CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Integration and Automation of Pre-Project Planning Through Circle Integration with a Shared Project Model

By

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CIFE Technical Report #115
March, 1998

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SUMMARY
CIFE TECHNICAL REPORT # 115

Header:
Title: Integration and Automation of Pre-Project Planning Through Circle Integration with a Shared Project Model
Authors: Edward L. Divita, Jr., Martin Fischer, John Kunz
Publication Date: October 1997
Funding Sources: Center for Integrated Facility Engineering
"Concurrent Design of Facilities and Delivery Processes and Organizations"

1. **Abstract:** This report investigates integration and automation of Pre-Project Planning (PPP) by linking otherwise fragmented specialty analysis processes through a shared project model. The shared project model provides a computer interpretable representation of a project that can be analyzed by software services capable of performing the various specialty analyses necessary for PPP (e.g., market analysis, site analysis, planning, cost analysis, financial analysis). We link the software services end to end in a circle composing an integrated PPP analysis system. This report describes a prototype integrated PPP analysis system, called the Facility Alternative Creation Tool (FACT), that performs automated PPP analysis for fast food restaurants. The integrated analysis system performs rapid automated PPP analysis providing inherent version control and a consistent basis for evaluating alternatives. Testing and experimentation with FACT reveals two important limitations of the current state of the art of integrated and automated PPP. First, there is a need for a PPP ontology to support knowledge and data sharing among the specialty PPP analysis software tools. Second, there is a need for circle integration mechanisms to define and operationalize the linking of applications and the automating of the integrated analysis process.

2. **Subject:** This report investigates two interrelated technologies: *shared project models*, the utilization of a common project representation for otherwise fragmented project analyses, and *circle integration*, the integration of independent software applications by linking them end to end to form a system of applications capable of automating an iterative analysis process. We suggest that utilizing a shared project model in conjunction with circle integration is an effective approach for integrating and automating PPP. Further, based upon this preliminary study, this approach can reduce the time and cost to perform project analysis while guaranteeing a consistent basis for comparing project alternatives.

3. **Objectives/Benefits:** Today's facility delivery process is characterized by its fragmentation across disciplines and phases and by the lack of tools that support the rapid generation and evaluation of project alternatives. This research implements and tests new

integration and automation concepts applied for an industry based test case, PPP for fast food restaurants. The prototype software demonstrates how normally fragmented analysis processes can be integrated providing the benefit of reduced time and improved consistency.

4. **Methodology:** The research methodology was to observe the PPP process of our industry partner and design and implement a prototype that integrates and automates PPP analysis utilizing circle integration and a shared project model. The prototype is implemented using the Powermodel development tool by Intellicorp and runs on Unix and Windows PC compatible platforms. Our industry partner, other AEC researchers, graduate students, and other industry practitioners have observed and reviewed the prototype.

5. **Results:**

- The design of an integrated system of applications for fast food restaurant PPP

- Implementation of a prototype software tool that demonstrates the benefits of circle integration and a shared project model for the integration and automation of PPP for fast food restaurants

- Insights into the development of a PPP ontology for knowledge sharing and re-use among independent specialty PPP analysis tools

- Insights into the design and development of circle integration mechanisms needed for implementing circle integration.

6. **Research Status:** The initial design and implementation of circle integration for PPP has been completed and is documented in this report. The researchers are currently involved in case studies of PPP for other types of facilities (e.g., office buildings, apartments, and warehouses). Further research will help us generalize the findings of this report and understand the required characteristics and capabilities of a PPP ontology that supports knowledge sharing and re-use for various types of facilities. In addition, more research is required to validate the characteristics and functionality of mechanisms to operationalize circle integration.

7. **Readers Guide/Outline of Report:**
    - Chapter 1 of this report is a prologue that poses a case scenario illustrating some of the challenges associated with PPP.

    - Chapter 2 describes PPP, introduces the issues related to current practice of PPP and presents the problems that current PPP practitioners face.

- Chapter 3 describes how we integrate and automate PPP through the development of a computer based PPP analysis system.
- Chapter 4 presents a case example of integrated and automated PPP using the Facility Alternative Creation Tool (FACT).
- Chapter 5 is a critique of FACT that identifies both the benefits and limitations of the prototype.
- Chapter 6 describes the plans for continued research in this area by the authors.
- Chapter 7 is a discussion about the findings of the report.

1.0 Prologue

The Situation

A Regional Manager of a fast food restaurant chain with 20 years of experience in restaurant facility development just spent 6 months and $45,000 investigating the market and site for a new facility. His feasibility study indicates that the project is expected to be marginally profitable. His development schedule predicts that the store will open in December of 1997. The organization's financial forecast for next year relies upon the on schedule opening of this new store. The escrow for the $850,000 land purchase closes tomorrow. A broker calls him to advise that a new parcel located within 3 blocks of the site is now available for $750,000.

The Decision

He must decide whether to proceed with the current deal or pursue the new deal within 24 hours. He doesn't have another 6 months nor $45,000 to undertake a thorough pre-project planning (PPP) effort consistent with the first site. However, a quick look at the site plan reveals that the new site is on the same main highway and almost exactly the same shape and size as the original site. A quick site walk reveals that there are no obvious differences between the existing conditions of the two parcels. He decides to cancel the first deal and pursue the new site. He figures that he can use some of the $100,000 savings for schedule acceleration and the rest will go towards project profits that will please senior management.

The Outcome

It turns out that, although only 3 blocks away, the new site was located in a different municipality governed by a different administration. The permit approval process took 3 months longer than was expected for the first site. The new site also did not have low pressure gas (required for kitchen equipment) stubbed in at the property line. The developer had to install 140 linear feet of gas line in the county right-of-way. This additional utility work was not budgeted. Also, the new site was located in a special management district which required onsite retention of all storm water. The additional sub-drains, drainage structures, and permeable pavement were also not budgeted. The Manager not only did not achieve his 1997 production plan, but the excessive development costs and the opportunity costs associated with the delay had a severe negative impact on the project's profitability.

A Vision

In this situation, the Regional Manager needed accurate information at his fingertips and the ability to do quick analysis from multiple perspectives. If the cost and time required to compare the two sites in a consistent manner was much less, the Regional Manager could have become aware of the risks associated with the new site and may have decided to stay with the original site. In fact, if he had the tools to consistently create and evaluate project alternatives in a rapid and low cost manner, he would consider significantly more sites and assess more risks during early project planning. Overcoming the time and cost limitations of consistent thorough pre-project planning could improve the probability of project success.

2.0 PPP For Commercial Income Generating Facilities

Description of PPP

Pre-Project Planning (PPP) for capital facilities, also known as project feasibility study, requires a multi-disciplinary team effort involving professionals specializing in marketing, architecture, engineering, planning, cost estimating, organization, construction, and finance. The widespread availability of microcomputers and commercial software has made automated analysis tools available to the specialists in these fields (e.g., geographic information systems (GIS) for marketing, computer aided design (CAD) for architecture and engineering, critical path method (CPM) for planning, spreadsheets for cost estimating). Despite the specialty technologies, PPP continues to be time consuming, costly, and is often inconsistent from project to project and from specialist to specialist because the overall PPP process is neither integrated nor automated.

PPP describes the process of creating, analyzing, and evaluating project alternatives during the early planning phase to support a decision whether or not to proceed with the project and to maximize the likelihood of project success. Figure 1 identifies PPP as the first phase of the project life cycle, which precedes design, construction, and operation (adapted from Barrie and Paulson 1992). The measure of influence curve illustrates that decisions made during the early phases of the project life cycle have a greater influence on the outcome of a project than those made later. The cumulative project cost curve reveals that project costs accumulate most during the later design and construction phases.

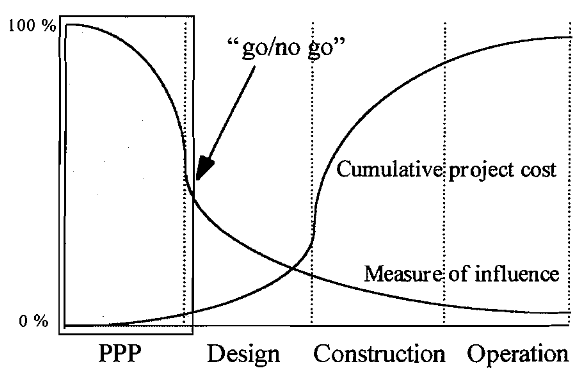

FIG. 1 The Project Life Cycle

PPP decisions (e.g., choice of market, selection of site, and determination of building size) have a significant influence on a project's outcome. PPP has two major outputs: first, the decision whether or not to proceed with the project under consideration ("go/no go"); second, if the decision to proceed is positive, a plan of action to guide later phases. Pre-project planning affects project outcome for all types of projects. In a study of 62 facility development projects (chemical, petro-chemical, power, consumer products, refinery, and other) the Construction Industry Institute (1994) found that more early project planning effort resulted in more successful projects.

PPP issues

Fragmentation of PPP specialists, heterogeneity, information sharing requirements, and the need to consider many project alternatives appear to contribute to the PPP problems of time, cost, and inconsistency.

Fragmentation of PPP specialists

Information and knowledge fragmentation complicates PPP. Project teams comprise many specialists, and each specialist is responsible for a portion of the project knowledge and information processing involved in PPP. It can take six months or longer to perform PPP and draft a decision support document describing the proposed project, its variables, and its expected behaviors. Fragmentation complicates PPP because the specialists who describe, analyze, or evaluate the project or its constituents are commonly distributed geographically, along with their software tools.

Heterogeneity

A further complication for PPP is heterogeneity. The specialists, their analysis, and their software tools are dissimilar in several ways. First, they conceptualize the project from a separate point of view. Second, they use different notation and vocabulary. Heterogeneity demands interpretation of information created by other specialists, and today much of this interpretation is performed manually by the specialists as they share information through the dissemination of reports and drawings.

Information sharing requirements

During PPP, project participants require information generated by others to perform their work. For example, when recommending the appropriate size and capacity for a commercial income generating facility, an architect requires market information (e.g., population demographics and demand indicators) prepared by a market specialist. When estimating construction cost, the construction professional requires a description of the project scope prepared by the architect. When performing cash flow analysis and predicting expected return, the financial analyst requires cost and schedule information prepared by several of the other participants. When information changes (e.g., a different site is considered or a different building configuration is proposed), the participants must disseminate the new information throughout the team. Upon interpretation, analysis, and evaluation, the participants provide feedback about the impact of the change to the other team members. This information processing is time consuming and costly. Because of the heterogeneity of information sources, it is difficult for PPP participants to provide specific project information and cost estimates until later in the process. This delays the economic evaluation of alternatives even though PPP decisions with important economic implications are under consideration.

Consideration of project alternatives

A principle of good facility design is the consideration of many alternatives. Nonetheless, as discussed above, consideration of alternatives is time consuming and costly. In today's competitive development arena, project teams are often provoked to reduce the time and cost of planning efforts. Projects are pushed forward because of time and cost constraints despite the knowledge that more early planning will lead to higher quality projects (Bon 1989). There is a need for methodologies and tools that can enable consideration of many project alternatives rapidly and cost effectively during early project planning.

Problems Currently Associated with PPP

Based on our observations, excessive time consumption, excessive cost, and lack of consistency are problems associated with current PPP in industry practice. We anticipate that improving these areas will increase the number of project alternatives considered, improve the PPP decision process, and lead to more profitable projects.

Time

Commercial facility pre-project planning is currently time consuming because the coordination process is manual and often informal. Symptoms of this problem include delays due to waiting and learning curve inefficiencies. The significance of this waiting and learning time motivates research into methods of reducing time. For example, one fast food restaurant chain (referred to as Joe's to maintain confidentiality) develops more than 400 new fast food restaurant facilities world wide each year. Figure 2 illustrates that on average, Joe's PPP requires 186 days of the 547 day total development time (Ernst & Young 1993). Ernst and Young also observed that 75% of Joe's overall process time is spent "on hold" as opposed to "hands on." In addition, Joe's market investigation participants have less than 3 years of experience, on average. This inexperience causes recurring job and marketplace learning curve inefficiencies. These "on hold" and "learning curve" inefficiencies constitute a significant portion of the total PPP time.

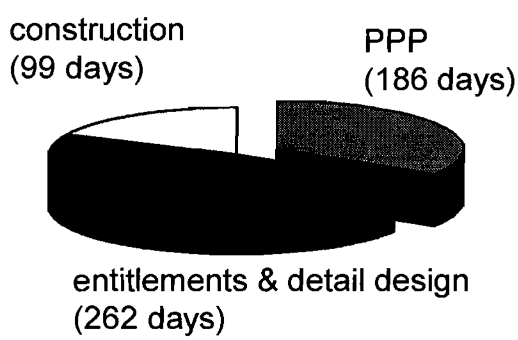

FIG. 2 Average PPP time for Joe's

Pre-project planning specialists often find themselves "on hold", waiting while others are gathering data and performing analysis. The PPP process involves many dependencies. Figure 3 illustrates some of the interdependencies among activities. Participants require results from others' work to perform their own. For example: *facility modeling* relies upon the *market investigation's* projected sales to size the building appropriately; *planning and scheduling* relies upon the agency approval durations from the *market investigation*, the site utility extensions from the *site investigation* and the components from the *facility modeling* to create the development schedule; the *financial analysis* relies on the estimated costs from the *cost analysis*, estimated sales from the *market analysis*, and activity timing from *planning and scheduling* to generate the cash flow projection.

