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Incorporating Global Characteristic Data into Virtual Product Development Models

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ABSTRACT

Computer-Aided Design tools (CAX: CAD/CAE/CAM) have dramatically changed the structure and activities of the product development process used by companies to develop and deliver product. Recent developments in Product Lifecycle Management (PLM) strategies and tools are also causing changes in the product development process. As important as the selection of the right product to develop, is the choice of the right process to develop it with. The proper process ensures that CAX tools and PLM strategies and tools are implemented and executed to the utmost advantage through product development deployment. Virtual product development is a process design and simulation strategy that provides techniques for preplanning the product development process and its deployment. Recent changes in the international market and business environments are also impacting product development processes. This paper presents research in methods to design and model the impact of global issues on potential product development processes.

Keywords: virtual product development, graph models, global issues
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1. INTRODUCTION

Computer-Aided Design tools (CAX: CAD/CAE/CAM) have dramatically changed the structure and activities of the product development process used by companies to develop and deliver product. Recent developments in Product Lifecycle Management (PLM) strategies and tools are also causing changes in the product development process. As important as the selection of the right product to develop, is the choice of the right process to develop it with. The proper process ensures that CAX tools and PLM strategies and tools are implemented and executed to the utmost advantage through product development deployment. Virtual product development is a process design and simulation strategy that provides techniques for preplanning the product development process and its deployment. Recent changes in the international market and business environments are also impacting product development processes. This paper presents research in methods to design and model the impact of global issues on potential product development processes. While the paper presents these methods and explores some examples, the research and tools are preliminary. Development of methods and tools to fully model all the complexities of transnational product development is beyond the scope of this work.

Nearly all product development today involves transnational organizations executing complex product development processes. This means that the actors who execute these product development processes are typically situated in different geographic locations, operate under different political and economic systems, and experience different education and training. It is therefore necessary for transnational corporations to develop models for analyzing the impact of global characteristics on their product development programs. Successful product development requires a careful balance of global characteristics, the actors within the organization, and the structure of the product development process. This paper presents a method that incorporates representations of such global factors while exploring virtual product development programs.

Virtual product development is a method for creating models and simulations of product development deployment. It enables the exploration of a variety of product development strategies in a given business situation and becomes especially useful as corporations expand internationally [20]. Graph based network models of the process and organization form the architecture of these models upon which a secondary calculus of metrics is imposed to score each deployment possibility. Necessary to the accurate representation of these business situations is the characterization and modeling of issues such as geographic diversity, political differences, educational disparities, etc. Development of a general theory for modeling these issues and their incorporation in virtual product development is the focus of this paper.

Virtual product development involves the construction of a reconfigurable network model that can be perturbed to identify all possible deployment configurations of the process and organization. These deployment configurations can be scored based upon a secondary calculus of metrics measuring the issues that will affect the deployments. The measurable metrics and secondary calculus are used to represent global issues and must be posed upon a model that incorporates process definition and organizational actors. A secondary calculus is a mathematical expression calculated over a network model to evaluate the effectiveness of the network. The combined process and organizational model must be reconfigurable in order to explore all possible deployment options; this is achieved by using autonomous agents to represent the matching of actors to process tasks. Agents are then combined dynamically to create a workflow which represents a product development deployment option, each agent carrying with it its own global characterization in the form of individual metrics that are propagated through the network using the secondary calculus. The resulting agent network enables dynamic workflow and the calculation of deployment performance through the rules of the secondary calculus applied across the network. These agent networks facilitate exploration of potential product development solutions based on combinations of actors and process configurations. Overall network performance calculations can be used to represent the impact of geographic, political, and other global elements within potential product development deployment models.

1.1 Problem Statement

Due to trends of increased globalization, the product development process is no longer localized or isolated. Whereas previously, each phase of a given process was executed in the same location by regionally similar actors, execution now occurs within a geographically diverse international community employing techniques such as virtual collocation and interaction, digital information management, and the use of global teams. Because the deployment of product development occurs in the international community, the resulting product development process is significantly more complex. Additionally, geographic diversity becomes an asset or liability, depending on the deployment strategy [3]. Successful global product development must be preplanned in a method that incorporates all issues that will potentially impact the deployment.

2. BACKGROUND

It is assumed that the reader is familiar with product development and the associated strategies and technologies. This background section will present material relating to methods of modeling product development processes, organizations, and incorporating global issues.

2.1 Graph Theory

The product development process models and organizational models used in this general method are based upon graph theory and network models. Graph Theory was developed through the solution of bridge problems in the late 1700's by Euler. The first book on Graph Theory was published in the early 1900s by Dennis Konig. The basic concept was to represent complex systems using collections of nodes and arcs that connected them [1]. From these graphs, mathematical theorems are derived which represent governing relationships in specific complex systems. These methods are used to model systems such as geometric simplexes used in solid modeling, where the nodes are vertices and the arcs are edges of geometric polygons. This led to the discovery of relationships such as Euler's characteristic number from the Euler-Poincare formula for the relationship between vertices and edges in the models of solid Euclidean Geometry [15]. Graph Theory has been applied to as diverse a set of systems as pedigree charts, sociograms, circuit diagrams, telephone systems, etc. For example, graph theory has been used to develop a general modeling technique for the design of mechanical systems. This technique is referred to as "Bond Graph Methods" [9].

In these methods, mechanical components are represented as nodes with associated physical characteristics. The arcs connecting the nodes represent the transfer of energy between the components in the form of motion, thermal energy, electrical energy, etc. The arcs therefore are annotated with associated values representing these flows of energy. The graphs are constructed by connecting nodes (components) through arcs (energy flows) and creating symbolic graph representations. The graph representations can then be traversed, collecting mathematical expressions at each node and along each arc to create the governing equations of the system.

In the late 1960s Charles Bachman applied the concepts of Graph Theory to computer systems and created what are known as network models [4]. Network models are a broad class of representations used to simulate systems of diverse entities and the interactions between them. The most common examples are representations of the World Wide Web, computer networks, and databases. Network models have been used to represent biological networks and task-based workflows in process models. In this paper, Graph Theory and the concepts of network models are used to represent real product development processes and organizational structures.

2.2 Product Development Process Modeling

The most common form of process modeling is a network model that represents workflow [18, 19]. Essentially, workflow can be represented as a schematic graph of all of the tasks or associated actors within a process where the arcs represent the interdependencies between the tasks or actors. These workflow models are used by organizations to identify, organize, and manage all of the tasks and actors within a product development process. Associated with these process models are organizational models which represent the personnel architecture of a company. In this paper, these models are treated as separate models and are linked through assignment of actors in the organization to tasks in the process.

2.3 Autonomous Agents

Autonomous agents are independent software elements that can be used to simulate real systems of actors. Autonomous agents have been used to simulate a variety of different types of systems such as military battles, economic markets, and political systems. Karpowitz provides a detailed background study of autonomous agent methods applied to the simulation of product development processes [10]. The basic idea of agent-based systems involves defining independently acting agents within an environment where interaction can occur. Lander explains that there is no clear definition of an agent [11]. However, a common, high level definition is that an agent is a computer system capable of independent action on behalf of a user. In the context of this paper, an agent is any actor, human, computer-system or otherwise that is capable of executing a specific task(s) that contributes to the pursuit of some overall product development process goal.

2.4 Globalization

The events of the late 20th century have resulted in a much expanded global market, economy, and social environment, the interconnectedness of political, social, cultural, and economic globalization becoming increasingly apparent [6]. The full effects of this globalization are yet to be discovered and the extent of their impacts realized. Companies today must convert from localized operations and strategies to globally resilient approaches in order to be successful in the 21st century marketplace. Much research has been performed to study the impacts of globalization through case studies. While general modeling theories have been developed for economic systems, market systems, etc, little has been accomplished in developing a general modeling theory specific to global product development. In this section we present a brief historical review of globalization and specific case studies.

2.4.1 History of Globalization

The so-called shrinking of the planet through globalization is not a new phenomenon, and not unique to the 21st or even the 20th century. The linking of geographically disparate locations, markets, governments, and other organizations can easily be seen in the establishment of ancient empires and economies. Bugliarello notes that the concept of production outsourcing was just as much a part of the ancient Ottoman Empire as it is a major element in current business strategy. The effects of modern globalization, however, are unprecedented both in their magnitude and in their reach [2].

