EXTENDING ENTERPRISE MODELING BEYOND ENGINEERING - A LIFE CYCLE MODEL OF HYDRAULIC SYSTEMS

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SUMMARY

In our work on enterprise engineering we are concerned with developing a framework and methodology for modeling real world enterprise. Our primary concern is that the resulting enterprise models should give *insight* into the operation of today's enterprise, and allow systematic studies to *predict* likely effects of proposed changes.

Last year, at the CIB W78 workshop in Helsinki, we presented an initial overview of CAESAR, an architecture for enterprise modeling in the AEC industry. CAESAR addresses the Objectives, Product, Process and Organization (OPPO) aspects of enterprise, and covers the complete life-cycle, including requirements specification, conceptual design, detailed engineering, approval, fabrication/ installation, operation, maintenance, and decommissioning.

This year we apply the CAESAR framework to develop a simple model of a hydraulic system for oil production facilities. Such hydraulic systems are used for a variety of control tasks on offshore platforms, where different users have a range of different functional and operational requirements.

We use the hydraulic system model to derive measures of coordination load, which may be used as input to simulate project execution as a set of information processing tasks. The Virtual Design Team (VDT) discrete event simulator is used to predict changes in development schedule and life-cycle cost due to changes in scheduling and execution of design and development.

1. INTRODUCTION

The objective of our research is to develop a methodology, framework and tools for rapid and reliable construction of project enterprise models. This is motivated by a belief that integrated models of project enterprise will constitute a valuable tool for decision support in both project planning, manning and execution.

At the CIB W78 conference last year in Helsinki, Finland, we presented the CAESAR framework for enterprise modeling in the AEC industry, and showed applications in offshore field development projects [Christiansen & Thomsen 94]. This year we extend the framework to include the complete life-cycle of AEC project deliverables, and show how the CAESAR enterprise models may be input for discrete event simulation of selected parts of "life-cycle projects." In related work [Christensen 95] we are investigating the means for reengineering the business and support processes of traditional enterprise as internal projects.

In support of our objective the specific aims of this paper are to (1) describe a framework for developing integrated models of project enterprise, (2) outline a methodology for using the models to derive coordination requirements for simulation of project execution, and (3) indicate initial simulation results relating to life-cycle performance. Throughout the paper we use simplified descriptions related to the various stages in the life-cycle of hydraulic systems.

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2. A LIFE-CYCLE ENTERPRISE MODEL OF HYDRAULIC SYSTEMS

Enterprise modeling takes time and costs money, and thus enterprise models should have a purpose. The representation and reasoning of the model must be developed with this purpose in mind. Our current purpose is to study how enterprise models may enhance planning, manning and execution of projects. In this section we review the CAESAR framework and apply it to modeling the life-cycle of a hydraulic system in offshore oil production.

2.1 The requirement for complete and correct models

At last years conference [Christiansen & Thomsen 94] we argued that enterprise models need to give a *complete* and *correct* description of the aspects and phenomena under study, in order to enable accurate and reliable predictions about the probable effects of proposed changes.

Figure 2.1 summarizes the CAESAR framework. As shown, completeness is addressed in our philosophy for thinking about enterprise in terms of "an ***organization***, carrying out some (set of) ***process***(es) to create ***products*** which satisfy predefined ***objectives***." This highlights the "pillars" on which purposeful human action rests: why we act (the objective), what is the result of action (the products), when and how we act (the process), and with whom we interact (the organization). Within this framework, project enterprise is characterized by an assigned team of people, working together for a planned period of time to deliver according to specification, and thus achieve a stated purpose.