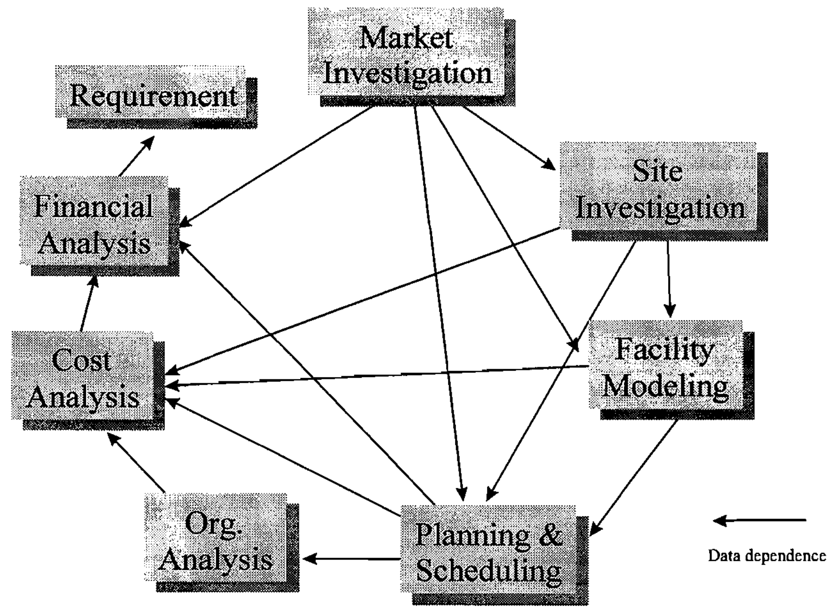

FIG. 3 Dependencies among PPP activities

Feedback cycles should iterate repeatedly during the PPP process. When project variables are revised, the effects must be propagated throughout the team. However, waiting for the dissemination of information to occur results in a significant consumption of time. This "on hold" time limits the number of project alternatives that are considered, which may limit the success of the project.

Today, methods for information processing during PPP are often manual. Each specialist prepares a report or drawing which is forwarded to the others for information or review. The documents are then manually interpreted by the participants to identify the key data that influences their analysis. Computer data sharing, software integration, and automated information processing could significantly reduce waiting and accelerate PPP. However, such data sharing, integration, and automation require formal information models (Fischer & Froese 1996).

Learning curve inefficiencies may also contribute to the excessive time required for PPP. Participants change from project to project and each has a unique skill level and skill set. The team itself also has a composite experience level. New project team participants are not always aware of the implicit processes and feedback loops that the more experienced participants use. Over time, these new participants gain experience and their productivity improves. However, the excess time consumed during the early phase of the learning curve contributes to the excessive length of the PPP process. Burton and Obel (1995) suggest that it is efficient to standardize organization member behaviors and that formalization is a means to do so. Formalization can improve the efficiency of new participants and will support computer automation of the PPP process.

Cost

In addition to being time consuming, commercial facility PPP is also costly for two reasons. First, PPP is coordination intensive, requiring many expensive consultant and specialist man-hours. Second, opportunities for profit are lost because of project delays attributable to waiting and learning curve inefficiencies. These human resource and opportunity costs diminish the profitability of commercial facility projects. Joe's spends 71 percent of its total new site human resource and development costs during the PPP phase (see figure 4).

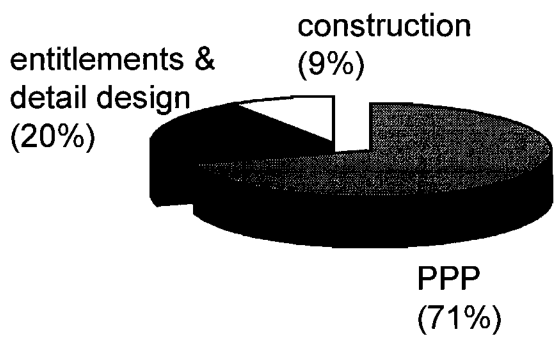

FIG. 4 Average PPP human resource and development cost for Joe's

Many of these costs are spent on coordination of inputs and outputs transmitted among the specialists. Using current PPP tools and methodologies, many of the efforts are duplicated. Consider the following scenario:

> A real estate representative investigates the zoning, utility, and building approval requirements for a site within a given municipality and includes discussion about the requirements and the estimated durations for approval in a report. The project manager must peruse the report and cull the necessary information he needs to address the appropriate activities in the development schedule. Later, the controller must interpret the schedule and assign project costs to the timeline to create a periodic cash flow from which a financial analysis can be performed. If the approval requirements change, the real estate representative must notify the other participants and the construction manager must revise the schedule and the controller will have to revise the financial analysis to assure that the profitability predictions are accurate.

Fischer and Froese (1996) suggest that these types of duplicated efforts can be reduced or eliminated through the use of shared project models.

Consistency

To select the best from a group of project alternatives, decision makers should base comparisons upon a consistent analysis framework. However, commercial facility PPP processes and outcomes are often inconsistent because much of the data sharing among participants is manual and the processes are informal. Some of the symptoms of this problem of inconsistency include missing or erroneous data and missing or incomplete analysis and evaluation.

During PPP, data can be ignored, lost, or corrupted as it is manually transferred from participant to participant. Project information is transmitted via written report, fax, e-mail, phone conversation, meeting notes, the back of a napkin, or other media. Missing or corrupt data can impair the consistency of the basis for comparison. Computer automated data sharing can support consistent evaluations by maintaining information integrity.

In addition, in some cases, PPP participants use varying analysis approaches. For example, one of Joe's equipment suppliers stated that each site development region has its own style and lacks consistency (Ernst & Young 1993). This process inconsistency can also impair the basis for fair project evaluation. For example, if the storm water management permit approval duration is not considered during PPP, the predicted project duration may be inaccurate. This corrupt schedule will affect the financial projections. Using an inconsistent basis for evaluation can lead to poor decision making. Formalizing the PPP analysis process and information requirements will provide the consistency required for good decision processes. Rational organization system theorists assume the importance of process formalization and devote their energies to developing precise guidelines to govern participants' activities (Scott 1992, p 33).

Goal - To Integrate and Automate PPP

The purpose of this research project is to investigate the above problems and pursue solutions that improve PPP for the future. Automation can help make PPP more rapid, less costly, and more consistent. However, because the PPP process is fragmented, it is necessary to integrate the various analysis perspectives before automating the process. To automate, we must understand and commit to a formal conceptualization regarding PPP variables and processes. A PPP ontology, or specification for the conceptualization, provides formalization. The goal of this research is to attempt integration and automation of PPP through the development and use of a shared ontology.

3.0 How we Integrate and Automate PPP

The FACT system

The purpose of the Facility Alternative Creation Tool (FACT) demonstration prototype application is to link software services to integrate available PPP specialty methodologies and tools and automate the PPP process. We also desire rapid feedback on modifications and simple yet effective management of project alternatives. To address these objectives, FACT implements circle architecture (Fischer & Kunz 1995) for PPP of fast food restaurants[1]. Our implementation of the circle architecture involves a simple set of linked autonomous software services, in which case the circle output is the union of the outputs of the individual applications. Figure 5 shows a concept diagram for the PPP circle architecture.

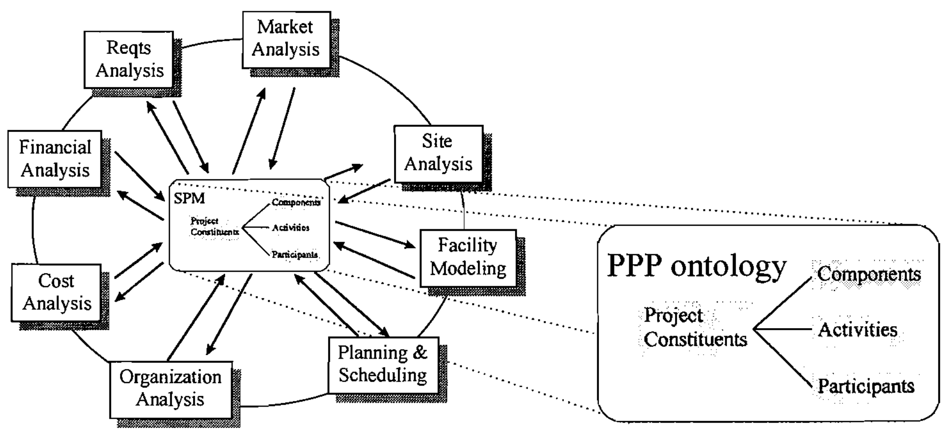

FIG. 5 Concept diagram of FACT prototype circle architecture

The system architecture applies specifically to our case study of PPP for fast food restaurants. At the center of the system is the shared project model (SPM). For each project alternative, the SPM is derived from an ontology. The nodes around the circle represent software services that work cooperatively to analyze the SPM.

The Shared Project Model (SPM)

We observe that a limitation of current PPP is the use of manual data sharing techniques. Manual data sharing is slow, error prone, and generally inefficient. Prior research efforts demonstrate the benefits of integration through the use of shared project models for other domains. Construction Knowledge Expert (COKE) (Fischer 1993) automates constructibility feedback for the preliminary design of a reinforced concrete structure using a shared model[2].

[1] Fischer and Kunz (1995) propose "circle integration" as a simple, testable approach to structure the integration of AEC software applications. They suggest that circle integration provides clear, accurate, rapid, and maintainable support for the creation and management of design versions. Our preliminary modeling and testing efforts using circle integration confirm these benefits. However, the conceptualization of circle integration lacks empirical testing with practical applications. Further, the integration mechanisms necessary to operationalize circle integration have not yet been specified.

[2] COKE's linking of a constructibility expert system with a project model contributes to the sharing of knowledge between professionals involved in the design and construction phases of a project. The model sharing is limited to the constructibility knowledge model being shared with the structural component model.

The Object Model Based Project Information System (OPIS) (Froese 1992) combines several project planning applications around a shared object-oriented project database[3]. The Intelligent Real Time Maintenance Management (IRTMM) research (Kunz et al. 1995) utilizes a symbolic process plant model shared among three analysis modules[4]. Preliminary efforts are underway to develop standards for developing models that can be shared among services, however none of these currently provide the representation required for integrating PPP[5]. PPP is significantly different from the processes represented by COKE, OPIS, and IRTMM, and research is necessary to develop an adequate information model for the PPP domain.

Ontology

In the FACT system, the SPM is a project model instance derived from the PPP ontology[6]. In this sense the ontology acts as a template for the creation of shared project models. The ontology includes the elements and variables of a project that are considered during PPP for fast food restaurants. We created the ontology by observing the PPP practice and documentation of our industry partner and abstracting the essential PPP concepts and variables. Using the FACT system, when the user desires to analyze a new project, a unique SPM is created. During automated PPP analysis, the services analyze the SPM to predict the project outcomes. By going around the circle, a planner develops a project scenario (alternative) in a consistent fashion and gets rapid and consistent feedback from the perspective of each specialty. We will provide a case example using the FACT system in section 4.0 and will discuss the PPP ontology in more detail in section 6.0.

COKE demonstrates how a symbolic project model supports design-construction integration wherein model sharing is the integration mechanism.

[3] OPIS supports information sharing among participants in the construction planning and execution phases of a project. OPIS is limited to construction planning and construction applications, however it has inspired the collaborative application approach that we apply to the domain of PPP. OPIS implements project data sharing but does not automate construction management processes.

[4] The analysis modules utilized by IRTMM are situation assessment, planner, and value analysis. IRTMM automates value based maintenance planning for process plants using these modules to reason about the shared plant model.

[5] Fischer and Froese (1996) review some of the efforts underway to develop standard project models for information sharing across multiple applications including the standard for the exchange of product model data (STEP) and Industry Foundation Classes (IFC). STEP models are complex to develop and use (Fischer & Froese 1996) and IFCs (Industry Alliance for Interoperability 1996) do not address PPP at this time. Further, these models currently lack explicit representation of function and behavior which are needed for PPP analysis as discussed in Chapter 6 of this paper. The products of these general standardization efforts are under development and changing rapidly. Depending on industry support, developments are likely to continue in this area.