A brief look at the history of Nike, Inc. from its conception to present-day status provides an example of the trend toward globalization and expansion in the 20th century. Now the world leader in athletic footwear, Nike, Inc. was founded as Blue Ribbon Sports in 1964 by Phil Knight and Bill Bowerman. Although originally the company began by outsourcing production to Japanese producers, changes in economy and market led Nike to seek producers elsewhere. Over the course of approximately one decade, Nike, Inc. opened shoe factories in New Hampshire and Maine, acquiring suppliers in Korea, China, Thailand, and Taiwan as well. In the early 1980s, the US Nike factories were closed and almost all production by Nike was outsourced to Asia. By 2006, Nike, Inc. had expanded to incorporate almost 700 factories, with nearly 800,000 employees in 52 countries, with 98 percent of Nike-brand footwear being manufactured by contract manufacturers in China, Indonesia, Thailand and Vietnam by the end of FY06 [17]. With a central location in the U.S. and 98 percent of production taking place overseas, the product development process becomes increasingly complex as deployment takes place on a global scale rather than in a centralized location. Nike's is only one of numerous examples demonstrating the difference in product development processes today from those of only a few decades previous. Because of this shift towards increased globalization, a change in the approach to product development is necessary.

2.4.2 Case Studies

There has been much research in characterizing and modeling the impact of globalization on businesses and organizations. Most of the modeling methods focus on development of hypotheses and collection of statistical data to validate or disprove these hypotheses. Examples of these methods are presented in this section. While these methods are essential to understanding and characterizing global changes, the focus of this paper is to present methods for a general modeling theory that can be applied practically to the preplanning and deployment of product development.

Malnight creates an evolutionary perspective through the study and modeling of the transition process, presenting a history of the transition of a multinational corporation from decentralized toward a network-based structure. While the model includes adjustments relating to global strategy, resource location, and operation management and structure, Malnight acknowledges that challenges accompanying expansion are not necessarily accounted for by multinational corporations making such a transition, making the response to both challenges and opportunities characteristic of this type of transition a strategic one [13]. In order to prepare for and where possible prevent such challenges, it is necessary to create a model that captures the relevant issues, placing them in a characterization for future models. Malnight's study of this transition process clearly presents the need for the model proposed in this paper.

The concept of determining product development capability is developed by Subramaniam and Venkatraman, with this concept being at the core of virtual product development. Although their work is valuable in aiding in the understanding of virtual product development and the transfer and deployment of knowledge across borders, it does not provide a usable model that can be employed in planning for product development [20].

Carpenter and Fredrickson develop a model for studying the impacts of the global issues of top management team characteristics such as international experience, education and other demographics that affect the ability of companies to expand and operate globally [3]. The model is developed by making a set of hypotheses regarding expected correlations between company effectiveness globally and these demographic factors. Data was collected from a set of companies and statistically analyzed through regression methods to determine if there were correlations. The conclusions show that there are correlations. The natural result from this model is that careful selection of top management team members should be done to positively influence the possibility of a company's ability to perform globally.

A study conducted by Tractinsky and Jarvenpaa examines the influence of global versus local contexts on an application's information technology distribution decision [21]. The amount and type of differences between managing information technology in a local context and in a global context is a source of debate among those involved in management activities, therefore this study was conducted in order to Tractinksy and Jarvenpaa assert that while the most important factors apply in both the global and domestic contexts, the global context brings into consideration important and relevant issues of variability, unfamiliarity, and complexity.

Fulk and DeSanctis provide a look at issues relating to organizational structure and their impact. Specifically, this study examines communication technology in relation to changing organizational forms. Although this study attempts to capture the changes that take place in terms of how an organization must be structured in order to best embrace the factors and issues that accompany globalization and affect the product development process, it simultaneously demonstrates the need to represent such issues in a product development process model [7].

Nault presents a modeling approach for representing investment organizations as a collection of nodes that are local and global investment centers. The effectiveness of the organization's overall investment strategy is calculated by summing a secondary calculus made up of local estimations of profit and costs [16]. Nault's approach incorporates the use of nodes, each of which are assigned specific quantities used in the application of a secondary calculus. This study specifically focused on modeling the impact of an effective information technology network on an investment organization. The organization was composed of centralized investment authority nodes as well as local investment authority nodes. A secondary calculus was defined for each of the nodes based upon the type of node, enabling the calculation of profit margins based upon investment decisions. The model, though not a complete graph model, allows for the profit margins to be calculated at each node and summed across all of the nodes. Optimization occurs by modifying the variables in the profit margin functions associated with market information allowing full investment.

This section has provided a very cursory overview of several examples of research and modeling methods for determining the impact of globalization on business operations when developing and offering products and services. The current literature does not provide a general modeling theory that could be practically applied by companies to preplan their product development process.

3. METHOD

As was explained in the Introduction, virtual product development is a method for creating models and simulations of product development deployment. In order to do this, the method must create the ability to evaluate product development programs that include characterizations of their global aspects. The potential to study product development programs requires an ability to automatically generate graph models of all possible workflows and apply secondary calculi to score these workflows. Graph models of workflows are created by assigning actors from the organization models to the tasks in the process models. Characterizations of the global aspects of these models are accomplished by establishing foundational principles and metrics for specific global issues. For purposes of illustration, reference to a global product development project coordinated by Brigham Young University will be included in this paper. PACE (Partners for the Advancement of Collaborative Engineering Education) provides software licenses each year to strategically selected academic institutions worldwide in order to improve the experience and education of engineering students. Participating students work on teams using software donated by PACE to design a project. In 2005, Brigham Young University was selected to participate as the lead university in this global design project, which involved over 140 students attending thirteen universities in eight different countries. Because of the global nature of this product development project and because it provides the opportunity for illustration and demonstration with simple models, examples will be used from this project to show the complexities and considerations associated with collaboration in the international community [8].

3.1 Characterization of Global Issues

Effective characterization of global issues requires the establishment of a database of metrics that have been collected, normalized, and validated. Much like the role of a company's material database, this global issues database will provide the metrics necessary for a company's modeling of product development. The establishment of this database is accomplished in four steps:

1. Identification of global issues,
2. Classification of global issues within a geographic context,
3. Definition of metrics for specific global issues, and
4. Collection and validation of global data.

3.1.1 Identification of Global Issues

Individual companies will find that certain global issues are more relevant to their activities than others. Identification of global issues, therefore, will be company-specific. In the context of this paper, global issues are characterized as any phenomenon – social, political, environmental, or otherwise – that influences a company's activities and varies on a global scale [6]. With this definition, each company will identify for itself a unique set of relevant global issues.

3.1.2 Classification of Global Issues

Globalization connotes a spatial distribution, therefore the foundational principles of geography form a context within which all other global phenomena can be examined and measured [6]. Five themes of geography that have been accepted generally are:

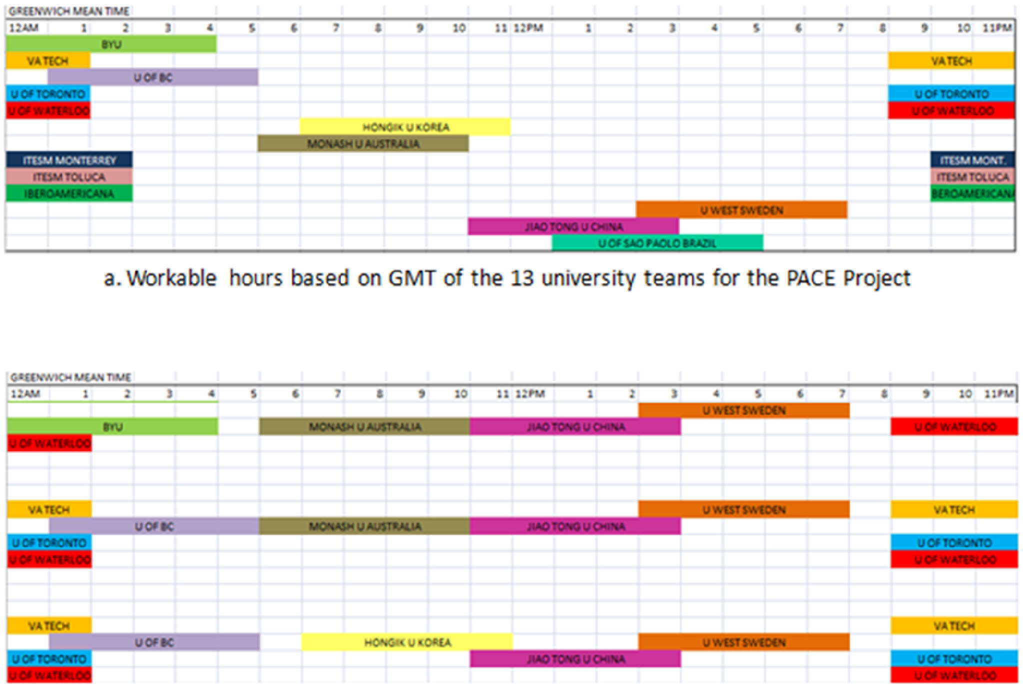
1. Region,

2. Place,
3. Location,
4. Movement, and
5. Human-Environment Interaction.

Within this contextual framework, metrics for measuring global phenomena can be selected based upon the relationship between the phenomena and each of the five themes. Not all phenomena will be classifiable. The purpose of classifying within the themes is to help identify those metrics that are most relevant in measuring the influence of global issues. Examples of this classification within the context of geography include but are not limited to:

Cultural Geography
Social Geography
Transportation Geography
Urban Geography
Political Geography
Development and Education Geography
Religion Geography
Health Geography
Historical and Time Geography
Etc.