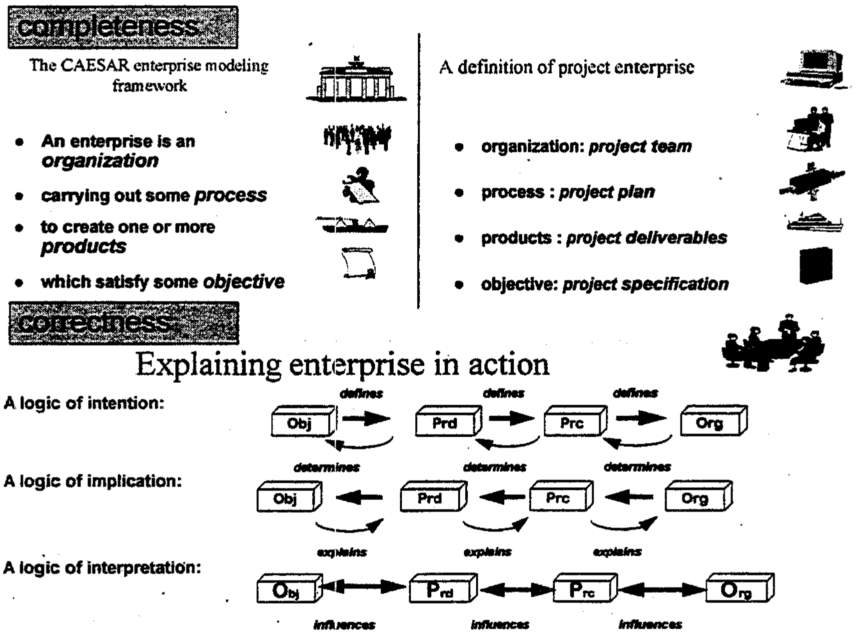


Figure 2. 1 An overview of the CAESAR framework for enterprise modeling

As purposeful professionals we like to believe that we inhabit a rational world, where enterprise is explained according to "*a logic of intention*" [March 88]. In this normative view causality is seen as a rational means for achieving fulfillment of stated objectives. In contrast, a natural systems view of enterprise, explains causality according to "*a logic of implication*" [March 88]. In this descriptive view causality is seen as a-posteriori justification of action. In reality, neither of the above models explain human enterprise in full. Reality is filled with bounded rationality [Simon 58], and causality can be seen in terms of "*a logic of interpretation*" resulting from both intention and implication.

Note how the word made up by the first letter of the four enterprise dimensions, ***OPPO***, is a palindrome. This symmetry symbolizes the way in which distance from enterprise whether in time, space or function, precludes accurate determination of causal mechanisms. That is, the difference between cause and effect is indistinguishable to the observer. The consequence of this duality for model correctness is that representation and reasoning must include constructs that allow description of the differences between intended and implied action, as well as *performance metrics* for the difference between planned action and actual behavior. The coordination load methodology outlined in section 3 attempts to address this difference by a set of coordination load measures which describe reasons for the differences between planned action and actual behavior.

2.2 A life-cycle model for AEC project deliverables

To cover the complete life-cycle of project deliverables we use a simplified, generic life-cycle model in which the various life-cycle phases are represented as sequential activities. These activities include requirements specification, conceptual design, detailed engineering, approval, fabrication/installation, operation, maintenance, and decommissioning. Within each activity (phase), there might be a large number of concurrent or overlapping subactivities, corresponding to the various tasks in the particular phase. In figure 2.2 we have used this view of the life-cycle to describe the complete life-cycle of a hydraulic system for process plant operation in offshore oil production.