[6] An ontology describes the concepts and relationships that can exist for an agent or a community of agents in a domain to enable knowledge sharing and reuse (Gruber 1993). A conceptualization is an abstract view of what we wish to represent for some purpose. An ontology is an explicit specification of that conceptualization.

Services

The software services that we chose to illustrate integrated fast food restaurant PPP (i.e., requirements analysis (RA), market investigation (MA), site analysis (SA), facility modeling (FM), planning & scheduling (PS), cost analysis (CA), organization design & analysis (OD&A), and financial analysis (FA)) are represented as the nodes on the circle in figure 5.

Wurtzebach and Miles (1994) describe the early phases of the capital facility development process in detail[7]. Gibson (1995) has conducted a thorough investigation of PPP (CII 1994, CII 1995, and CII 1996)[8]. Others provide methodologies for performing the various types of individual analysis required during PPP[9]. The work presented in this paper does not contribute to these individual areas of knowledge. While the individual activities are essential to PPP, this research focuses on the issue of process fragmentation and the associated problems of time, cost, and consistency. For this research, we use these prior works as foundations for development of the PPP ontology and services (computer programs) to support each PPP activity. From these works and case observations, we derive the information requirements of PPP. We create an ontology of variables to fulfill these information requirements. Each time a user analyzes a new project scenario, a unique SPM is created from the ontology. During the PPP process, as the project is analyzed, variables of the SPM are assigned values. In this work, we address the challenge of integrating the services into a unified PPP analysis system that can perform automated PPP using a SPM.

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[7] Wurtzebach and Miles (1994) identify the players and their perspectives as well as the steps of the project feasibility analysis process. Although they point out that individual project developments vary in their particulars and participants have very different personal styles, a certain sequence of activities characterizes the great majority of PPP efforts. Further, their description emphasizes that while the process is fragmented into specialty tasks performed by individual players, the efforts must be coordinated because they should be both interdependent and focused towards a common goal.

[8] These studies conclude that organized, multi-disciplinary teamwork is essential to the PPP process and that PPP leads to successful projects. Gibson argues that PPP is a process that can be standardized and broken down into discrete tasks that can be identified and organized in a structured manner. One product of the CII research is a process map describing PPP methodology using the IDEF0 diagramming technique. However, CII's PPP methodology is constrained by time requirements and manual data sharing. CII (1995) states that planning can be time-consuming and both technically and administratively challenging, emphasizing that time must be made available to team members to carry out their PPP responsibilities. CII (1995) methodology requires preparation of written formal reports at various junctures in the PPP process. Other participants must interpret these reports later in the process. We seek ways to improve the time consuming aspects of this methodology.

[9] Messner and his colleagues (1977), Clapp (1987), and Gsottschneider (1990) provide established methodologies for market studies and marketability analysis. Russell (1984), Colley (1986), Brewer and Alter (1988), and Dion (1993) provide theories and methodologies for various aspects of site analysis, including land development, site planning, and site development. Pena (1987) provides architectural programming theory and methodologies. Pinedo (1995) presents scheduling theory, algorithms, and systems. Kerzner (1995) provides a systems approach to planning, scheduling, and controlling projects. O'Brien (1994) provides theory and methodologies for concept budgetary and schematic estimates. VDT (Levitt et al.1994) provides a tool for analysis of project organizations. Jaffe and Sirmans (1989), Greer and Farrell (1988), Boyce and Messner (1990), Weitzman (1990), Mockler (1989) and Luenberger (1996) provide theories and methodologies for financial investment analysis.

4.0 Case Example

The following illustrative case example provides the reader with the experience of using the FACT prototype to perform integrated and automated PPP analysis for one project alternative. From this example, the reader will observe how the services, and more importantly, the information are integrated during the analysis through the SPM. The section reads much like a user's manual but provides insights into the research issues explored and discovered through testing of the prototype system.

Using FACT

Figure 6 shows the FACT component circle interface. Initialize the system (press *Initialize*) to begin creating a fast food restaurant facility project alternative.

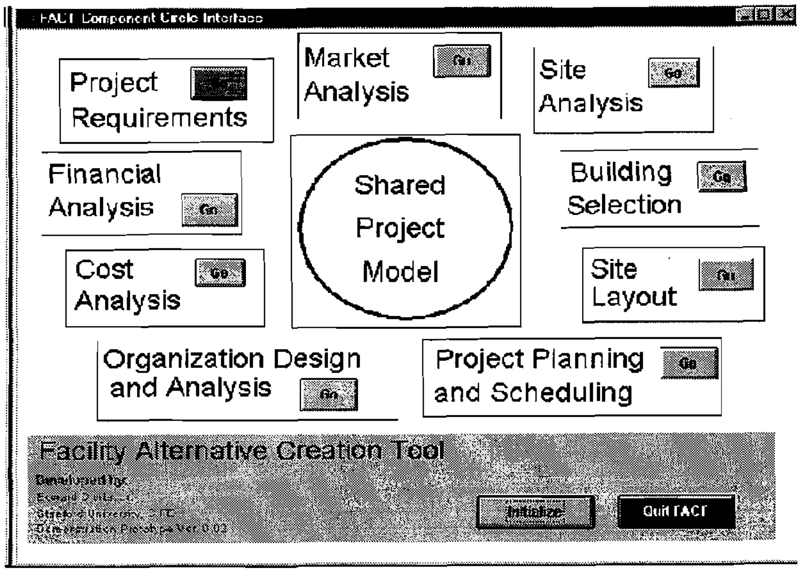

FIG. 6 FACT Component Circle Interface

To create a new project alternative, open the project requirements service (press *Go* on the Project Requirements application box). This activates the Project Requirements Service Interface shown in figure 7.

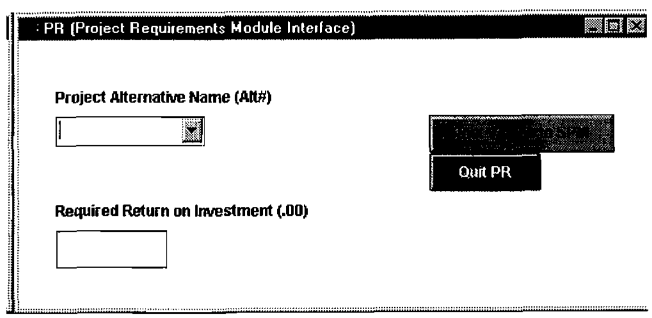

FIG. 7 Project Requirements Service Interface

For this simple case, the project requirement is the required return on investment. Gero (1990) presents a design prototype that provides the basis for the start and continuation of a design[10]. In FACT, when the alternative is named, an instance of a SPM is created from the basis of the PPP ontology. Like Gero's design prototype, the initial SPM represents the beginning of an alternative providing a structure for exploring project variables.

In the project requirements dialog box, first input or select a project alternative name. Then input the required return as a decimal percentage. For this example we select `Alt 1` and input `.18` to require an 18% internal rate of return (figure 8).

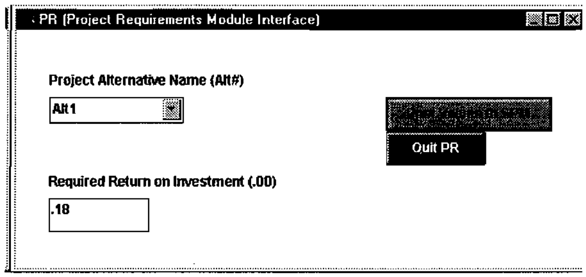

FIG. 8 Project Requirements Service Interface with inputs

After inputting the project requirements, post the values to the Shared Project Model (press *Post Values to SPM*) and quit the project requirements service (press *Quit PR*). This returns us to the FACT component circle interface (figure 9).

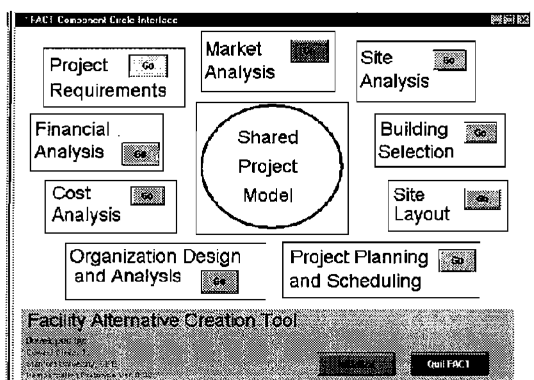

FIG. 9 FACT Component Circle Interface after Project Requirements completed

The *Go* button on the project requirements service is now yellow indicating that we have completed the PR activity for this PPP iteration. Also, the *Go* button on the market analysis

[10] Gero (1990) proposes that designers design by positing functions (requirements) to be achieved and producing descriptions of artifacts capable of generating these functions. Further, Gero argues that designing involves exploring what variables might be appropriate. He proposes designing with design prototypes involving first identification of the client's requirements and then retrieving appropriate prototypes by index to the requirements. When a prototype is selected, an instance is created, representing the beginning of an alternative. The alternative can be modified, analyzed, and evaluated to confirm consistency with the original requirements.

service is green prompting us for the next activity. Start the market analysis service (press green *Go* button). The system displays the Market Analysis Service Interface (figure 10).

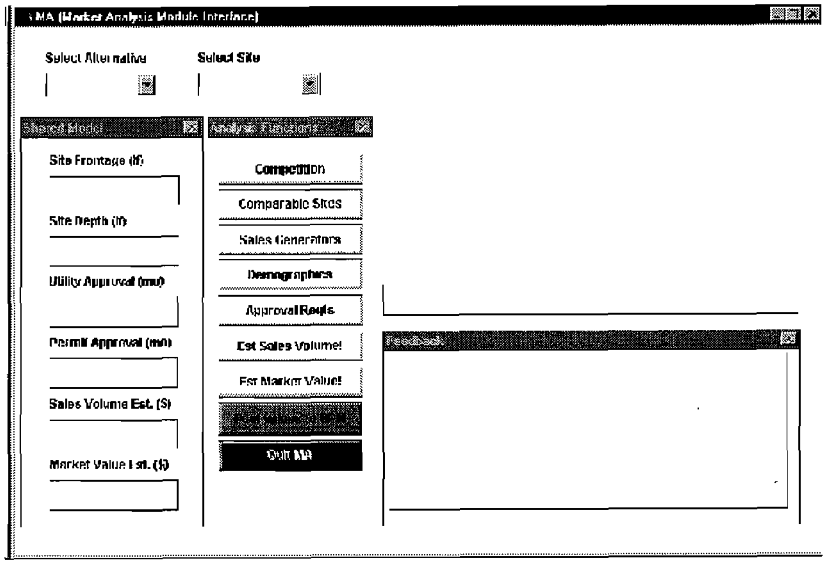

FIG. 10 Market Analysis Service Interface

Now begin to compose a project model by matching a site to a project alternative. Select alternative `Alt 1` and site `S1`. A map of the trade area and the site's frontage and depth dimensions display in the interface (figure 11). Site *S1* comes from a library of sites stored in a data base. Site attributes stored with the site in the data base include *competition* (blue stars on map), *comparable sites* (green houses on map), and *sales generators* such as a shopping mall or highway (red circle on map). The dashed outline on the map indicates the *trade area* associated with the site. For our fast food restaurant example, we establish the trade area using a 3 minute drive time. The service analyzes the population demographics for the project's trade area.

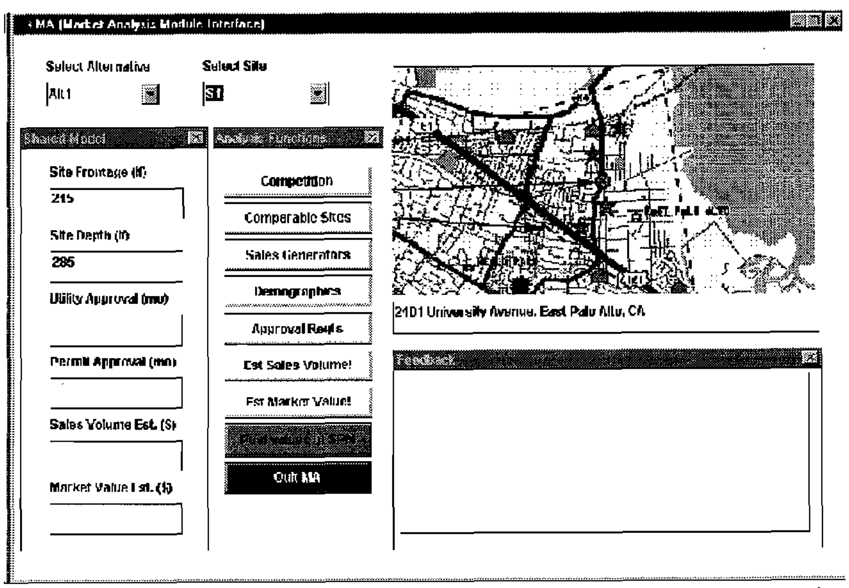

FIG. 11 Market Analysis service with alternative matched to site

The site is in a municipal environment. We are interested in the approval requirements associated with the site in that environment. By pressing the *Approval Reqts* button, we retrieve the utility approval and permit approval durations associated with the municipality within which site S1 is located (2 and 3 months respectively). Press the *Est Sales Volume!* button. This activates a function that calculates the predicted sales volume for the site based upon population demographics, competition, and sales generators ($1,372,000 per year). Press the *Est Market Value!* button. This activates a function that calculates the estimated fair market value of the site ($981,932) based upon the size, shape, and sales price of comparable sites. Figure 12 shows the status of the MA interface after these actions.