A specific example of identifying metrics in the PACE Project involves the measurement of Time Geography for determining effective usage of software licenses across time zones. Metrics must be identified that aid in the organization of teams in order to ensure that the fewest number of software licenses are used over the longest period of the 24-hour clock. Figure 1 shows some scheduling possibilities for usage of software licenses for the involved teams. Though these are best in terms of Time Geography, they will not necessarily satisfy other process or organizational demands, hence the need for a model that encompasses all the process and organizational demands and allows for optimal balancing.



a. Workable hours based on GMT of the 13 university teams for the PACE Project

b. Possible scheduling options to maximize license usage

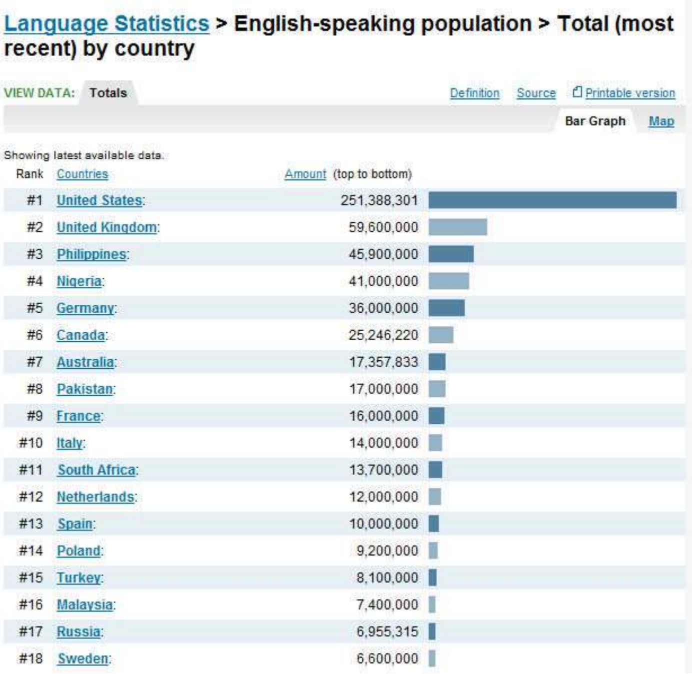
Fig. 1: Scheduling options for the different PACE teams.

3.1.3 Definition of Metrics for Specific Global Issues

Once the specific global issues have been identified and characterized within a geographic context, metrics must be selected which will allow measurement of the level of influence these issues have on product development. Although each product development program may have unique sets of global issues that influence them, a general set of commonly used metrics can be identified and used to develop a database. Various government agencies, in addition to commercial organizations provide collections of such metrics along with the associated data.

3.1.4 Collection and Validation of Global Data

As was mentioned, government agencies and commercial organizations provide repositories for commonly used metrics. These repositories are usually linked to national metrics and are updated on a yearly basis. Often, these metrics are insufficient for the level of detail required in product development models. Therefore, most organizations will need to develop their own specialized repositories of metrics that are of particular interest to their organization and activities. This will also require a regular collection and validation process to ensure the data is up-to-date and valid. Figure 2 shows an example of this type of data.



Language Statistics > English-speaking population > Total (most recent) by country

VIEW DATA: Totals — Definition — Source — Printable version

Bar Graph — Map

Showing latest available data.

Rank	Countries	Amount (top to bottom)
#1	United States:	251,388,301
#2	United Kingdom:	59,600,000
#3	Philippines:	45,900,000
#4	Nigeria:	41,000,000
#5	Germany:	36,000,000
#6	Canada:	25,246,220
#7	Australia:	17,357,833
#8	Pakistan:	17,000,000
#9	France:	16,000,000
#10	Italy:	14,000,000
#11	South Africa:	13,700,000
#12	Netherlands:	12,000,000
#13	Spain:	10,000,000
#14	Poland:	9,200,000
#15	Turkey:	8,100,000
#16	Malaysia:	7,400,000
#17	Russia:	6,955,315
#18	Sweden:	6,600,000

Fig. 2: Global data regarding language capabilities of different populations.

3.2 Creation of Graph Models

The development of a product development deployment model requires the creation of two graph models representing the process to be followed and the organization that will execute it. These two models are used to identify agents that will ultimately create the simulation that produces the product development deployment combinations. These two models are created using Graph Theory and network models and details of their creation are presented in the next two sections.

3.2.1 Process Models

The process model is a graph-based network model where the nodes are the tasks to be accomplished and the arcs represent the input and output dependencies between the tasks. When the process is particularly complex, the network model can be organized into multiple linked representations based upon ontological abstractions. The creation of the process network model is accomplished in three steps; first, a process ontology is selected if needed, second, the elements or tasks of each level of the ontology are delineated, and third, the network architecture is formed by deterministic mapping.

Selecting a process ontology involves choosing a hierarchical classification scheme that will encompass all pertinent elements of the process. It is an abstraction hierarchy. At the highest level, the overall process is represented and at the lowest level, individual tasks are identified and represented, please see Figure 3. The process ontology is used to control the level of complexity within a single network model. Each ontological level represents a different network model. All models representing the ontological levels may need to be linked if the secondary calculus must be calculated vertically as well as horizontally through the graph.

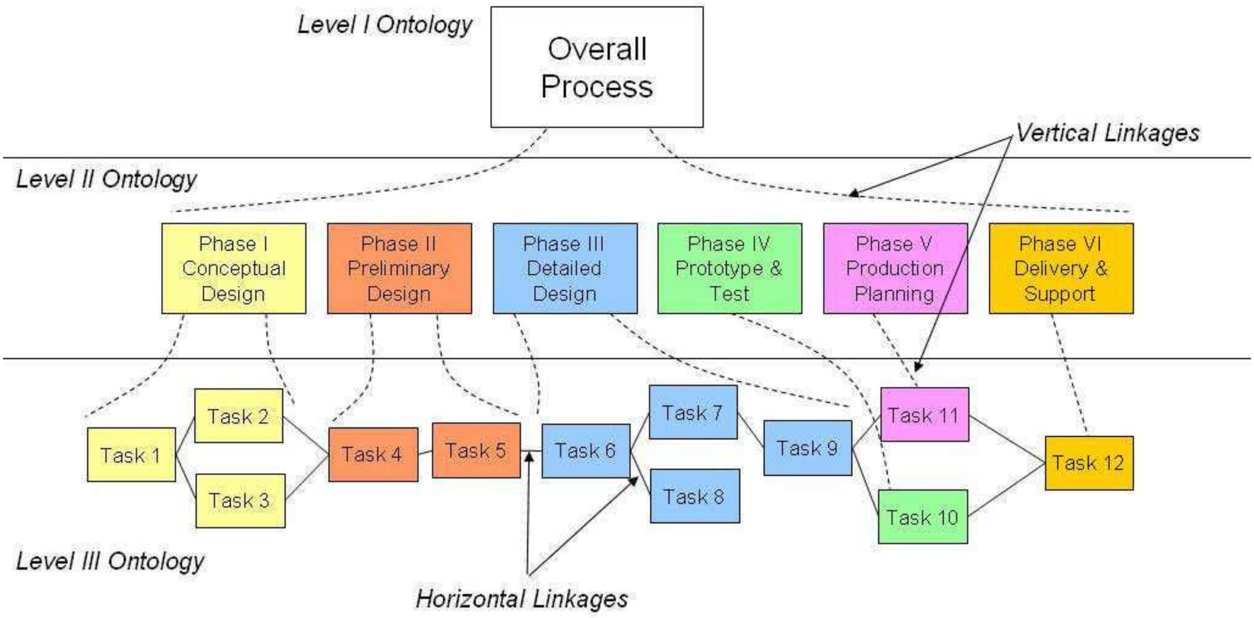


Fig. 3: Ontological Hierarchy of Process models.

The second step is to delineate the elements of each level of the ontology. Essentially, the target process must be decomposed into elements at each level of the ontology. In a process model, the elements represent tasks or logical collections of tasks that must be executed to complete the product development process.

The third step involves deterministically mapping all of the identified elements within the ontologies into graph models where all dependencies have been satisfied. The resulting model is a collection of static graph models for each ontological level. Figure 4 shows one ontological level of the network model for the PACE Project. Each node is a collection of tasks or phase of product development. The level of ontological abstraction is dependent upon the level of detail needed in the model. It is possible to have multiple models linked in a hierarchical fashion to represent multiple levels of detail. This type of model allows the secondary calculus to be defined horizontally through the graph as well as vertically through the levels of abstraction.