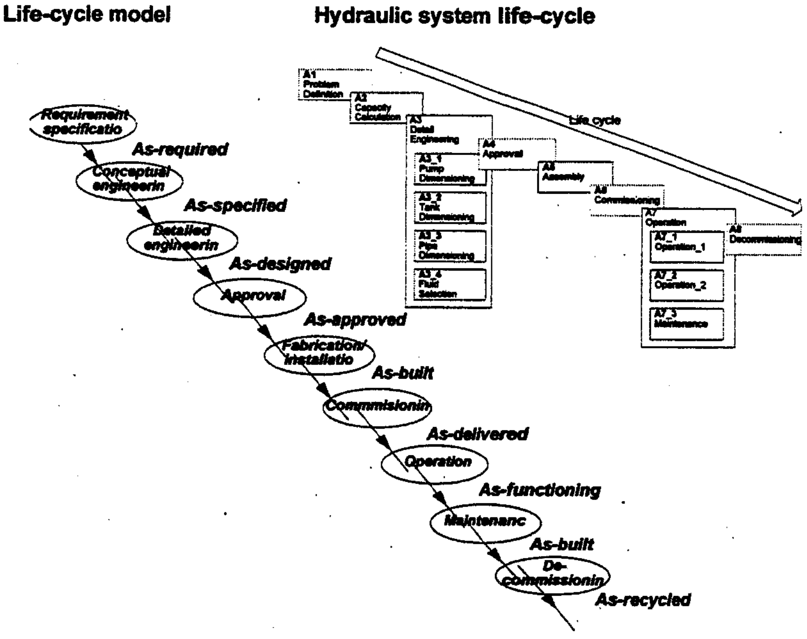


Figure 2. 2 The CAESAR life-cycle model of hydraulic systems

2.3 A spiral process model of the design process

To represent the design process deliverable we use a graphical representation of the various product model versions in a so-called REFUTS (REquirements - Functional Unit - Technical Solution) diagram for design of a hydraulic system. This is an elaboration of the well established FUTS diagram for product modeling in STEP [Willems 88]. The REFUTS diagram illustrates how a requirement for hydraulic energy is met by an abstract hydraulic system concept, which is solved by the actual hydraulic system. The *requirement structure* decomposes the overall hydraulic energy requirement into more detailed requirements for production, storage and distribution of energy. The *functional structure* describes the function and behavior of the hydraulic design concept, and decomposes the functional structure into a set of more detailed functions. The *topological component structure* describes technical solution in terms of a decomposition hierarchy of hydraulic system components, such as pump, tank and piping.

Using the REFUTS, the resulting "requirement driven" product model is a result of a design process which alters between requirement, function and solution in a spiral manner as the project deliverable is developed. Figure 2.3 shows an overview representation of the various product model structures and the design process for the hydraulic system.

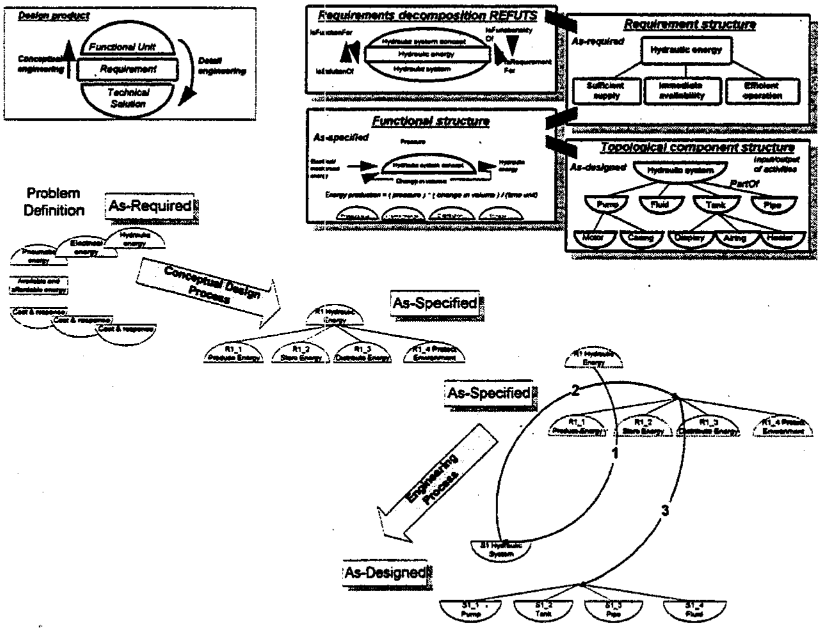


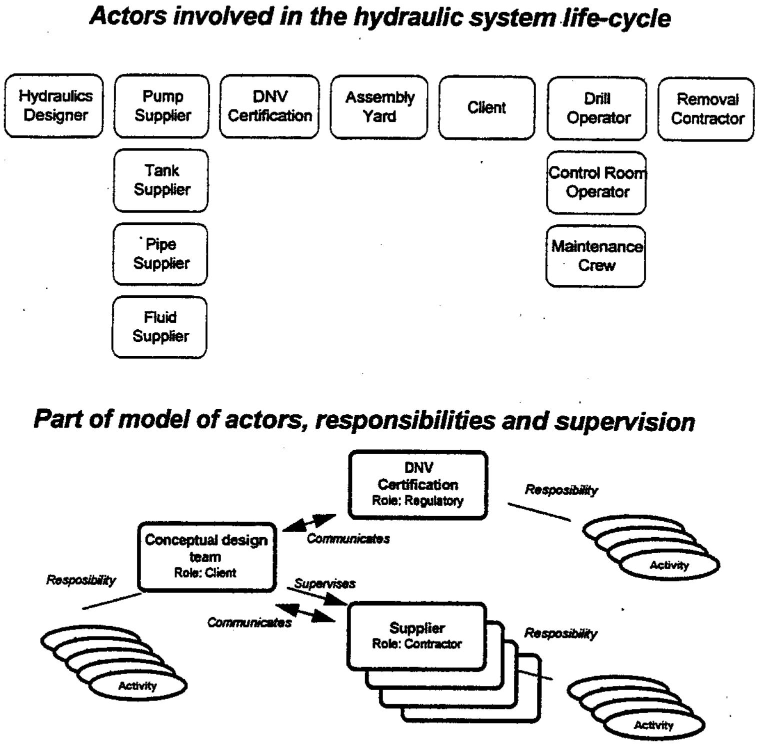
Figure 2. 3 An integrated view of the design process for hydraulic systems