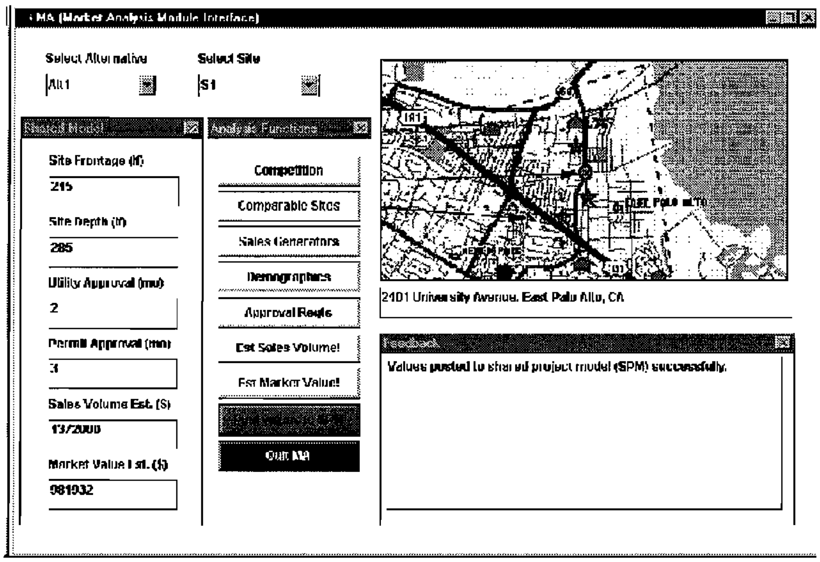

FIG. 12 Market Analysis Service Interface at completion of MA activity

Upon completion of the market analysis, we post the values to the Shared Project Model (press *Post values to SPM*) and quit the market analysis service (press *Quit MA*) to return to the FACT Component Circle Interface. As FACT executes, computer interpretable objects are being shared among the services and the SPM. Figure 13 illustrates an example of this object sharing between the SPM and the Market Analysis service.

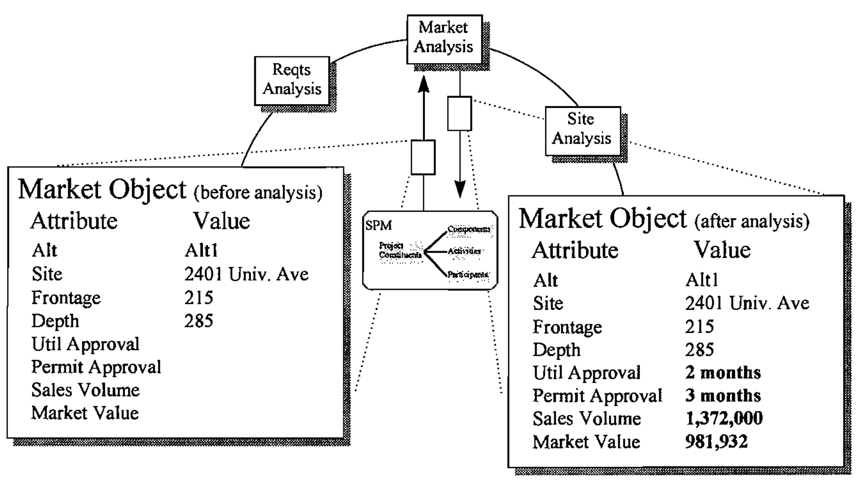

FIG. 13 Object sharing between SPM and Market Analysis service

Prior to market analysis, the Market Object is passed from the SPM to the Market Analysis service. Some of the market object's attributes have values (e.g., Alt, Site, Frontage, and Depth), while other attributes do not yet have values (e.g., Utility Approval, Permit Approval, Sales Volume, and Market Value). The Market Analysis service analyzes the values of the Market Object attributes that are known and predicts values for the unknown attributes. When analysis is complete, the Market Analysis service assigns the values to the unknown attributes and passes the Market Object back to the SPM. Later in the process, other services will need these values to perform their analyses.

Next we activate the Site Analysis Service Interface and select Alternative `Alt 1` and site `S1`. The system displays a map of the site and the site frontage and depth dimensions in the interface. We are interested in the status of the utility connections for the site. We want to know if we have to extend any of the utilities to the site. If so, we want to quantify the extensions. Press the *Utility Analysis* button in the Analysis Functions frame. This action measures the length of the required utility extensions and displays the values in the Shared Project Model frame. We find that the electric, phone, and water utilities are at the site property line. However, we must extend the sanitary, drain, and gas utilities `55'`, `35'`, and `110'` respectively (figure 14).

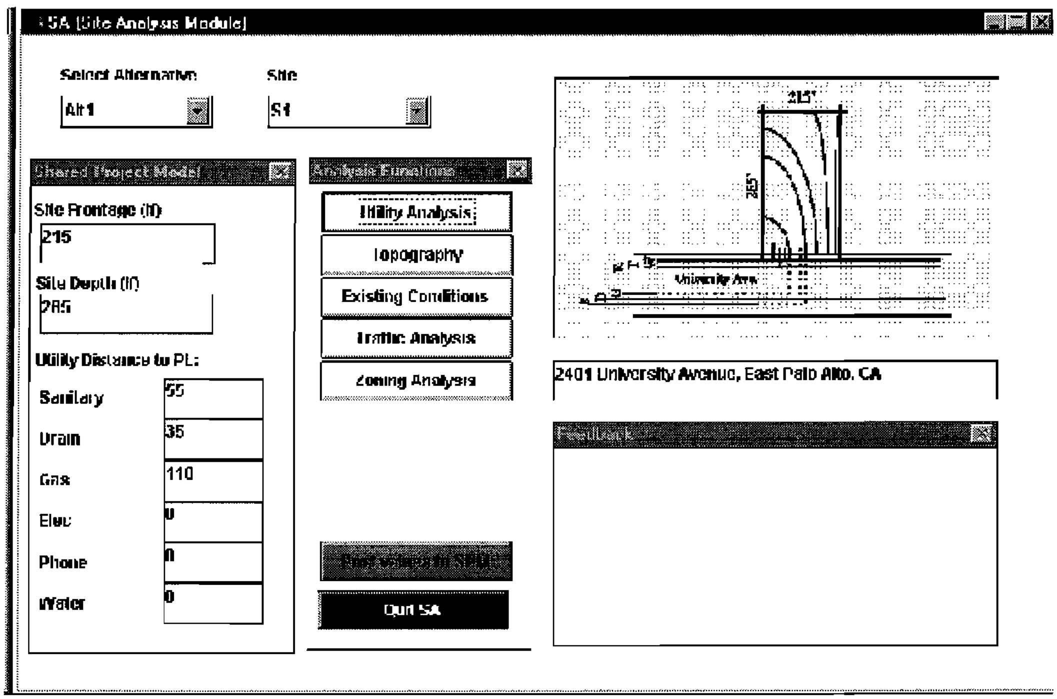

FIG. 14 Site Analysis Service

We are also interested in the zoning issues associated with the site. Activate the Zoning Analysis Interface by pressing the *Zoning Analysis* button in the Analysis Functions frame. Display the zoning considerations associated with the site (press *Get Zoning Data* button). Note that re-zoning is not required for this site, therefore the zoning approval duration is `0` months (figure 15).

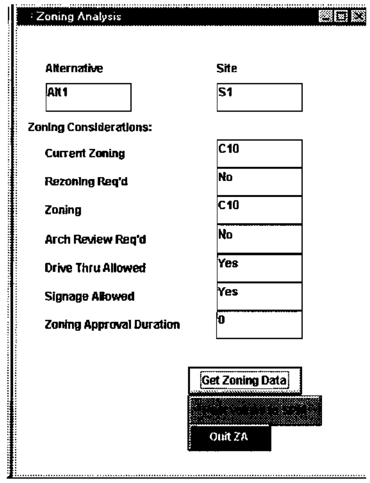

FIG. 15 Zoning Analysis

Post the site analysis values to the shared project model and return to the FACT Circle Component Interface (press *Post values to SPM* and *Quit ZA*). Next, select the Building Selection service. In the Building Selection Interface select `Alt 1`. This displays the sales volume estimate, market value estimate, and site area in the Shared Project Model frame (figure 16).

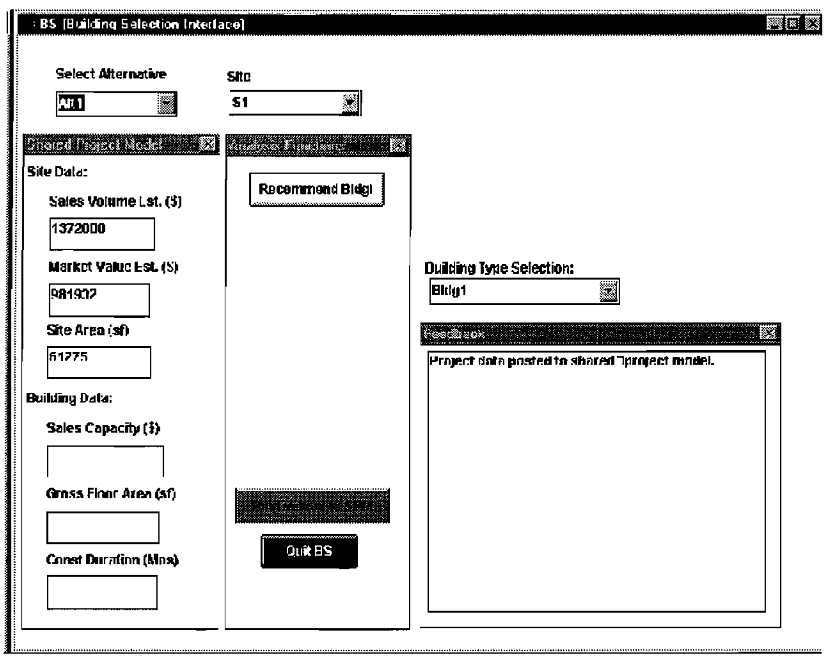

FIG. 16 Building Selection Interface

We want to match a prototype facility to the site with consideration for site and market conditions. Press the *Recommend Bldg!* button. A classification algorithm matches a prototype building to the site. In this example, the system proposes `Bldg. 2` and displays the corresponding sales capacity, gross floor area, and construction duration in the Shared Project Model frame. The interface also displays a 3-D view of the prototype facility (figure 17).

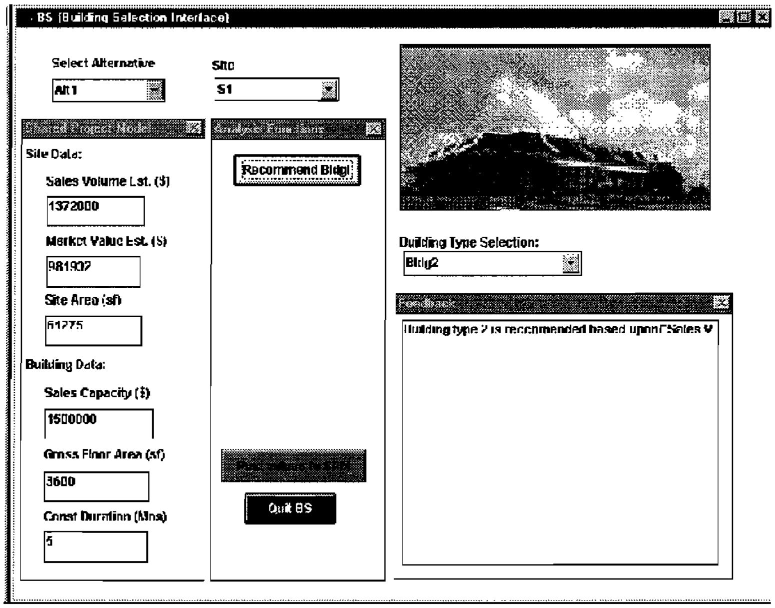

FIG. 17 Building Selection Interface after running classification algorithm

In figure 17, note that the sales capacity of Bldg 2 is somewhat larger than the sales volume estimated for the site ($1,500,000 vs. $1,392,000). This provides room for growth in the market. The prototype facility has a gross floor area of 3,600 sf and a construction duration of 5 months. Post the selected building prototype and its values to the shared project model and return to the FACT Component Circle Interface.

