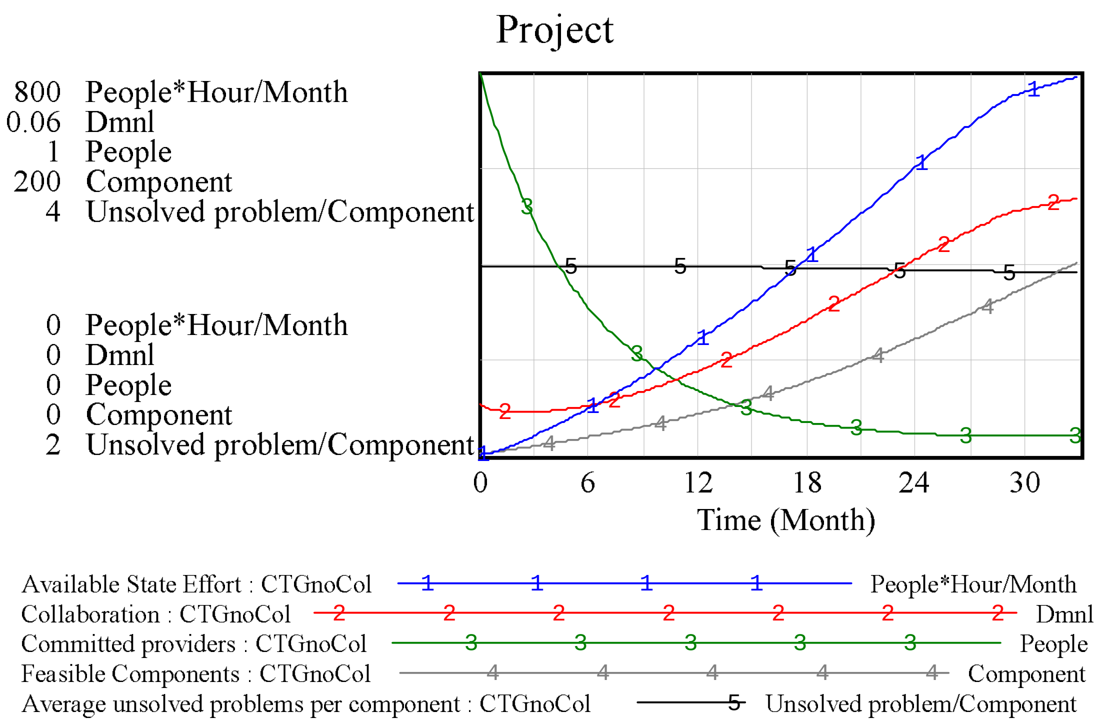
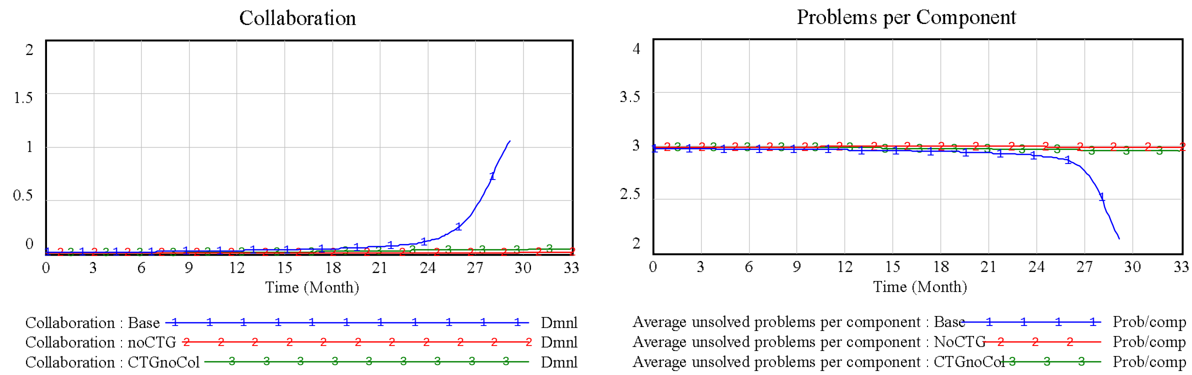


Figure 11 - Model behavior without facilitation effort

VII. Discussion

The modeling group developed the model with a relatively short time and low level of effort. Although *Trust1* is a preliminary model, it shows how the dynamics of trust and collaboration can be important to project management. Moreover, the same feedback structure generates both successful and unsuccessful scenarios. The policies used in experiments 1 and 2 show that the way in which collaboration and engagement are managed makes the difference.