The purpose of the process model is to identify the individual tasks or collections of tasks so that global characteristics can be associated and actors assigned to those tasks.

3.2.2 Organizational Models

The same method is used to create organizational models as is used to create process models. This time the nodes are actors or collections of actors and the arcs represent relationships between these actors. Figure 5 shows the organizational model for the PACE project.

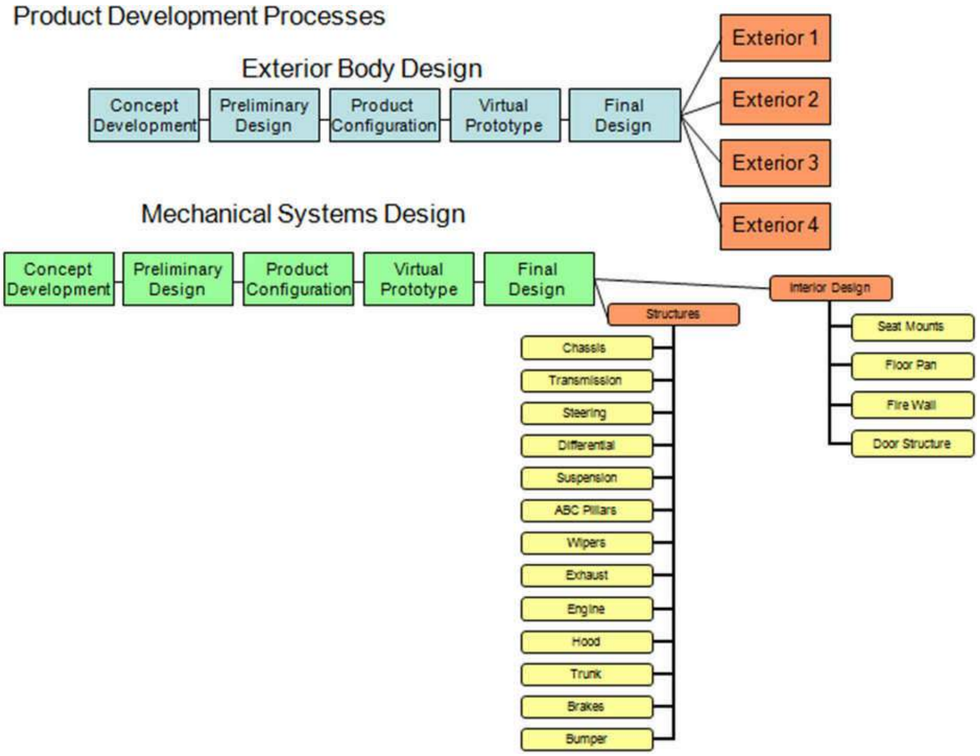


Fig. 4: Network model of one ontological level of the PACE process.

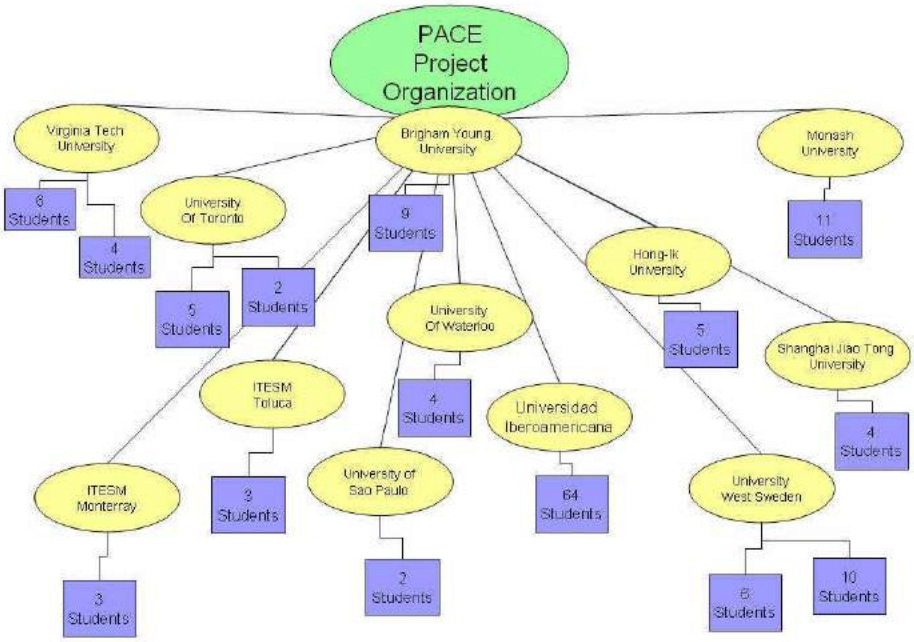


Fig. 5: Organizational model for PACE project.

3.3 Development of Secondary Calculus

The development of the secondary calculus begins by identifying the factors that govern the success of the product development process. Once the factors have been identified, a graph based equation must be defined that can be applied to the graph models of the process or organization. Finally, the metrics required at each node in the graph must be identified. This creates a graph based secondary calculus that can be calculated to evaluate the possibility for success for a given product development deployment option.

3.3.1 Identification of Evaluation Criteria

The purpose of the models usually determines the factors of most interest. For example, the work by Nault develops a model for determining the effectiveness of an organization's investment operations [16]. To do this the factor chosen to evaluate the organization's effectiveness is overall profit. This factor is calculated as a function over the set of nodes in the model. We simplify their equations to be:

$$P = \int_{Network} (D - C)dx$$

where P is the overall profit and it is summed across the network of nodes. The profit is a difference of demand and costs for local and global investments. Daley uses a simple process model of a CAD-CAE process for predicting stress in an impellor as his model and applies a secondary calculus of four factors; cost, time, reliability, and precision [5]. The selection of the factors will drive the form of the secondary calculus and the function of the model.

3.3.2 Definition of Graph-based Calculus

Once the factors have been selected, the definition of the graph-based calculus must be developed. This is typically done by developing a sum or product over the nodes or arcs of the model. In Nault's work, the sum was over the set of nodes representing local and global investment houses within the organization of interest. The calculation involves subtracting the individual node's demand and cost and then summing that over the set of nodes.In Daley's work, the factors are the sum of the individual node's cost, time to execute, reliability and precision. The overall model's reliability and precision, however, are normalized across the entire network of nodes.

3.3.3 Assigning of Metrics

The definition of the secondary calculus determines the individual nodes' or arcs' metrics. These metrics are assigned to the various nodes and arcs, but values are not assigned at this point. Only the type of metric is assigned. The values will be determined in a later step.

3.4 Optimization Studies

The ultimate objective in building these network models is to explore all the possible product development deployment options. At this point all elements of the model are defined and now we apply autonomous agents to enable optimization. There are four steps to this part of the process. The agents must be defined, the deployment options generated as workflow models, each model must be scored, and these scores must be connected into an optimization loop.

3.4.1 Creation of Agents

The creation of the agents follows the methods outlined by Daley [5]. This first step creates a list of agents that can be used to create deployment options. In this method, the agents are created by taking each task in the process model and matching it with an actor from the organizational model. The tasks and actors bring with them their individual metrics. The agents therefore have explicit knowledge of what task is to be completed, who will complete it and what metrics must be collected or calculated. Figure 6 shows a representation of this matching process.

The figure shows all the tasks within an individual phase of the process and then two organizations and their actors are assigned to the tasks. There can be multiple assignments that create redundant agents. This allows for the different deployment options. In the case in Figure 6, the main organization actors are shown in blue and gold and a subcontracting organization's actors are shown in red. The modeling of different deployment options is accomplished by creating all the possible agents from the different organizational structures (e.g. all in-house, all subcontract, or a mix) and all the process variations (e.g. different tasks, different workflow, different locations where the tasks are performed). Figure 7 shows this basic strategy where a process model and an organizational model are combined to create deployment options.