Select the Planning and Scheduling service. Obtain the approval durations and construction duration from the shared project model (press *Approval Durations* and *Construction Duration* buttons). Recall that approval durations were posted to the model during the market and site analysis and the construction duration was posted during building selection. Run the Schedule analysis function (press *Schedule!*). The system calculates a total duration of 16 months (figure 18).

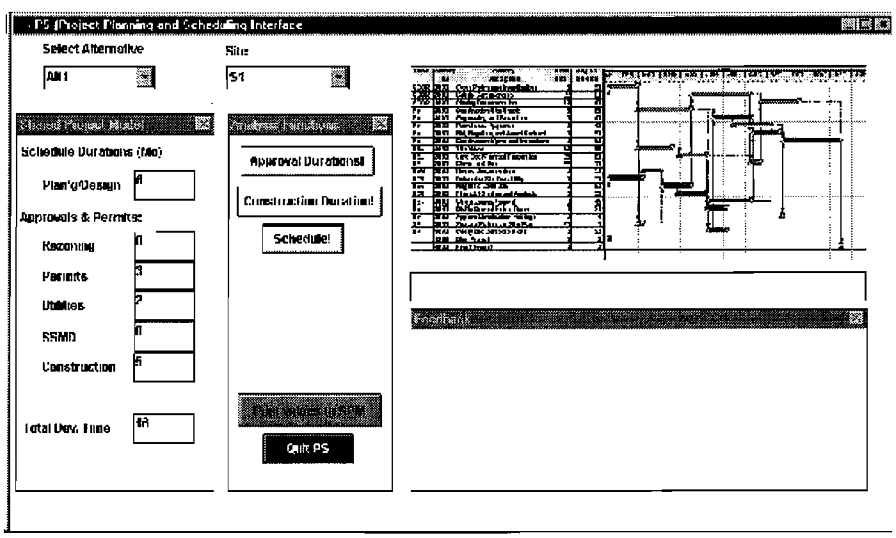

FIG. 18 Project Planning and Scheduling Interface

Post the values to the shared project model and quit to return to the FACT Component Circle Interface. Next we are interested in the cost associated with the project alternative. Activate the Cost Analysis Interface. Obtain the quantities for the project alternative from the shared project model by pressing the *Quantities* button (figure 19).

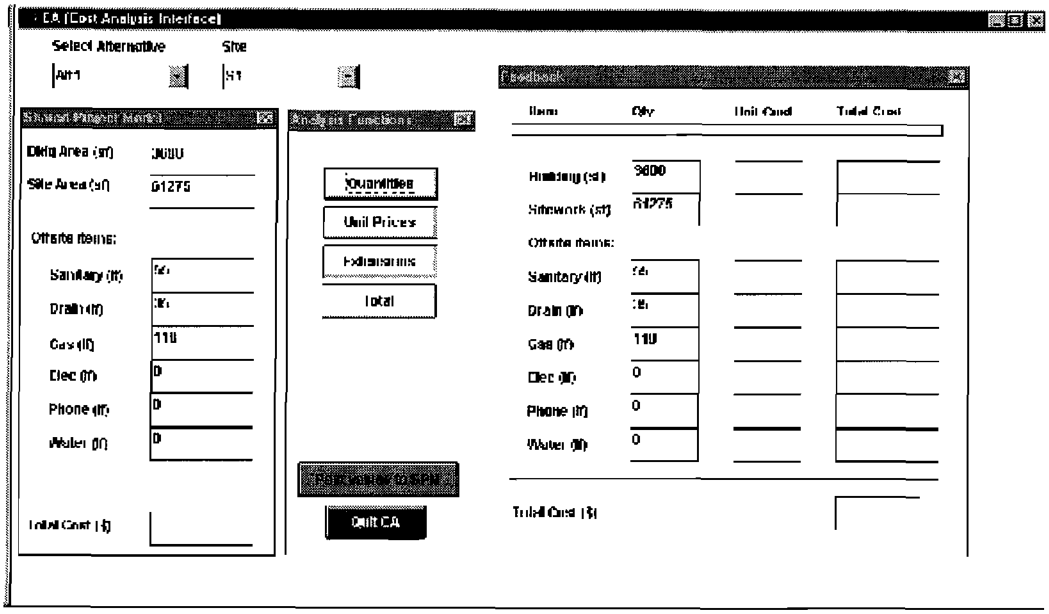

FIG. 19 Cost Analysis Interface with quantities from SPM

Then match unit prices from the data base (*Unit Prices* button) to the quantities, perform the mathematical extensions (*Extensions* button), and calculate the total cost (*Total* button) of construction ($484,051). Figure 20 shows the Cost Analysis Interface after these steps.

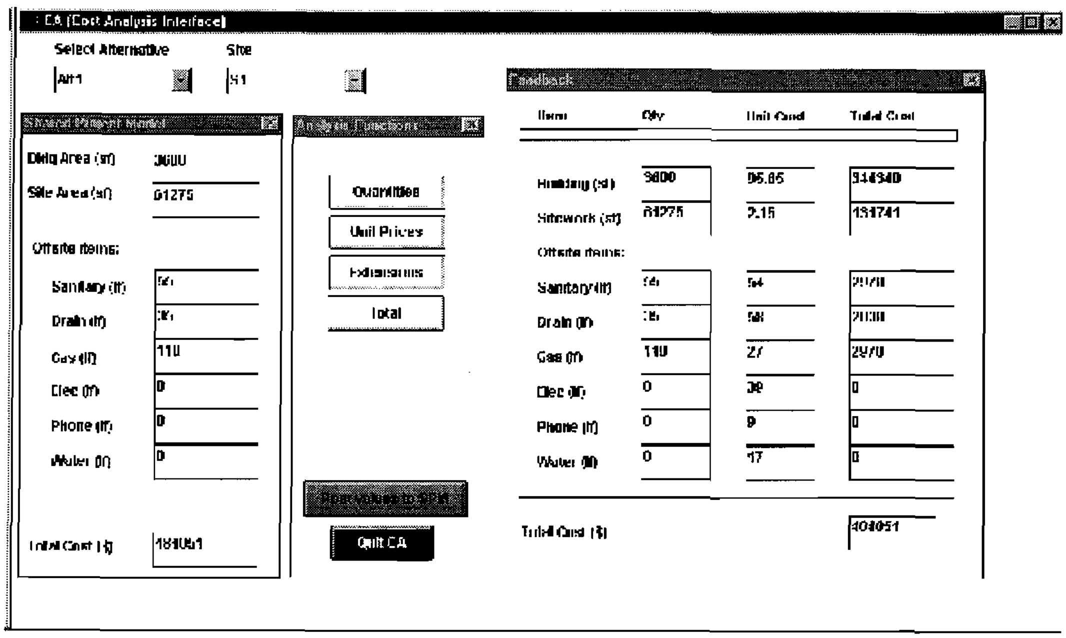

FIG 20 Cost Analysis Interface with quantities, unit prices, extensions, and total

Post the cost values to the shared project model and quit the cost analysis service. Next, activate the Financial Analysis Interface to analyze the project alternative from a financial perspective. Start by gathering all of the project data necessary to perform a financial analysis (press the *Get SPM Data* button). Figure 21 shows the financial analysis service with values of land costs, improvements cost, estimated sales, required return, and schedule imported from the SPM.

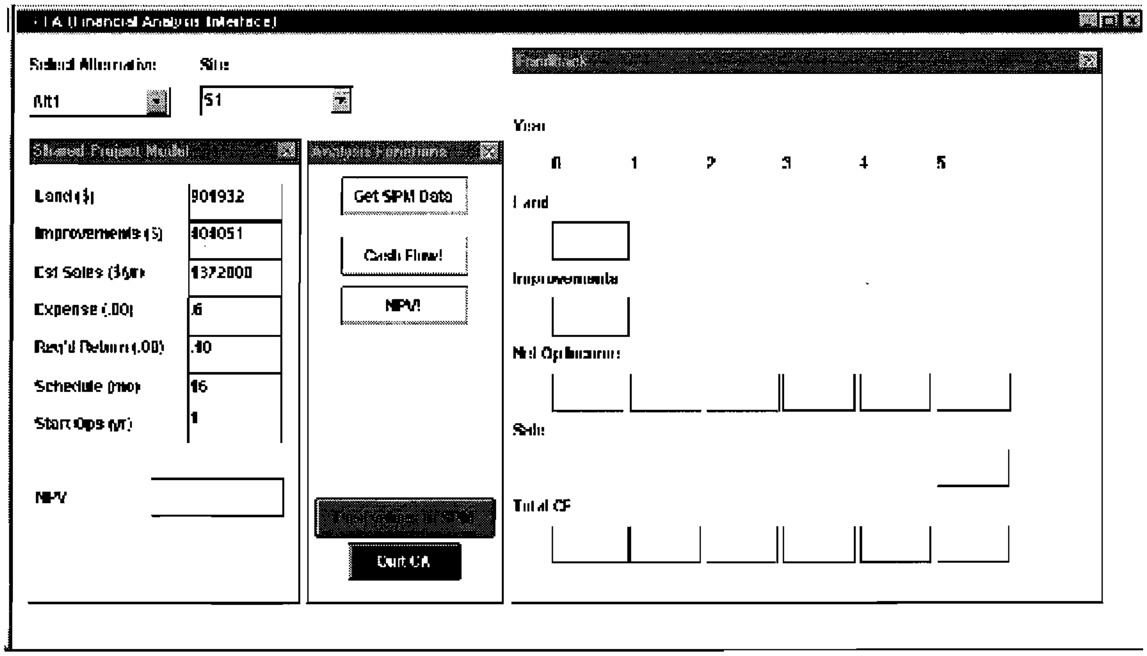

FIG. 21 Financial Analysis Interface with SPM data

Using the project data from the SPM, generate a cash flow estimate (press *Cash Flow!* button). In this fast food restaurant example, we include development costs and five years of operating income with a sale at the end of the five year period. Now calculate the net present value (press *NPV!* button) of the project alternative to predict whether or not the alternative achieves the required rate of return. In our example, the net present value is positive at $735,975 which indicates that the facility alternative scenario that has been created is predicted to exceed the required rate of return (see figure 22).

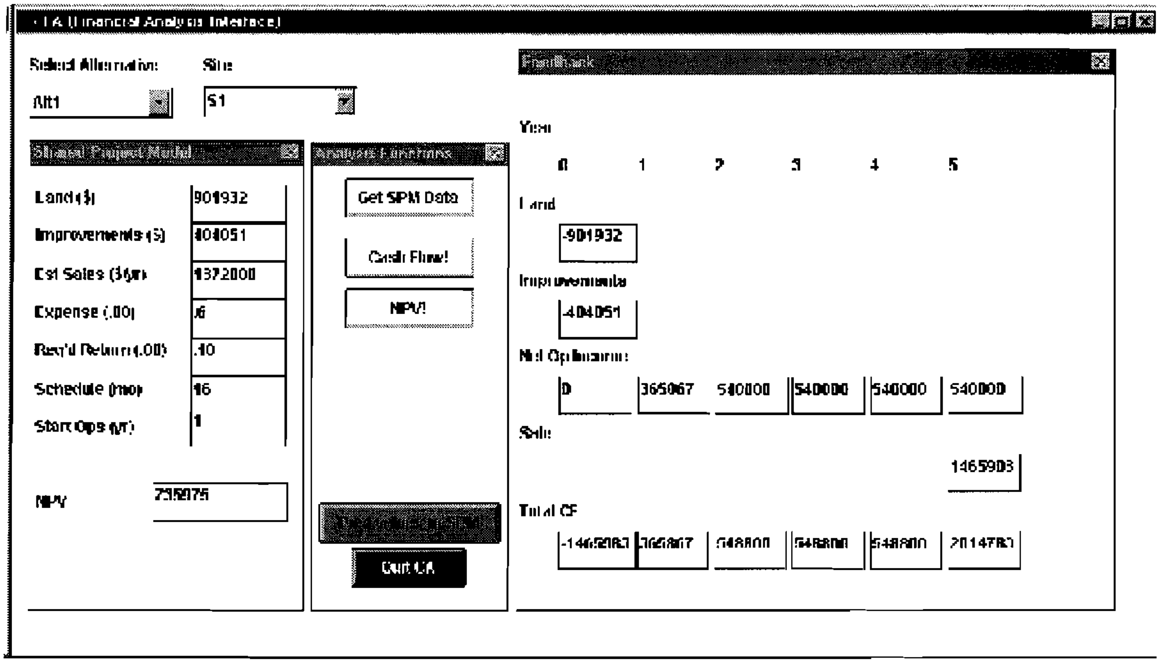

FIG. 22 Financial Analysis Interface with cash flow and NPV

As illustrated earlier with the Market Analysis example, computer interpretable objects are being shared among the services and the SPM. Figure 23 illustrates an example of this object sharing between the SPM and the Financial Analysis service. In this case, the Financial Analysis service requires many different types of data. It obtains all of the information it needs from objects within the SPM (e.g., market, site, building, schedule, cost, and financial objects).