Though level of collaboration was not important for project completion, it was important to drive out unsolved problems. Figure 12 a and b show comparative plots of collaboration and problems per component in the base run, the No-CTG and the No-facilitation-effort policy scenarios. Collaboration never improves in the policy scenarios where the effort on collaboration is eliminated, no-CTG and No-facilitation. Problems per component also remain at its higher level in the same policy settings. However, these results are very preliminary and *Trust1* model needs further work.



(a) (b)

Figure 12 - Comparative plots of collaboration and problems per component in the base run and the No-CTG and No-facilitation-effort scenarios

VIII. Future Research

After analyzing model behavior during the second modeling session, the CTG research team considered that the preliminary model constitutes a valuable tool to analyze collaboration in intergovernmental project settings, showing interesting and realistic behavior. However, the team identified several areas of further work in the model.

1. Fixing known problems. *Trust1* has some known problems that should be fixed in order to improve model behavior. It is needed to include a quality control structure to review the unsolved problems per component. The lack of this quality control structure and the accumulation of problems are the main explanation for satisfaction never to take off.
2. The "epidemic" nature of committed units ends with an all or nothing behavior. It could be important to experiment with alternative structures to model providers commitment.
3. On this preliminary model, collaboration is a CTG burden, that is to say, providers are assumed not to have the ability to collaborate or learn how to collaborate. Future versions of the model should add to providers the capacity to learn how to collaborate.
4. Explore how CTG allocates effort dynamically in terms of the observed results is an other interesting path to further model development.
5. The initial model considers a one-stage project, while HIMS development is a 4-stage project. Expanding to a multi-phase view is another feasible way to go. Through the development of these four stages, it could be interesting to explore providers' project understanding as an iterative process. That is to say, project understanding and learning never stops during project development.
6. Trust dynamics need to be explored in future model versions.

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Appendix – Model Equations

```
********************************
  .Control
********************************

(02)    INITIAL TIME = 0
        Units: Month

(03)    SAVEPER = TIME STEP
        Units: Month

(04)    TIME STEP = 0.125
        Units: Month

********************************
  .CTG Sector
********************************

(06)    CTG effort on Collaboration = Total CTG effort * Fraction of CTG effort on collaboration
        Units: People*Hour/Month

(07)    CTG Effort on project tasks = Total CTG effort * ( 1 - Fraction of CTG effort on collaboration
          )
        Units: People*Hour/Month

(08)    CTG Effort on responsibility of collaboration = CTG effort on Collaboration
     * Weight on responsibility
        Units: People*Hour/Month

(09)    ECTGC f ( [(0,0)-(2,2)],(0,1),(0.2,1.02),(0.4,1.1),(0.6,1.2),(0.8,1.33)
       ,(1,1.5),(1.2,1.67),(1.4,1.8),(1.6,1.9),(1.8,1.98),(2,2),(10,2)
       )
        Units: Dmnl

(10)    Effect of CTG effort on collaboration = ECTGC f ( CTG effort on Collaboration
       * ( 1 - Weight on responsibility ) / Indicated effort on collaboration
          )
        Units: Dmnl

(11)    Effect of responsibility of collaboration on contacts = ERCC f ( CTG Effort on responsibility of collaboration
       / Indicated effort on responsibility of collaboration )
        Units: Dmnl
```

(12) Effect of responsibility of collaboration on time to commitment to break down
= ERCT f (CTG Effort on responsibility of collaboration / Indicated effort on responsibility of collaboration
)
Units: Dmnl