This integrated design product and process model thus results in a set of aspect models of the project deliverable, corresponding to various stages in the life-cycle of the project deliverable.

2.4 A model of organization in AEC projects

The organizational model in CAESAR defines the organization in terms of actors, each of whom are tied to other actors in the organization by relations of supervision (reports-to) and information exchange (communicates-with). and are assigned to selected process activities (and thus to requirements and solutions) by responsibility relations.

As mentioned previously, hydraulic systems serve a variety of control tasks on offshore oil platforms, subjected to a range of functional and operational requirements, and serving a number of different users. Figure 2.4 shows the main actors responsible for various parts of the life-cycle and illustrates the actor model of organizations.


Actors involved in the hydraulic system life-cycle

Part of model of actors, responsibilities and supervision

Figure 2. 4 A model of organizational actors, responsibilities, and supervision

2.5 A reference model of coordination in AEC project teams

The way in which organizational actors coordinate their work is an important determinant of action and performance of the enterprise. In the CAESAR model we distinguish between [Fergusson 94] -

- *vertical coordination* associated with the flow of control. This includes verification.
- *horizontal coordination* associated with the flow of information, energy and resources. This includes communication, collaboration and competition.
- *longitudinal coordination* associated with the flow of experience. This includes adaptation of organizational behavior (organizational learning).

In order to model coordination we use a set of different coordination mechanisms, including *verification* to find errors, *communication* to exchange information, *collaboration* to support work processing, *competition* to secure resources, and *adaptation*, to modify behavior in response to environmental change. In the simulation of projects in VDT [Jin 95] described in the next section, only the first two mechanisms, verification and communication are implemented.

3. AN INFORMATION PROCESSING MODEL FOR SIMULATION

Our view of project execution is in terms of information processing [Galbraith 73]. This view is based on the analogy between organizational and physical structures. Both consist of elements, connected by nodes, and both respond to given loads from the environments. For both we can also think of structural performance in terms of the required behavior under load. The big difference between organizational and physical structures lies in the characteristics of the material properties, since the properties of humans are both non-linear, stochastic, and time- as well as history-dependent.

3.1 A methodology for deriving coordination load

To describe the load and structure we have developed a methodology for defining coordination load, as a formal description for discrete event simulation of project execution [Christensen 95]. That is, we use the CAESAR model as input, and describe the interactions between requirements and solutions to get measures of product complexity. We couple requirements and solutions to process activities, to calculate requirements to the process, and obtain corresponding complexity measures for process activities. We also look at the flow of information between process activities to get calculation of product uncertainty, from the difference between required and available information. Finally we use the responsibility of project team members for the various requirements and solutions (i.e., for process activities) to get overall measures of interdependence between them. Figure 3.1 gives an summary overview of our methodology for defining and modeling the *load distribution* on the various project team members during project execution.