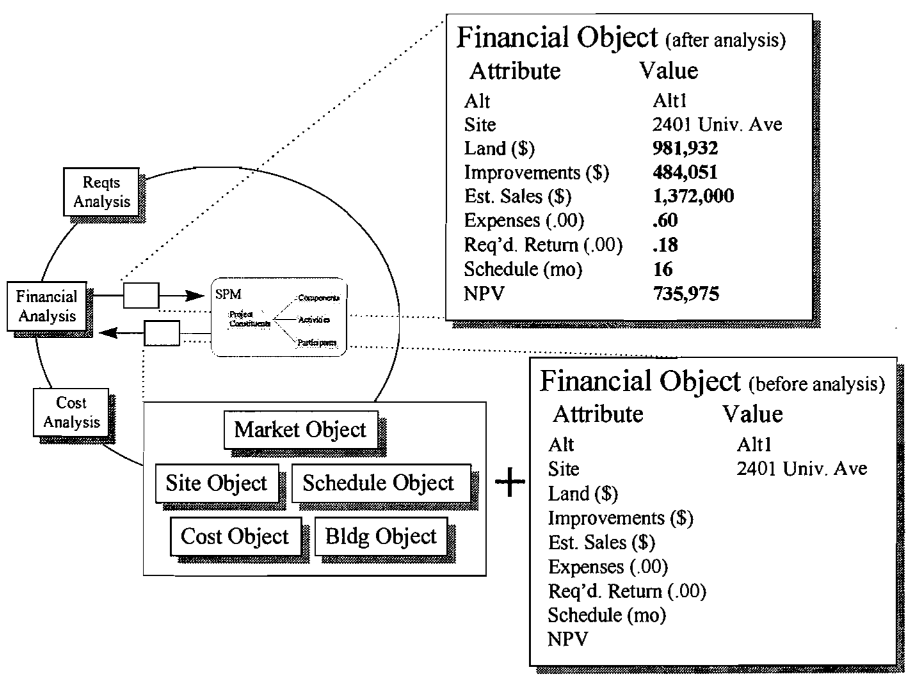

FIG. 23 Object sharing between SPM and Financial Analysis service

The Financial Analysis service analyzes the values of the various object attributes that are known and predicts values for the unknown attributes of the Financial Object. When analysis is complete, the Financial Analysis service assigns values to the unknown attributes and passes the Financial Object back to the SPM. These values are now available for evaluation by the user. The user may compare the values from this alternative to other alternatives or to historic data.

In the preceding demonstration of FACT, we synthesized a project alternative by matching a prototype building to a site within a specific market environment. Then we analyzed the alternative in terms of schedule, cost, and finance. We are able to do these tasks rapidly with the support of an integrated and automated PPP system (FACT). We represent the project alternative as a project model shared by the various software services. Once we create this model, we can do sensitivity analysis for any number of variables from the perspective of any service subscribed to the circle. For example, we can vary market conditions, site conditions, building parameters, or other independent variables and re-iterate around the circle to predict the behaviors (e.g., market value, sales volume, schedule duration, cost, and NPV). By evaluating the various behaviors resulting from varying values for uncertain project variables we can better understand the risks associated with a particular project alternative. Using this tool, we can rapidly and consistently compose and analyze project alternatives and compare their behaviors. Then, using the comparison principle, we select the best alternative.

Looking back to the situation described in the Prologue, the Regional Manager could have performed a better decision process with the help of a tool such as FACT. Using an integrated and automated analysis system, the Regional Manager could have created a project model using values for the original site. Then, when the alternative site was proposed, he could have quickly created a second project model in a consistent manner using new values. The longer approval durations and larger quantities of site work would have been represented in the model and the NPV of the second project would have been less than the first. His decision would have been to choose the project with the highest expected NPV.

5.0 Cool, but... (Critique of FACT)

Fischer and Kunz (1995) suggest criteria for evaluating the effectiveness of implementations of integration strategies. The following addresses the issues related to those criteria and others that we have observed through testing and demonstration of the prototype system.

Benefits of the Facility Alternative Creation Tool (FACT)

Speed

Using FACT, a user can develop a project alternative rapidly if adequate project information is available. Also, a user can perform what-if analysis and obtain rapid feedback from all perspectives in just a few minutes. FACT enables consideration of many project alternatives in a very short time. Speed is one benefit of integrating and automating PPP.

Version Control

FACT automatically creates clear design versions. The system instantiates a project model with a unique name for each version. Each application on the circle displays the version name and the relevant project model data in its interface. Each iteration around the circle creates a unique project model that has been analyzed from each of the various PPP perspectives. Other integration approaches were considered during the early stages of this project but they were disregarded due to their lack of inherent version control characteristics.[11]

Consistency

Every SPM derived from the PPP ontology shares a common information structure. In addition, each iteration of the circle shares a common analysis process and sequence. In this way, FACT guarantees a consistent basis for creating and comparing project alternatives.

Limitations of the Facility Alternative Creation Tool (FACT)

Adaptability

Because different project phases require different analyses, Fischer and Kunz (1995) suggest that a software integration strategy should allow relatively simple addition and deletion of applications. In its infancy, the current implementation of FACT lacks this capability. We are developing a circle integration mechanism (Circle Broker) by which software services can join an integrated suite of applications by committing to an ontology.

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[11] Khedro, Genesereth, & Teicholz (1994) demonstrate software integration for AEC projects by linking separate program modules called software agents. The software agents utilize a communication standard called the agent communication language (ACL) to interact with other agents through a coordinating program called a facilitator. Put simply, agents send queries for information to the facilitator, the facilitator forwards the queries to other interested agents who respond back to the facilitator, and the facilitator forwards the reply to the original agent. This approach is very flexible because agents can be added, replaced, or removed without changing the functionality of the system as a whole, albeit specific functionality would be affected. However, the feedback loops of this system are implicit and version and revision control is not inherent.

Incomplete Information

Many of the reviewers of FACT have expressed that the system is effective when complete and certain information is available. However, FACT does not support the user under conditions of uncertainty and incomplete information. We are developing a circle integration mechanism (Circle Explorer) that exploits the information structure inherent to the PPP ontology to support users with simple yet intelligent information searches when faced with incomplete information.

Process Automation

The current version of FACT requires the user to press interface buttons to advance around the circle. This in itself can be time consuming and monotonous. We are experimenting with information classification schemes to support automated analysis from multiple perspectives. To prove this concept, we are developing a circle integration mechanism (Circle Navigator) that will intelligently determine the information and analysis requirements and automatically control the circle integration process.

Types of Projects

The current FACT prototype only responds to the requirements of PPP for fast food restaurants. We are interested in determining how the requirements for a PPP ontology might vary if the system it supports must be responsive to various types of facilities (such as office buildings and apartments in addition to fast food restaurants).

Features of the Ontology

The current PPP ontology that supports FACT relies on an ad-hoc structure meeting the minimum information sharing requirements of the first fast food restaurant test case. We believe that the current limitations of automated PPP may be overcome through the structuring of the information model. Therefore, we are developing a PPP ontology whose structure purposefully addresses the limitations of adaptability, incomplete information, process automation, and types of projects.

In summary, the FACT prototype demonstrates good speed, version control, and consistency. FACT and PPP are currently limited in the areas of adaptability, incomplete information, process automation, and types of projects. The creation and initial testing of FACT is a part of a larger research plan that provides for evolutionary development. Plans for continuation of this research include extension of the PPP ontology and creation of circle integration mechanisms. The next chapter discusses how these goals might be achieved.

6.0 Developing Circle Integration Mechanisms and a PPP Ontology

We have conceptualized circle integration mechanisms to overcome the limitations of adaptability, incomplete information, and process automation currently associated with integrated and automated PPP. These mechanisms are designed to work in harmony with a new PPP ontology. Together the mechanisms and ontology will support integrated and automated PPP for various types of facilities. In this chapter, we start with a system overview and introduction of the circle mechanisms. Then we describe our concepts for a new PPP domain ontology for FACT. In the future, we will develop a new prototype system to test these concepts.

Circle Integration Mechanisms

Figure 24 is a conceptual diagram of the extended FACT system architecture illustrating the addition of three circle integration mechanisms. The *circle broker* enables services (specialty software applications) to join the suite of applications on the circle. The *circle navigator* uses model-based reasoning to rapidly create project alternatives by iterating through the suite of applications automating the PPP process. Users and services invoke the *circle explorer* during navigation when information is incomplete. The circle explorer uses heuristic classification (Clancey 1985) to obtain project information from historic or other data sources that are also committed to the PPP ontology.

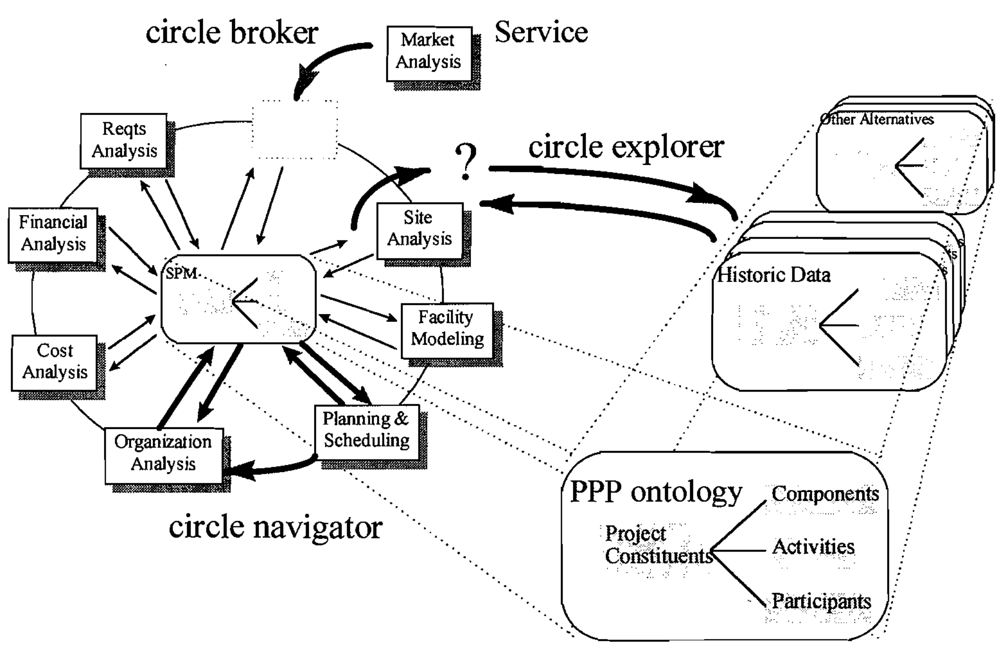

FIG. 24 System architecture. The *circle broker* enables services to join the suite of applications. The *circle navigator* iterates through the services automating the PPP process. The *circle explorer* is invoked to support the user when information is incomplete.

We are developing a next prototype PPP analysis system that incorporates and tests these mechanisms. The information requirements of the mechanisms are to be supported by the new PPP ontology. We will test the new system using cases for several different types of facilities to observe and measure the effectiveness and generality of the PPP ontology and circle integration mechanisms.

A PPP Domain Ontology for FACT

The role of an ontology in software engineering

As discussed, integrating and automating PPP to reduce the time and cost of PPP while providing a consistent basis for comparing project alternatives proposes a challenging engineering problem. Fragmentation of project specialists, heterogeneity of conceptualizations, and the demand for sharing information and knowledge, while not unique to PPP, all exacerbate this challenge. In response to these types of challenges, Sutcliffe et al. (1996) suggest a trend in software engineering toward the recognition of the importance of models embedded within computer programs and the value of making those models more explicit, editable, and maintainable. These models are referred to as domain models. Musen et al. (1995) have been developing methodology for creating and maintaining explicit domain models in the area of medical informatics specifically addressing problems associated with automating protocol-based patient care using component-based approaches. For computer-based patient care systems, the domain model includes patients, their medical problems, and the interventions that health-care providers may make in the management of patients.

For computer-based PPP, as demonstrated in chapter 4, we want various computer programs that support specific analysis processes (e.g., market analysis, site analysis, facility modeling, etc.) to share a common model when data sharing and exchange is necessary. In addition, we want that model to encapsulate a project representation, unique for a given design version or project scenario. Rather than embed models into each of the services, we propose a common model, a shared information structure, that provides sufficient project representation to support reasoning by each of the analysis programs. When all of the programs have analyzed the model, it becomes a project model version that can be evaluated against other versions to determine the best alternative.