(13) ERCC f ([(0,0)-(2,5)],(0,1),(0.1,1.05),(0.2,1.15),(0.3,1.3),(0.4,1.5)
,(0.5,1.75),(0.6,2.1),(0.7,2.55),(0.8,3.4),(0.9,4.5),(1,4.8),(1.1,4.9)
,(1.2,5),(1.3,5),(1.4,5),(1.5,5),(1.6,5),(1.7,5),(1.8,5),(1.9,5)
,(2,5),(10,5))
Units: Dmnl

(14) ERCT f ([(0,0)-(2,5)],(0,1),(0.1,1.05),(0.2,1.15),(0.3,1.3),(0.4,1.5)
,(0.5,1.75),(0.6,2.1),(0.7,2.55),(0.8,3.4),(0.9,4.5),(1,4.8),(1.1,4.9)
,(1.2,5),(1.3,5),(1.4,5),(1.5,5),(1.6,5),(1.7,5),(1.8,5),(1.9,5)
,(2,5),(10,5))
Units: Dmnl

(15) Fraction of CTG effort on collaboration = 0.5
Units: Dmnl

(16) Indicated effort on collaboration = 40
Units: People*Hour/Month

(17) Indicated effort on responsibility of collaboration = 15
Units: People*Hour/Month

(18) Total CTG effort = 168
Units: People*Hour/Month

(19) Weight on responsibility = 0.3
Units: Dmnl

*********** *********************
.Project Sector
****

(21) Average unsolved problems per component = Unsolved problems / Feasible Components

Units: Unsolved problem/Component

(22) Collaboration = (Average commitment per provider * Fraction of providers committed
* Potential provider effort / (Potential provider effort + Potential State Effort
) + BHS and QA engagement * Potential State Effort / (Potential provider effort
+ Potential provider effort)) * Effect of CTG effort on collaboration

Units: Dmnl

(23) EAPS f ([(0,0)-(6,1)],(0,1),(0.5,0.99),(1,0.95),(1.5,0.9),(2,0.8),(2.5,0.67)
,(3,0.5),(3.5,0.33),(4,0.2),(4.5,0.1),(5,0.05),(5.5,0.01),(6,0)
)
Units: Dmnl

(24) ECOP f ([(0,0)-(2,2)],(0,1),(0.2,1.12),(0.4,1.4),(0.6,1.73),(0.8,1.95)
,(1,2),(1.2,2),(1.4,2),(1.6,2),(1.8,2),(2,2))
Units: Dmnl

(25) ECUC f ([(0,0)-(2,1)],(0,1),(0.2,0.87),(0.4,0.58),(0.6,0.22),(0.8,0.05)
,(1,0),(1.2,0),(1.4,0),(1.6,0),(1.8,0),(2,0))
Units: Dmnl

(26) Effect of average problems on satisfaction = EAPS f (Average unsolved problems per component
/ Group tolerance to unresolved problems)
Units: Dmnl

(27) Effect of Collaboration on Productivity = ECOP f (Collaboration)
Units: Dmnl

(28) Effect of collaboration on Unresolved Components = ECUC f (Collaboration
)
Units: Dmnl

(29) EPPP f ([(0,0)-(1,1)],(0,1),(0.1,1),(0.2,1),(0.3,0.95),(0.4,0.85),(0.5,0.65)

,(0.6,0.2),(0.7,0.05),(0.8,0.03),(0.9,0.01),(1,0.001))
Units: 1/Month

(30) Feasible Components = INTEG(Progress rate , 0.001)
Units: Component

(31) FINAL TIME = IF THEN ELSE (Perceived progress fraction < 1 - 0.001, 100
, Time)
Units: Month

(32) Group tolerance to unresolved problems = 0.5
Units: Unsolved problem/Component

(33) Maximum unresolved problems = 3
Units: Unsolved problem/Component

(34) Normal productivity = 1
Units: Component/(People*Month)

(35) People on project development = SMOOTH (Available people , 1 / Willingness to adjust workforce
)
Units: People

(36) Potential provider effort = Maximum effort per provider * Provider total population

Units: People*Hour/Month

(37) Productivity = Normal productivity * Effect of Collaboration on Productivity

Units: Component/(People*Month)

(38) Progress rate = People on project development * Productivity
Units: Component/Month

(39) Project definition = 100
Units: Component

(40) Unsolved problem generation = Unsolved problems per component * Progress rate