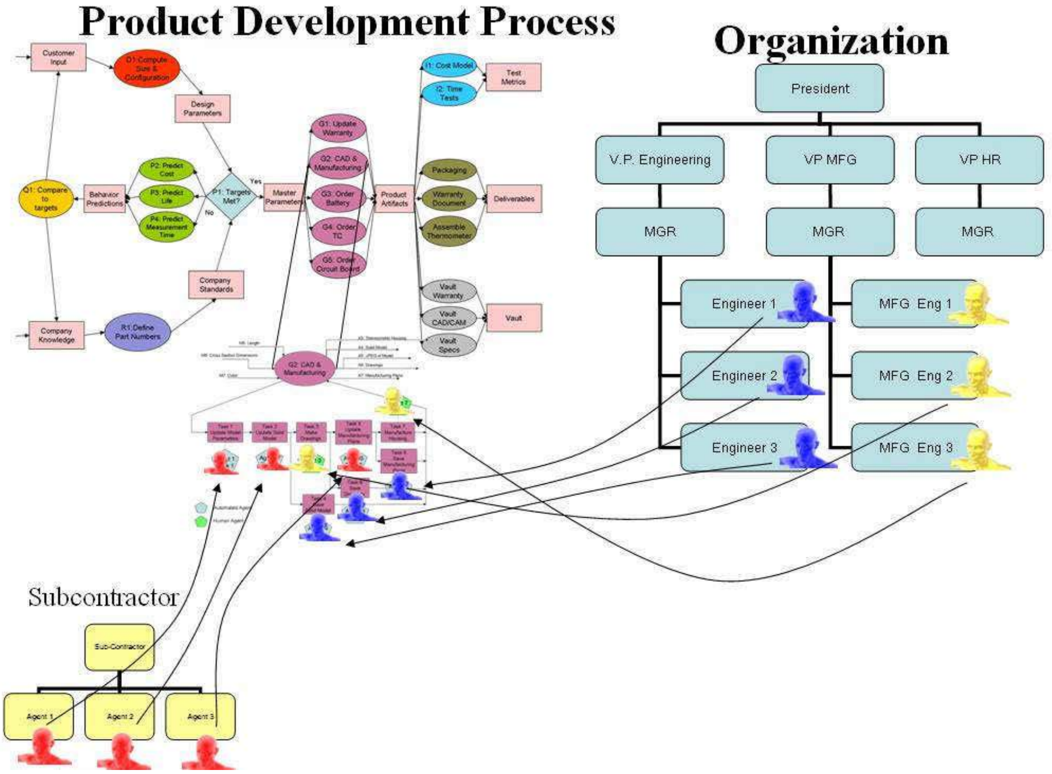


Fig. 6: Creating agents by matching actors to tasks.

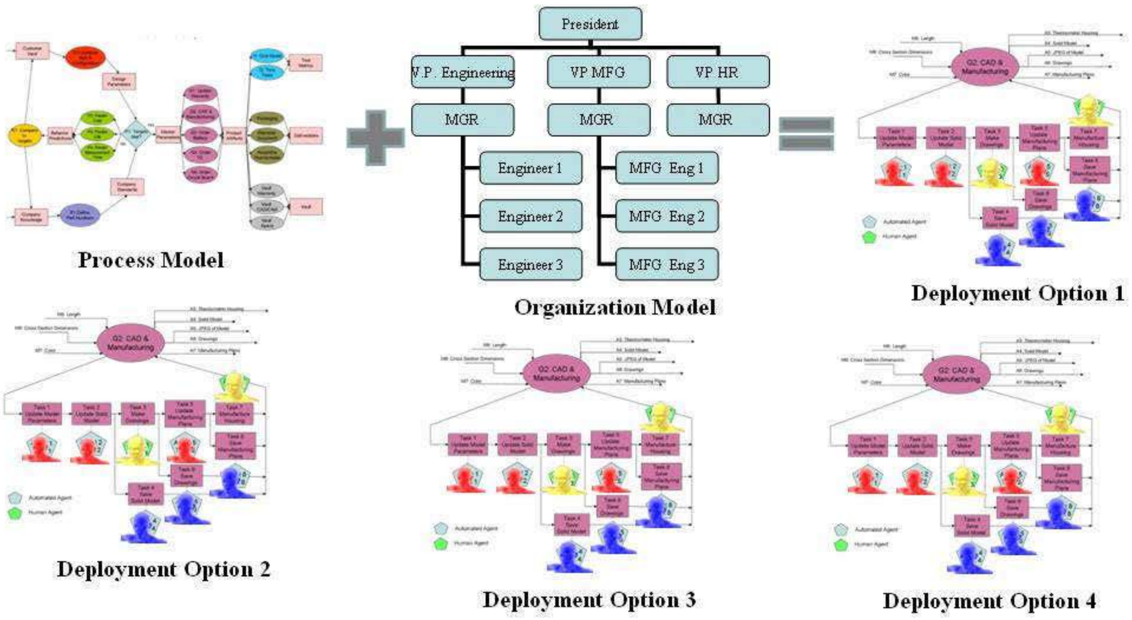


Fig. 7: Modeling strategy to produce multiple deployment options.

3.4.2 Deterministic Mapping

Once the agents have been defined they are registered with a registry agent that tracks what they do and what their dependencies (inputs and outputs) are. A deterministic mapping agent can then be invoked by placing a request for a certain process output. The mapping agent then begins a process of mapping from the end of the product development process to the beginning through matching dependencies. This can be as simple as matching input requirements to outputs of agents in the registry. Daley defines methods for abstracting the dependencies for implementation in a more general sense [5]. When this is implemented in an agent environment, all the network models representing all the possible product development deployment options can be generated. Figure 8 shows a representation of a four step CAD-CAE process where two agents have been defined for each task. This model is just a portion of an overall product development process that consists of four tasks: creating a CAD geometry model, meshing the geometry, calculating flow around the geometry, and calculating the ensuing stresses. This is a very simple model but allows us to demonstrate mapping, scoring and optimization.

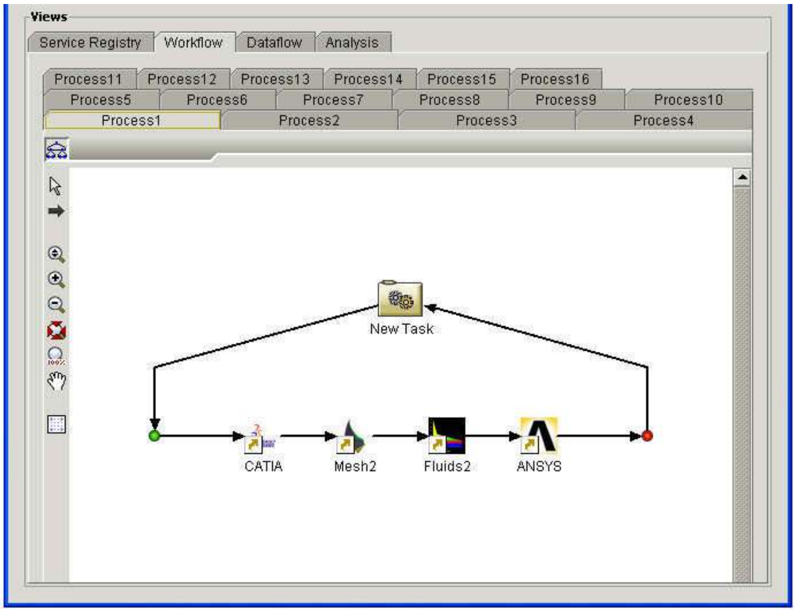


Fig. 8: A four step deployment option.

In this example, the mapping of the process is not complicated. However, there are sixteen combinations of deployment options available. Figure 8 shows a software implementation on iSIGHT-FD or FIPER. The deployment option is represented by the graph and the tabs in the middle of the control panel indicate which deployment option is being viewed.

A second example is shown in Figure 9, where a more complex process is mapped. This example is of the industrial design portion of the PACE project. The process model used was the exterior body design process shown in Figure 4, which is a Level II ontological representation of the process where the nodes are phases rather than tasks. The different schools involved in the project are assigned to these phases to create the agents and then all possible deployment options are created. Teams of students were created and assigned to perform conceptual development, preliminary design, product configuration, virtual prototyping, and final design. Multiple teams are assigned to create three independent conceptual designs and multiple teams are also assigned to develop the models of the individual parts of the product configuration. The branching seen in Figure 9 represents these aspects of the process. Only one deployment option is shown here. The purpose of the figure is to show process mapping complexity rather than details of the resulting process.

In these examples, the agents are represented by a scroll icon. Each of the agents are automatically inserted into the process at the appropriate location to execute the overall process workflow. Each agent also contributes its own set of metrics that are used to score the workflow model.