To make domain models more accessible and reusable within a field, their content can be specified in the form of an ontology. We argue that one reason why PPP currently lacks unification and automation within practice is the lack of an ontology for the domain. PPP analysis includes predicting the cost of facility ***components***, analyzing project ***activities*** to determine event timing and project duration, and analyzing the team of ***participants*** to assure adequate and appropriate organization configurations. The principle elements which represent a project during the PPP phase are therefore facility *Components*, process *Activities*, and team *Participants*. Other researchers use project component, activity, or participant representations for various purposes not specifically related to PPP.[12] Collier et al. (1996) link construction activities to facility components to perform a visual simulation of the construction process.[13] Darwiche et al. (1989), Winstanley et al. (1993), and Jin et al. (1992) describe activities using object, action, and resource constituents for hierarchical planning.[14] We are proposing a PPP ontology based upon the principle PPP constituents of *components, activities,* and *participants* (CAP).

To structure the information requirements of the software services, we represent PPP components, activities, and participants within service objects. Figure 25 is a screen dump of the object browser displaying the *service objects* of the FACT application. Service objects are the highest level objects that are shared among the services on the circle. The primary subclasses of service objects are Components, Activities, and Participants. In the figure, the Component, Activity, and Participant objects are highlighted in the class-subclass-instance tree. The slot table at the bottom of the figure displays the attributes for these objects. The attributes shared among service objects include functions, forms, and behaviors. In the following section, we describe an ontology of service objects with function, form, and behavior attributes that provides a basis for integrating and automating PPP.

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[12] The Virtual Rapid Prototyping project (Kunz et al. 1995) combines a 4D CAD model with the VDT system to support integrated analysis of product, process, and organization. The project focusses on the design & construction phases of high-tech projects and does not address the information needs of PPP, although it also uses component, activity, and participant models. The Virtual Design Team model (Levitt et al. 1994) represents a project using the basic components of actors and activities. The actors are composed into an organization structure and the activities are composed into a sequenced project schedule. The actors are then linked to the schedule through their responsibility for activities. This representation is effective for reasoning about the project to simulate information processing. We propose the VDT analysis as a fundamental service of PPP.

[13] 4D-CAD (Collier & Fischer 1995) links a 3D CAD model of a facility to a construction schedule to enable a construction simulation that enhances construction plan understanding and critiquing. The 4D-CAD project representation includes a product model (a composition of facility components) and a process model (a composition of construction activities with precedence relationships to other construction activities). In the object-oriented programming implementation (McKinney et al. 1996), each component object is linked to an activity object. During the simulation, as activities occur, the associated component is drawn in the CAD graphic environment. While the 4D-CAD project has a continuing agenda to facilitate rapid development and analysis of alternative building designs and construction plans, the current implementation does not involve reasoning about the product model beyond associating it with a construction process. PPP requires reasoning about a facility model to determine its cost, schedule, and profitability. The current 4-D CAD representation is not adequate for PPP because it lacks the essential objects, attributes and methods required for PPP (e.g., market, trade area, site, population demographics, and expense during).

[14] OARPLAN (Darwiche et al. 1989, Winstanley et al. 1993, Jin et al. 1992) is a computer software tool that generates project plans through reasoning about objects, actions and resources. OARPLAN's purpose is to generate plan activities based upon the project objects and its output is sequenced activities. The principle elements of planning are activities. OARPLAN represents activities as groupings of their constituents: objects, actions and resources. In OARPLAN, planning knowledge is represented as constraints based on these activity constituents and their interrelationships. Through constraint satisfaction, OARPLAN generates and sequences activities.

The FACT PPP domain ontology

All of the software services in the FACT architecture use the shared, computer-interpretable representation based upon the PPP ontology. There are no data transformed by nor exchanged among any of the FACT services that are not explicitly contained within the PPP ontology. In this way, the ontology defines a precise and consistent data model for PPP. The ontology is useful for automated reasoning because of the decomposition into function, form, and behavior.

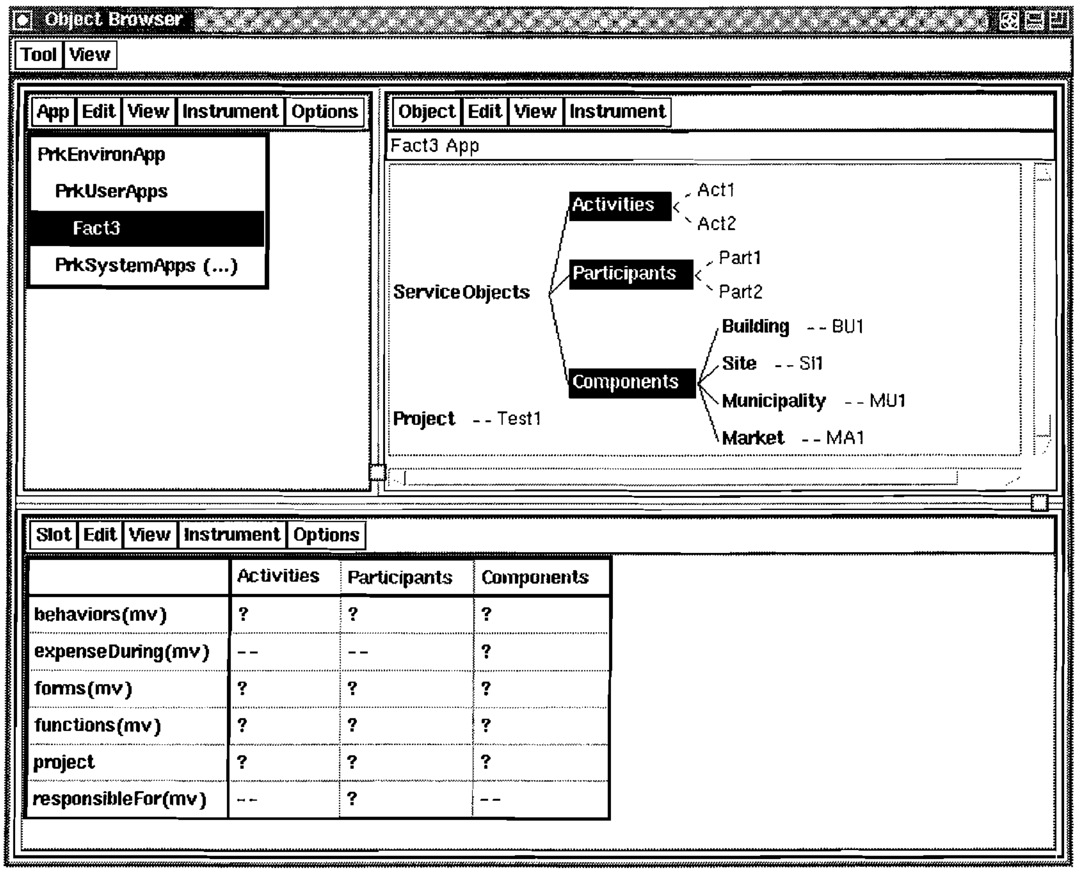


FIG. 25 FACT PPP components, activities, and participants as sub-classes of service objects. The slot table at the bottom of the figure reveals that each component, activity, and participant has form, function, and behavior attributes. The question mark symbols ("?") in the slot table indicate that the attributes do not have values at the class level.

Function, Form, and Behavior

Luth (1991) advocates representing structural systems using function, form, and behavior views for integrated structural design. Separating the various views of a structural system, Luth claims, makes it possible to develop efficient data storage strategies to support automated analysis. Gero (1990) describes the role of function, behavior, form[15] models as a powerful means of articulating a framework for design processes. Clayton et al. (1996)

[15] Gero actually uses the term "structure" to describe the physical entities or components of a design artifact. For our purposes the terms "structure" and "form" are interchangeable. We use the term "form" throughout this paper.

describe a theory of design evaluation wherein behavior follows form follows function. In Clayton's definition, behaviors are predicted from the form by means of reasoning and functions are the desired qualities against which behaviors can be assessed. The elements required for PPP are considerably different than those for structural or architectural design. However, we draw insights from these prior works to create an ontology involving function, form, and behavior for PPP project representation.

Figure 26 illustrates how we use FFB for the Market Analysis and Evaluation aspect of PPP. Market conditions are described as forms (e.g., *Trade Area, Comparable Sites, Income Generators*, and *Competition*). By analyzing these forms, market behaviors are predicted (e.g., *Excess Demand, Population, Current Demand,* and *Current Supply*). After behaviors have been predicted, they can be evaluated against functions (e.g., *Excess Demand* is compared to *Minimum Demand*).

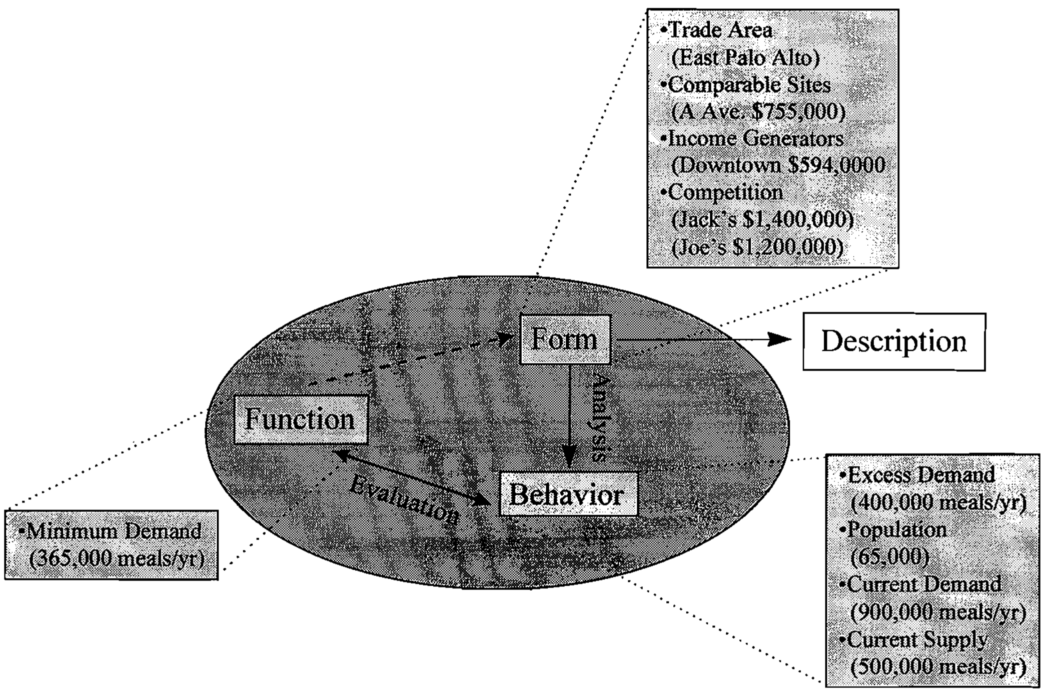


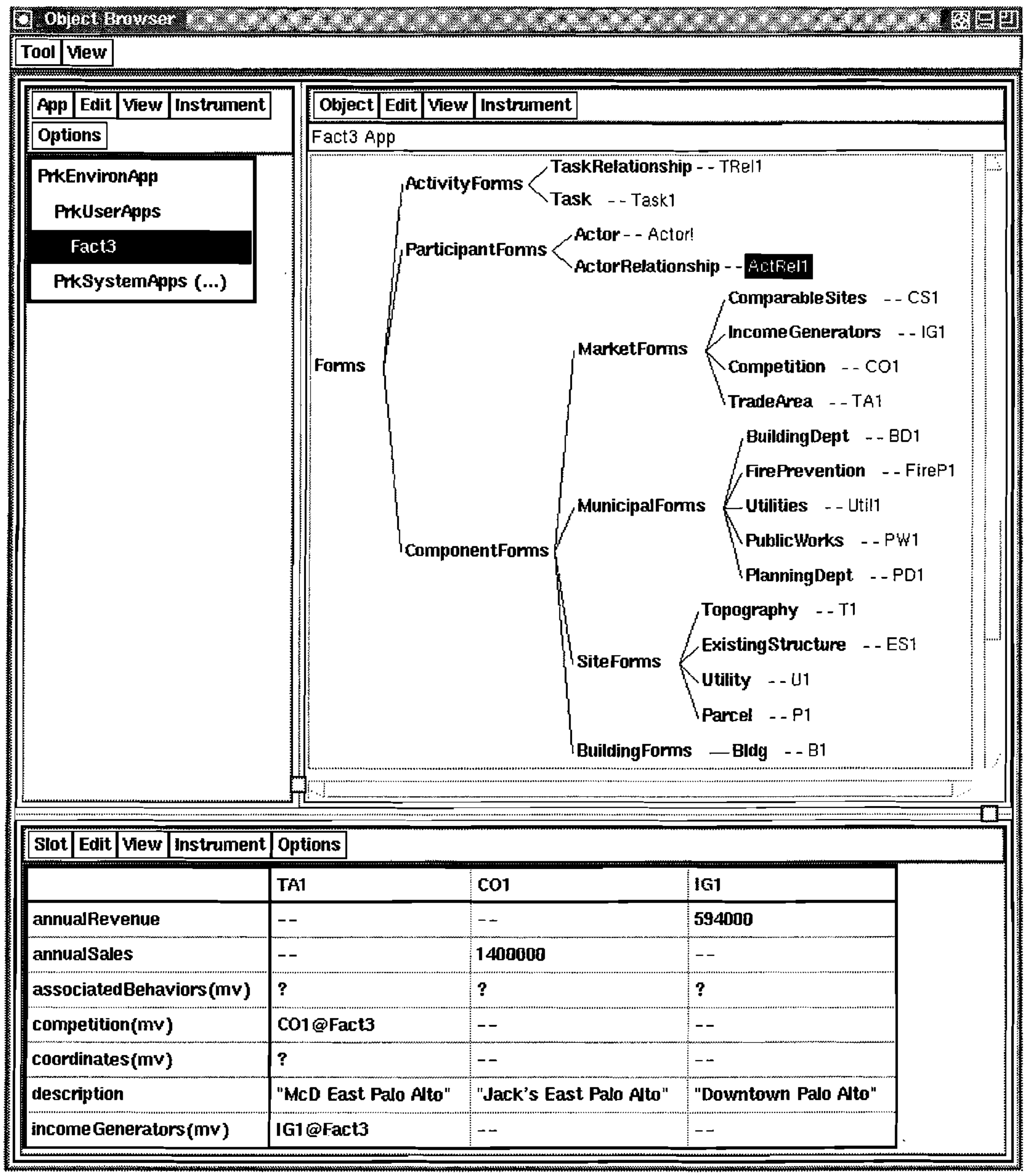
FIG. 26 Market Analysis and Evaluation using FFB