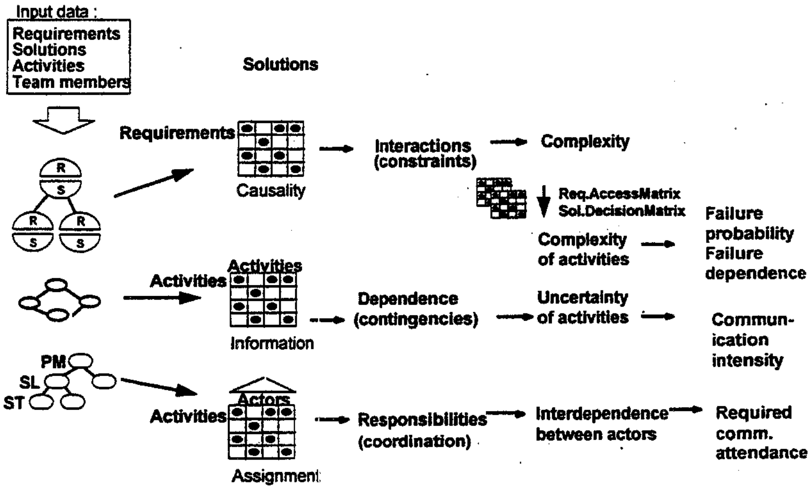


Figure 3. 1 An overview of coordination load calculation

These measures may be used to quantify the probability of failure in producing the various solutions and satisfying requirements, the required communication frequency, and the required participation by project team members. This is, in our view, an important part of describing work processes carried out in the real world by organizations consisting of boundedly rational (human) actors [Simon 58].

We have implemented the CAESAR framework and our coordination load modeling methodology in the Enterprise Development Toolkit (EDT) [Christensen 95]. EDT is a set of tools for enterprise modeling and analysis (enterprise engineering), built with the aim of defining, describing, analyzing and interpreting enterprise. The EDT tools, which are implemented on top of the Microsoft Office desktop and make extensive use of Object Linking and Embedding (OLE) and Dynamic Data Exchange (DDE), include a Definition Tool using the Visio[3] object oriented graphics editor, a Description Tool using Excel[3], a Load Calculation tool using the Powersim[3] system dynamics tool, an Analysis tool using the VDT simulator on top of Kappa[3], a Results Presentation tool using Excel[3], a Data Storage tool using Access[3], a Reporting tool using Word[3], and a Data Interchange tool based on OPDL (Organization and Project Description Language) [Jin 95]. Collectively, these tools will enable us to systematically investigate various aspects of enterprise design and development.

3.2 Discrete event simulation of project execution

The Virtual Design Team (VDT) program [Christiansen 93], [Jin 95], uses a formal description for discrete event simulation of project execution in engineering design. The VDT simulates performance to give predictions for the probable performance effects of proposed changes in project task and organization. Figure 3.2 shows the conceptual model of project participants as information processors, linked to the formal organization by supervisory relations, and to the requirements and deliverables by responsibility relations. The information exchange between project team participants are modeled in terms of communication tools and message passing between project team actors.

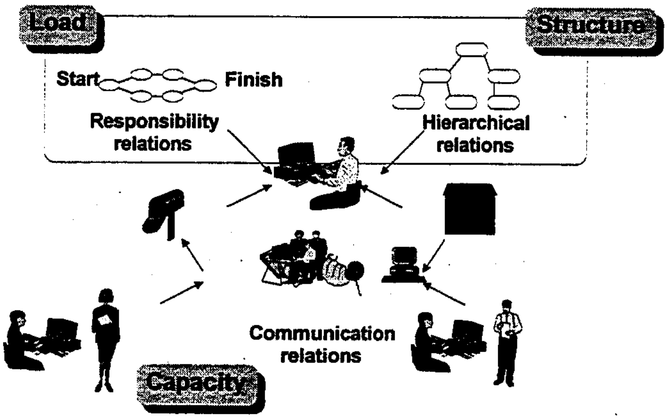


Figure 3. 2 An outline of the conceptual model for the VDT discrete event simulator

Given this formal representation of the CAESAR model we may simulate enterprise to obtain predictions of various performance characteristics. These may then be obtained for various enterprise configurations, to predict probable effects of changing the organization, process, product deliverables or project objectives. In the next section we show some typical simulation results related to the overall life-cycle performance of the hydraulic system.

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[3] (Visio - TM of Shapeware Corporation; Excel, Access and Word - TM of Microsoft Corporation; Powersim - TM of Modelldata; Kappa - TM of Intellicorp)

4. SIMULATION RESULTS

In this section we briefly review some typical simulation results for development time and life-cycle cost of hydraulic systems, obtained by simulation in the VDT [Jin 95].

Figure 4.1 shows a plot of the ration of actual to ideal project duration, as a function of the verification failure probability (complexity of the project requirements and solutions). This non-dimensional measure of efficiency may be thought as a form of Mach number in fluid mechanics. In the current model, projects can not be executed faster than ideal time, corresponding to the sonic barrier at Mach number 1, if the project could (somehow) be executed without coordination. Any coordination effects will slow down execution, resulting in "subsonic flow" at a Mach number below 1. An extension of the current simulation model, allowing actors to collaborate on activities (a coordination mechanism not yet included in the VDT model), would allow a duration below the "ideal" (supersonic flow)..