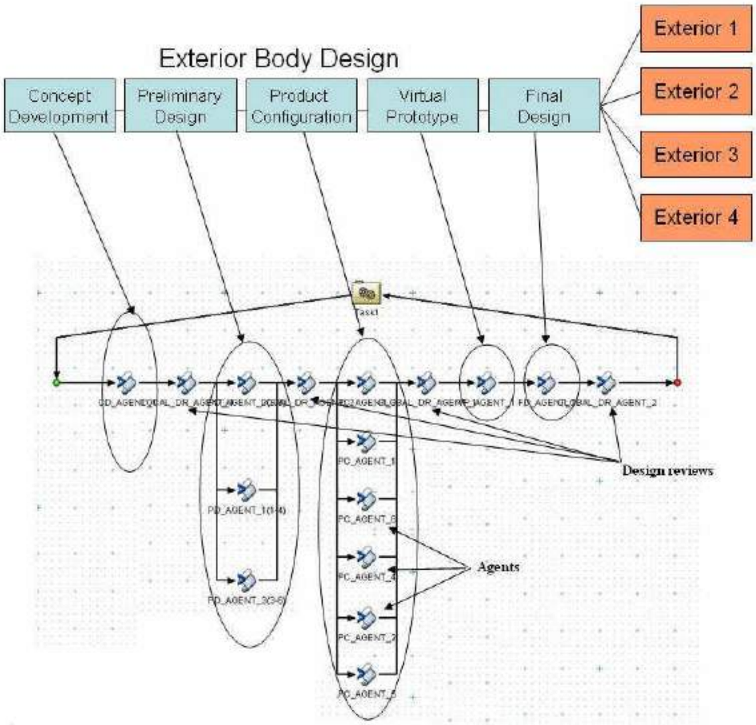


Fig. 9: A product development deployment workflow model created through deterministic mapping of agents.

A third example of deterministic mapping is shown in Figure 10 where a manufacturing process is represented. This manufacturing process occurs in three different countries using three different company facilities. There are several deployment options and two are shown here. The purpose of the figure, once again, is to show that different process structures are possible based upon the redundant agents in the registry. In this case, two of the sites can perform multiple tasks within the process and this produces the redundancies.

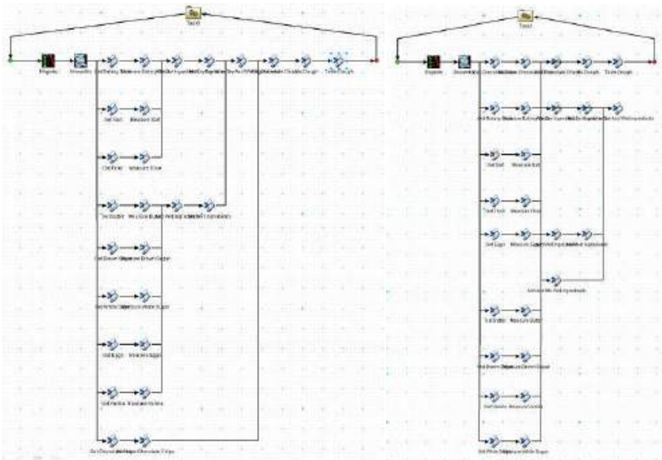


Fig. 10: Two different product development process deployment options created using deterministic mapping of agents.

3.4.3 Scoring

Since the agents carry their own individual metrics, once they are mapped into a deployment option the overall score for the deployment option can be calculated through the defined graph calculus. In the four step CAD-CAE process example, the sixteen deployment options are scored with respect to cost, time, reliability and precision. Figure 11 shows the scores for process one. These scores are normalized and a weighted combination of the four overall factors provides a single score.

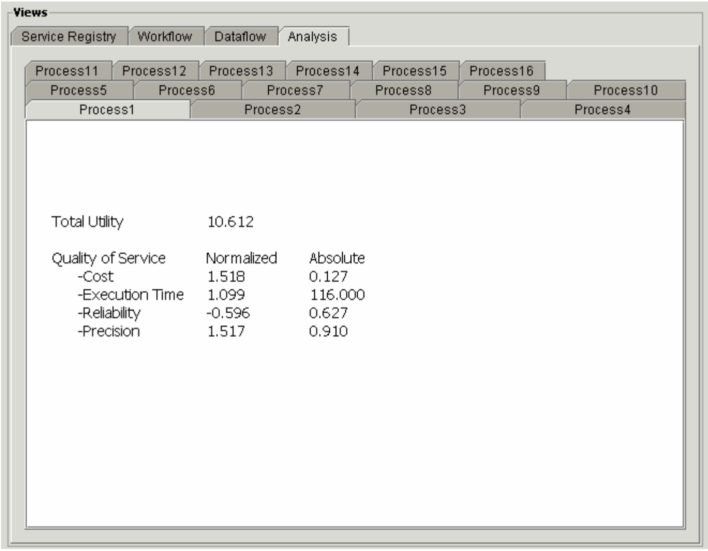


Fig. 11: Scoring of a single deployment process.

3.4.4 Optimization

Once the scores are available, it is possible to select the "best" deployment option. Figure 12 shows sliders that indicate the weight of each of the four overall factors. Changing these weights increases the importance of one factor over another's.

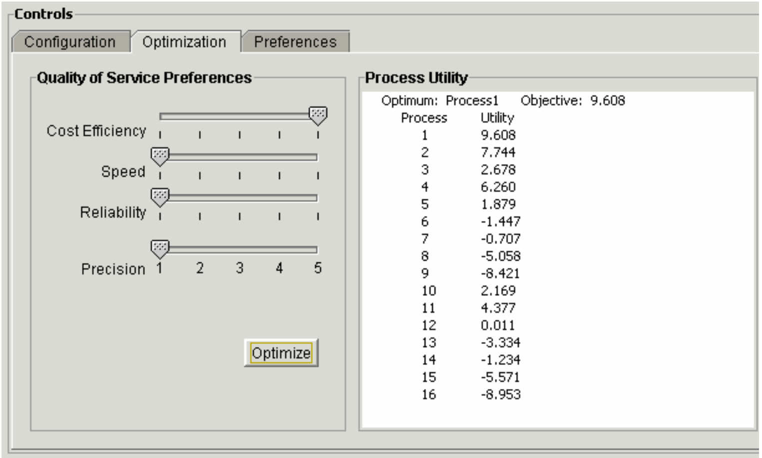


Fig. 12: Optimizing with cost efficiency as the highest priority.

The scores of each of the 16 deployment options are shown where their overall scores are weighted with respect to cost efficiency. The best process for cost efficiency is in this case process one. The weights of the factors can now be changed and the impact of the secondary calculus and its associated metrics can be explored. When the secondary calculus is based upon metrics representing global characteristics, then the effects of these global issues on product development deployment can be explored

4. MODEL OF PACE PRODUCT DEVELOPMENT PROJECT

To illustrate the methods presented in Section 3.0, a model of the PACE product development project is constructed. This model is a simplified version of the entire product development process. It focuses on the process of developing the exterior design of prototype automobiles as shown in Figure 4.

4.1 Characterization of Global Issues

Three issues are identified as the key factors in the exterior design process. The first is overall process time in terms of working days, the second is teaching assistant and associated language costs, and third is cost recovery through software license sharing. Each of these factors can be classified in terms of its geographic context. Overall process time is determined at the location where the tasks are executed. Language skills are a characteristic of the place where the universities are located, and license sharing is determined by time zone differences between world regions.

The metrics used to measure the impact of each of these key factors are:

1. Working days to complete process tasks,
2. Hourly cost for language teaching assistants including total hours of supervision, and
3. Software license cost per day and total days of use.

Collection of this data involves placing each of the universities within their time zone regions, identifying software license cost data, establishing cost rates for language supervision, and finally, determining required task execution times. Figure 13 shows a summary of this data for each of the three cases used in the model.

U West Sweden Agents	Students	Workable manhours/day	Language Local Faculty = no	Supervision required	Required time	License cost/day
CD Agent	Students 1-6	1	Swedish/English	yes	6 hours	none
PD Agent 1	Std 1,2	2	Swedish	yes	5 hours	Maya 200
PD Agent 2	Std 3,4	2	Swedish	yes	5 hours	Maya 200
PD Agent 3	Std 5,6	3	Swedish/English	yes	5 hours	Maya 200
PC Agent 1	Std 1	4	Swedish	no	3 hours	Alias 100
PC Agent 2	Std 2	4	Swedish	no	3 hours	Alias 100
PC Agent 3	Std 3	4	Swedish	No	3 hours	Alias 100
PC Agent 4	Std 4	4	Swedish	No	3 hours	Alias 100
PC Agent 5	Std 5	4	Swedish	No	3 hours	Alias 100
PC Agent 6	Std 6	4	Swedish/English	No	3 hours	Alias 100
VP Agent	Students 1-6	1	Swedish/English	Yes	6 hours	NX 150
Final D Agent	Students 1-6	1	Swedish/English	Yes	5 hours	none
DR Student Agent	BYU 1	1	Swedish/English	No	1 hour	none
DR Faculty Agent	BYUF 1	.5	English	no	1 hour	none

BYU student English speaking \$15/hr BYU student Swedish speaking \$30/hr

a. Global data and agent summary for University West.