Units: Unsolved problem/Month

(41) Unsolved problems = INTEG(Unsolved problem generation , 0.003)
Units: Unsolved problem

(42) Unsolved problems per component = Maximum unresolved problems * Effect of collaboration on Unresolved Components

Units: Unsolved problem/Component

(43) Willingness to adjust workforce = EPPP f (Perceived progress fraction
)
Units: 1/Month

****
.Provider Sector
****

(45) Average contacts normal = 4
Units: 1/Month

(46) Building = Gaining commitment * Indicated engagement
Units: 1/Month

(47) Contacts = Average contacts normal * Effect of responsibility of collaboration on contacts

Units: 1/Month

(48) Engagement of committed providers = INTEG(Building - Eroding , 1)
Units: Dmnl

(49) Eroding = Average commitment per provider * Losing commitment
Units: 1/Month

(50) Fraction of providers committed = Committed providers / Provider total population

Units: Dmnl

(51) Gaining commitment = Committed providers * Contacts * Perceived Potential
* Positive word of mouth effect * Saturation effect
Units: People/Month

(52) Indicated engagement = IE f (Perceived Potential)
Units: 1/People

(53) Losing commitment = Committed providers / Time for commitment to break down

Units: People/Month

(54) Normal time to commitment to break down = 6
Units: Month

(55) Positive word of mouth effect = PWOME f (Average commitment per provider
)
Units: Dmnl

(56) Provider total population = 118
Units: People

(57) PWOME f ([(0,0)-(1,0.1)],(0,0),(0.1,0.005),(0.2,0.01),(0.3,0.02),(0.4,0.04)
,(0.5,0.068),(0.6,0.088),(0.7,0.095),(0.8,0.097),(0.9,0.099),(1,0.1)
)
Units: Dmnl

(58) Saturation effect = SE f (Fraction of providers committed)
Units: Dmnl

(59) SE f ([(0,0)-(1,1)],(0,1),(0.1,0.98),(0.2,0.9),(0.3,0.8),(0.4,0.67),(0.5,0.5)
,(0.6,0.33),(0.7,0.2),(0.8,0.1),(0.9,0.02),(1,0))
Units: Dmnl

(60) Time for commitment to break down = Normal time to commitment to break down
* Effect of responsibility of collaboration on time to commitment to break down

Units: Month

****
.State Sector
****

(62) Available people = (Available providers effort + CTG Effort on project tasks
+ Available State Effort) / One people effort per month
Units: People

(63) Available providers effort = Committed providers * Average commitment per provider
* Maximum effort per provider
Units: People*Hour/Month

(64) Available State Effort = Potential State Effort * BHS and QA engagement

Units: People*Hour/Month

(65) Average commitment per provider = Engagement of committed providers /
Committed providers
Units: 1/People

(66) BHS and QA engagement = INTEG(Engaging , 0)
Units: Dmnl

(67) Committed providers = INTEG(Gaining commitment - Loosing commitment ,
1)
Units: People

(68) Engaging = (Indicated state engagement - BHS and QA engagement) / Time to perceive potential

Units: 1/Month

(69) IE f ([(0,0)-(1,1)],(0,0),(0.1,0.3),(0.2,0.55),(0.3,0.75),(0.4,0.9),(0.5,0.95)
,(0.6,0.99),(0.7,0.99),(0.8,1),(0.9,1),(1,1))
Units: 1/People

(70) Indicated state engagement = IE f (Perceived Potential)
Units: Dmnl

(71) Maximum effort per provider = 84
Units: People*Hour/Month

(72) One people effort per month = 168
Units: hours/Month

(73) Perceived Potential = Satisfaction in demonstrated results * (1 - Weight in results
) + Perceived progress fraction * Weight in results
Units: Dmnl

(74) Perceived progress fraction = Feasible Components / Project definition

Units: Dmnl

(75) Potential State Effort = 840
Units: People*Hour/Month

(76) Satisfaction in demonstrated results = Effect of average problems on satisfaction

Units: Dmnl

(77) Time to perceive potential = 1
Units: Month

(78) Weight in results = 0.5
Units: Dmnl