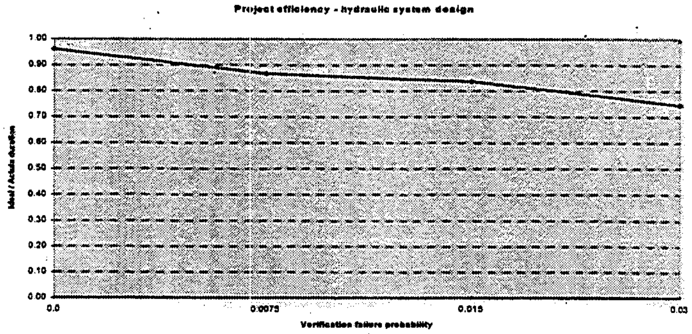

Figure 4. 1 The cost of complexity in design - development time as a function of complexity

The simulation in figure 4.1 illustrates how decoupling of requirements and solutions (lowering the verification failure probability) is likely to lead to a shorter project duration. Of course, since the figure shows the complete life-cycle, the term "duration" should not be taken literally. A shorter duration does not mean that the product lasts shorter, but rather that the life-cycle is executed more efficiently.

Figure 4.2 shows the coordination cost for the complete life-cycle, as a function of development time. The coordination cost is simply obtained by summing the time spent for rework and communication by all project team participants throughout the complete life-cycle. Development time is the project duration at completion of design approval.

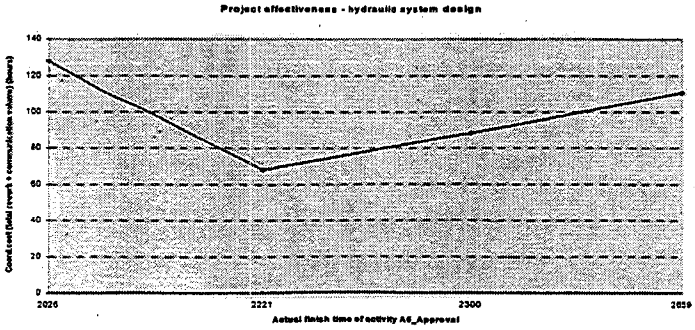

Figure 4. 2 The cost of concurrency in design - life-cycle cost as a function of development time

Development time in figure 4.2 is not equal to the project duration of figure 4.1, but increasing development time still corresponds to increasing failure probability. The reason for the increase in coordination at the lowest development time (lowest failure probability), is a marked increase in communication by all actors (who have more time to participate in communicatoin without a series of failures that needs to be handled). On the other hand, with higher failures probability there is more rework, and thus again coordination cost increases.

The simulation in figure 4.2 illustrates that life-cycle cost does not necessarily decrease linearly for any shortening of development time. Rather, there seems to be an optimal development time giving minimum cost. Below this "ideal development time" savings in production cost due to reduction in rework are countered by increase in coordination cost due to more communication both during development and in operation.

Comparing the two figures indicate how project performance is contingent on preferences. If rapid development of a maximally decoupled design is the primary target in the development phase, there may be a penalty due to higher communication requirements in the operational phase. This contingency of project execution on performance requirements illustrates yet another aspect of Thompson's [67] principle of contingency: "there is no best way to coordinate projects, but not all ways to coordinate are equally good".

Other simulation results include process quality in terms of how coordination was handled during execution. That is, the quality results involve the effects of not participating in coordination. This may be used to derive predictions for the quality of the project deliverable (the various requirements, functions and technical solutions), which serves as input for operational planning and maintenance scheduling.

5. ONGOING AND FUTURE WORK

In ongoing work we are further investigating the relationship between developmental and operational costs. By tying this to different policies for handling coordination, and the resulting coordination quality, we wish to obtain measures of the "life-cycle cost of confusion" in handling coordination.

In future work we will introduce explicit measures of man-hour cost. By allowing this cost to differ for different categories of personnel we plan to study the cost effectiveness of different ways to organize projects. In particular, we are interested in the "cost of contracting" in development and maintenance.

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