Hong-IK (5 St)+ UWEST (6 St) Agents	Students	Workable manhours/day	Language Local Faculty = no	Supervision required	Required time	License cost/day
CD Agent	Students 1-6	1	Swedish/English	yes	6 hours	none
PD Agent 1	Std 1,2	2	Swedish	yes	5 hours	Maya 200
PD Agent 2	Std 3,4	2	Swedish	yes	5 hours	Maya 200
PD Agent 3	KStd1, KStd3	4	Korean	yes	5 hours	Maya 200
PC Agent 1	Std 1	4	Swedish	no	3 hours	Alias 100
PC Agent 2	Std 2	4	Swedish	no	3 hours	Alias 100
PC Agent 3	Std 3	4	Swedish	No	3 hours	Alias 100
PC Agent 4	Std 4	4	Swedish	No	3 hours	Alias 100
PC Agent 5	Std 5	4	Swedish	No	3 hours	Alias 100
PC Agent 6	Std 6	4	Swedish/English	No	3 hours	Alias 100
VP Agent	Students 1-6	1	Swedish/English	Yes	6 hours	NX 150
Final D Agent	Students 1-6	1	Swedish/English	Yes	5 hours	none
DR Student Agent	BYU 1	1	Swedish/English	No	1 hour	none
DR Faculty Agent	BYUF 1	.5	English	no	1 hour	none

b. Global data and agent summary for University West and Hong-IK University

(BYU -9ST, 1FAC, UWEST-6ST, Hong-IK 5ST) Agents	Students	Workable manhours/day	Language Local Faculty = BYU Yes, UW No, H No	Supervision required	Required time	License cost/day
CD Agent	BYU 1-9	.5	Engl, Kor, Swed	yes	6 hours	none
PD Agent 1	BYU 1-3	1	English, Swedish	yes	5 hours	Maya 200
PD Agent 2	UW 5-6	3	Swedish, English	yes	5 hours	Maya 200
PD Agent 3	H 1-2	3	Korean	yes	5 hours	Maya 200
PC Agent 1	BYU 4-6	2	English	no	3 hours	Alias 100
PC Agent 2	BYU 7-9	2	English, Korean	no	3 hours	Alias 100
PC Agent 3	H 3-4	2	Korean	No	3 hours	Alias 100
PC Agent 4	H 2,5	1	Korean	No	3 hours	Alias 100
PC Agent 5	UW 1-2	4	Swedish	No	3 hours	Alias 100
PC Agent 6	UW 3-4	3	Swedish	No	3 hours	Alias 100
VP Agent	BYU 1-9	.5	Engl, Kor, Swed	Yes	6 hours	NX 150
Final D Agent	BYU 1-9	.5	Engl, Kor, Swed	Yes	5 hours	none
DR Student Agent	BYU 1	1	English	No	1 hour	none
DR Faculty Agent	BYU 1F	.5	English	no	1 hour	none

c. Global data and agent summary for University West, Hong-IK University, and Brigham Young University

Fig. 13: Global data summaries used in evaluating three deployment options

This data was collected for three teams: the industrial design group from Brigham Young University in Provo, Utah, USA; the industrial design team from Hong-IK University in South Korea; and the industrial design team from University West in Sweden. Though there were other industrial design teams involved in the PACE project, these three were selected for purposes of simplification.

4.2 Creation of Graph Models

The development of the graph models for this example requires the definition of two ontological levels as shown in Figure 14. Level I identifies the phases of the exterior design process. Level II identifies the tasks within those phases. Note that the green tasks represent the design reviews that must be completed to indicate the end of each respective phase.

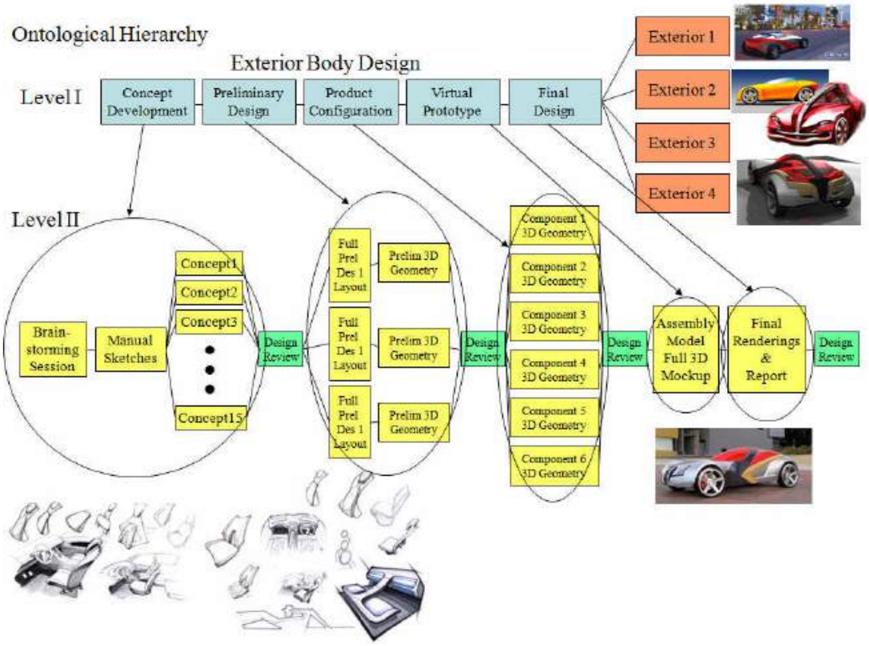


Fig. 14: Breakdown of ontological levels.

Construction of the model requires the development of an organizational graph model and a process graph model. For this example, the Level II graph model shown in Figure 14 is the process model. The organizational model is made up of three universities and twenty students as shown in Figure 15.

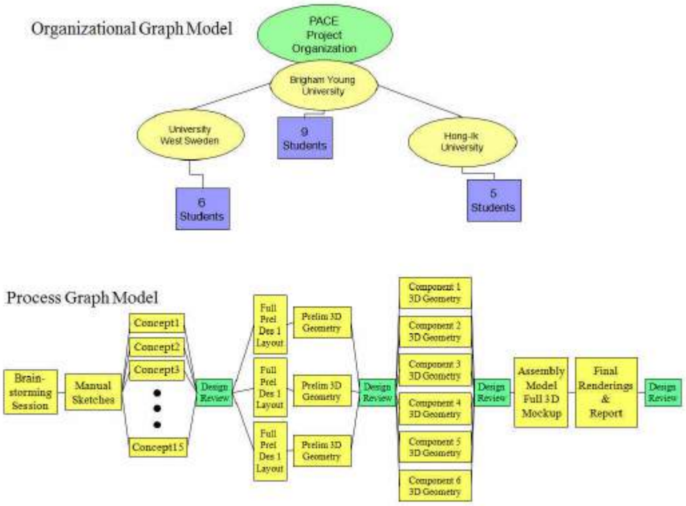


Fig. 15: Organizational and Process graphs for PACE model.

To create the model of deployment options, the actors in the organizational graph model are annotated with their respective global data. In this case, this involves student availability (which is used to calculate workable man-hours) and language skills. The process graph model is also annotated with its respective global data which includes need for supervision by a teaching assistant, required execution time, and needed software licenses as well as associated license costs per day.

Agents are created by matching actors in the organizational graph model to tasks in the process graph model as shown in Figure 13. Each row in the table represents a different actor and its associated global data.

4.3 Development of Secondary Calculus

The definition of the secondary calculus for this model is as follows:

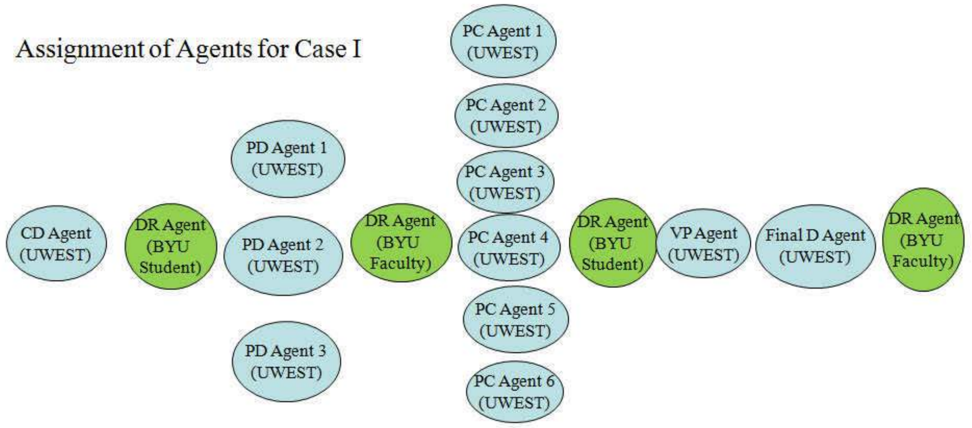
Total Process Time = The sum over the network of each agent's required task time divided by the workable man-hours of the students assigned to the specific task.

Oversight Cost = The sum over the network of each agent's required oversight hours multiplied by the respective language teaching assistant cost per hour.

Cost = The sum over the network of ((Required time to complete each task)/(Agent workable hours per day))* License cost per day. License sharing is possible if agents do not overlap within a time zone.

4.4 Optimization

Once the agents and secondary calculus have been defined, deployment options can be derived for all possible combinations of agents that can execute the process. Three of the possible deployment options are shown here. Case I, shown in Figure 16, is the option where all tasks are accomplished by agents solely from University West in Sweden, excluding the design reviews and oversight, which are accomplished by students from Brigham Young University. Once the deployment option is configured, the secondary calculus can be used to score that option. Scores are shown for Case I of 26.5 working days, $720.00 oversight cost, and $4300.00 software license costs.



<u>Scores</u>
Process time: 6+1+2.5+2+1+1+6+5+2 = 26.5 working days
Oversight cost: (6*15)+(1*15)+(5*30)+(5*30)+(5*15)+(1*30) +(1*30)+(6*15)+(5*15)+(1*15)= $720
License cost: 200*(2*3 days)*2 teams working parallel + 200*2 days*1 team + 100*1day*6 people working parallel + 150*6 days = $4300

Fig. 16: Case I Deployment Option using students from University West in Sweden.

Case II is a deployment option that is the same as the first option except that one agent is used in preliminary design from Hong-IK University in Korea. This provides the opportunity to share software licenses but increases the oversight costs due to language differences. As can be seen in Figure 17, the scores for this option are: 26.5 working days, $825.00 oversight cost, and $2700.00 software license costs.

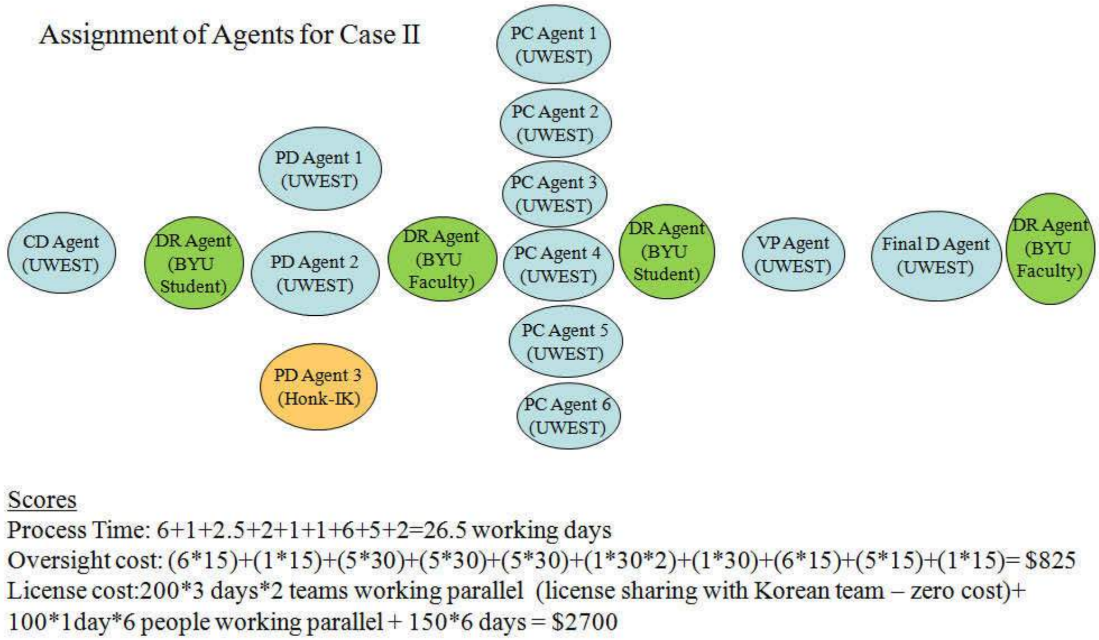


Fig. 17: Case II Deployment Option with one agent from Hong-IK University.

The third option was chosen to maximize license sharing. Agents were created from all three Universities; Brigham Young University, Hong-IK University, and University West in Sweden. In this case the scores are: 28.5 working days, $315.00 oversight costs, and $1900.00 software license costs as shown in Figure 18.

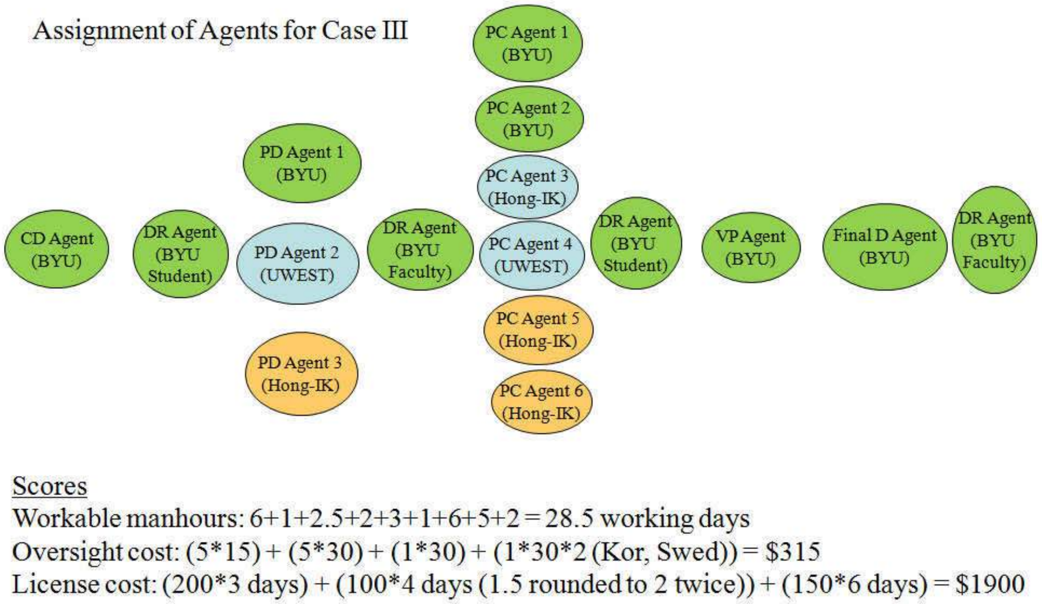


Fig. 18: Deployment Option III maximizing license sharing.

Further studies can now be done to explore all the possible options and optimize with respect to the factors chosen when building the models. Because these models can produce many combinations, it becomes overwhelming to do this by hand. Software tools are being developed to aid in generating all the possible deployments as well as calculating the associated secondary calculus. Figure 19 shows the generation of a single deployment option using an automated system within iSIGHT-FD.

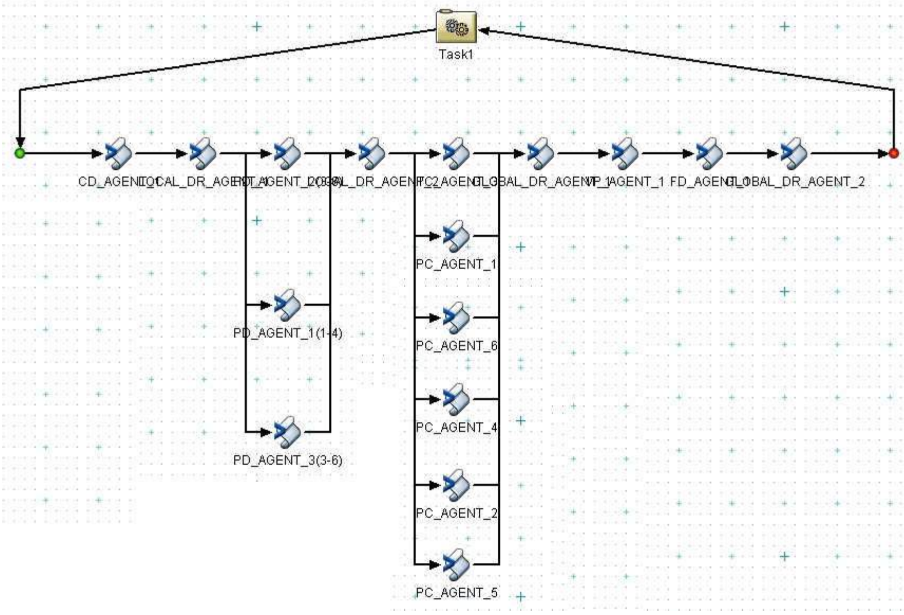


Fig. 19: Automated generation of deployment options.

5. CONCLUSIONS

The following conclusions can be made from this work: (1) it is possible to include data that characterizes global issues into models of product development processes; (2) these virtual product development models provide prediction capability for anticipating global issues in the deployment of product development; (3) because of the large number of deployment options that can be generated, software tools will be required to fully implement these methods; and (4) there is a need for properly characterized and validated repositories of data relating to global issues that can be used for virtual product development models.

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