For our next FACT prototype system, the PPP ontology will specify function, form, and behavior of a facility project during the PPP process. In this chapter, we use this market analysis example to describe the structure of the PPP ontology and its use for integrated and automated PPP.

Forms

For our purposes, forms are the components and their relationships that describe a project during PPP. Figure 27 is an object browser view of the form object hierarchy we are developing for the FACT PPP ontology showing the class-subclass-instance relationships. The Forms class has subclasses that correspond to components, activities, and participants.

These subclasses are further decomposed into specific classes of form elements with the attributes required for PPP analysis. *TA1* is an instance of the *TradeArea* class that is a subclass of *MarketForms* and *Forms*. The slot table at the bottom of figure 27 shows the attributes and some values for the specific trade area *TA1*. The attributes of a trade area include competition, income generators, description, and associated behaviors. This trade area object can be analyzed by a market analysis program to predict associated behaviors (e.g., population demographics). *CO1* is an instance of competition that is related to *TA1* and *IG1* is an instance of income generators that is related to *TA1*. In market analysis practice, it is natural to associate competition and income generators with a trade area. The market forms (e.g., trade area, competition, and income generators) are analyzed to predict market behaviors (e.g., current demand, current supply, and excess demand).



	TA1	CO1	IG1
annualRevenue	--	--	594000
annualSales	--	1400000	--
associatedBehaviors(mv)	?	?	?
competition(mv)	CO1@Fact3	--	--
coordinates(mv)	?	--	--
description	"McD East Palo Alto"	"Jack's East Palo Alto"	"Downtown Palo Alto"
incomeGenerators(mv)	IG1@Fact3	--	--

FIG. 27 FACT PPP ontology form entity class-subclass-instance relationships

Behaviors

The values of behaviors can be derived from forms by means of reasoning, or analysis. Figure 28 is an object browser view of the behavior object hierarchy that we are developing for the FACT PPP ontology showing the class-subclass-instance relationships.

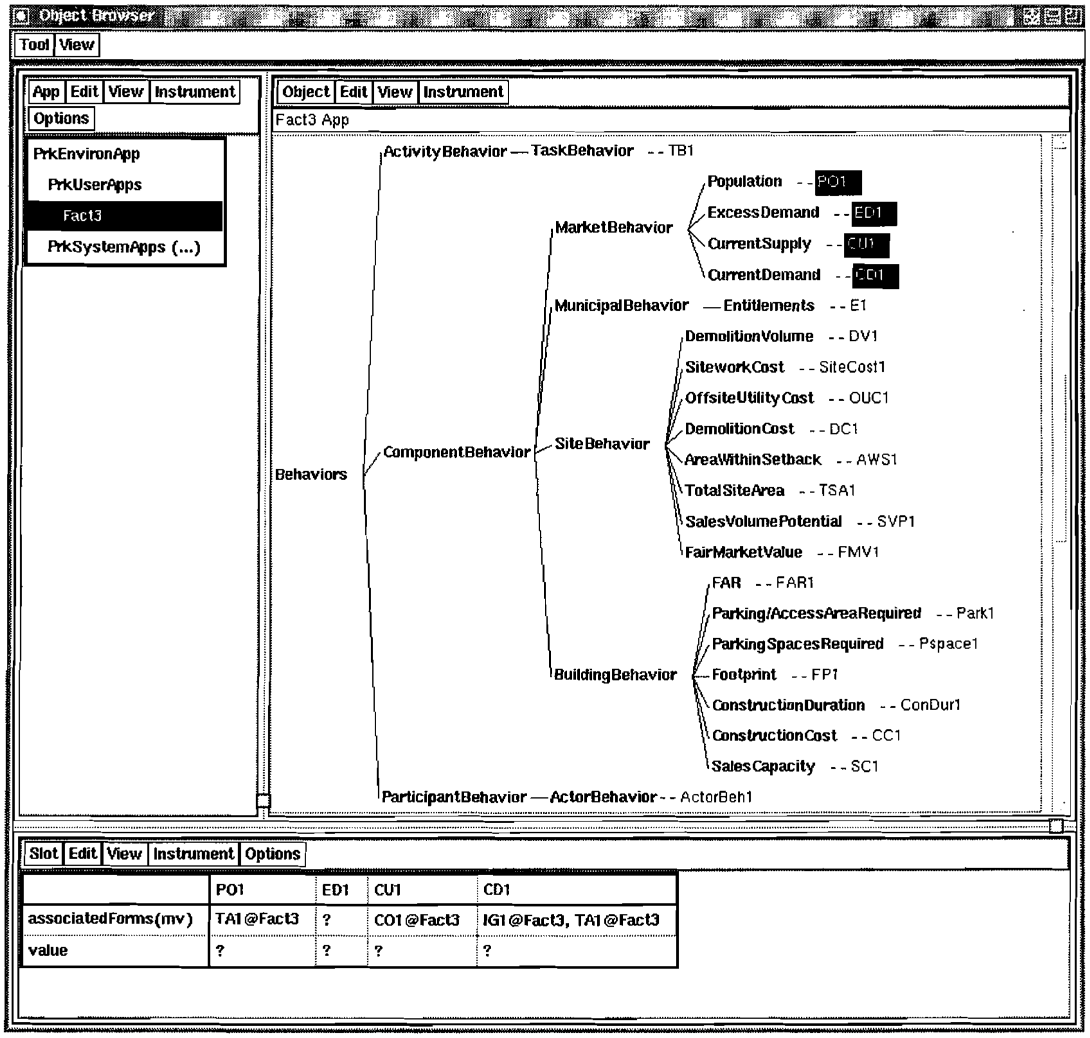


FIG. 28 FACT PPP ontology behavior class-subclass-instance relationships

Like the forms class, the behaviors class has subclasses that also correspond to components, activities, and participants. These subclasses are further decomposed into classes of specific behaviors that are normally predicted during PPP analysis. In figure 28, several behavior instances are highlighted. Each behavior instance has an attribute for its value and multi-value attribute for associated forms. The associated forms are those that are required to predict the value of the behavior. Using this structure, a behavior object knows what forms must be referenced to derive its value. For example, *current demand* is a behavior and *income generators* and *trade areas* are associated forms. To predict the current demand for a project, trade area and income generator forms are required. In the slot table of figure 28, *IG1* (income generator) and *TA1* (trade area) are the forms associated with behavior *CD1* (current demand). The current demand for the proposed facility can be derived by analyzing its associated forms.

Functions

Functions are described as requirements, intents, purposes, and objectives (Clayton et al. 1994, Gero 1990). For example, *minimum demand* is a function for market analysis. That is to say that it is a requirement to have at least a certain minimum amount of demand to justify construction of a new facility. Functions are useful for evaluation. After behaviors are predicted (e.g., excess demand) they can be compared with functions (e.g., minimum demand) to determine if the form is appropriate, or adequate.

Modeling/Relating FFB Objects to Services

Recall that we refer to the various computer programs on the circle that perform analysis as *services*. Services need something to analyze and a place to put the results. For PPP, various services share project information. As shown in figure 23, at times behaviors predicted by one service may be used by another service to predict other behaviors. At the project level (high level abstraction), the purpose of our model is to analyze a project scenario to predict a project's performance, or behavior. At the object level (low level specific details), the purpose of form objects is to represent specific project entities so they can be analyzed. Also at the object level, the purpose of behavior objects is to provide a pointer to associated forms and a placeholder for the predicted behavior value. At the service level (intermediate level at which data is passed from SPM to services and back) service objects support analysis by services. These service objects encapsulate form and behavior objects and make them accessible to appropriate services. Referring back to figure 26, service objects is the top level class of components, activities, and participants.

To automate PPP, we provide the services with a description of form. Then, the services analyze the form and predict behaviors. Then the behaviors can be compared with functions for evaluation. The PPP ontology (library of forms, behaviors, and functions) provides the vocabulary for the services and SPM. The services are aware of what behaviors they can predict and what forms they require. The values of the forms, behaviors, and functions vary from project to project while the definition of variables remains consistent. However, as hierarchies of forms and behaviors grow, they become increasingly challenging to manage. We are experimenting with an approach to overcoming this object management challenge by composing related forms and behaviors into service objects.

Figure 29 illustrates the hierarchical classification scheme for the PPP ontology using component, activity, and participant service objects with forms, behaviors, and functions. A *Project* is the highest level concept in the PPP ontology. Each project is composed of service objects that include *components*, *activities*, and *participants*. Components can be *buildings*, *sites*, *municipalities*, and *markets*. All service objects contain *form*, *function*, and *behavior* objects. Figure 29 illustrates the forms, functions, and behaviors for the market component service object. The forms, functions, and behaviors provide a basis for automated analysis and control of information requirements.

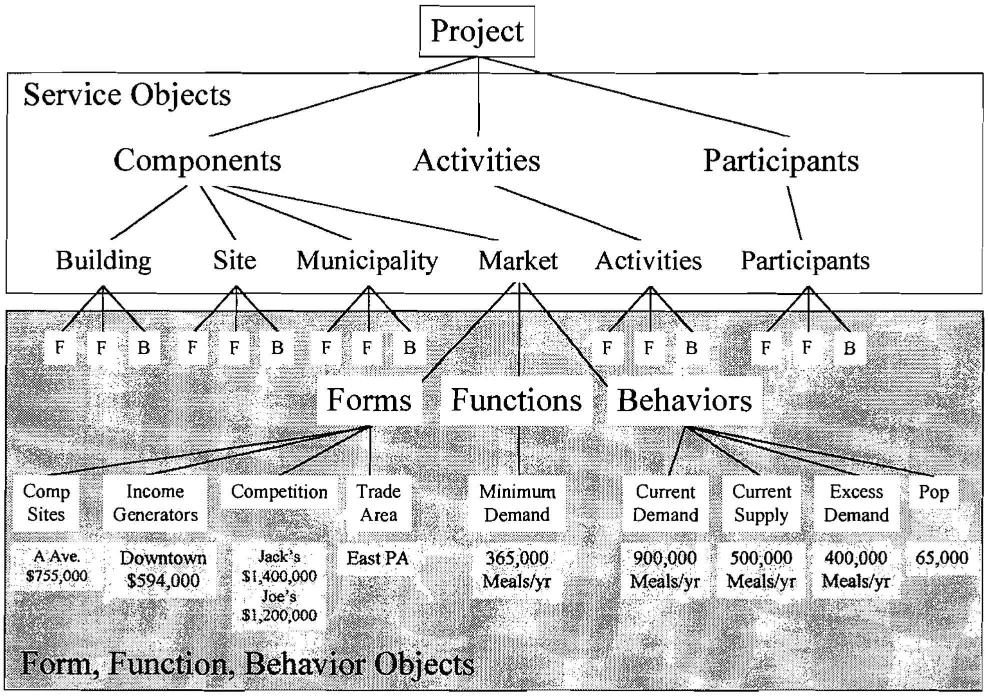


FIG. 29 Hierarchical classification scheme for component, activity, and participant service objects with forms, behaviors, and functions.

For example, in figure 29 the market object has forms that include *Comparable Sites*, *Income Generators*, *Competition*, and *Trade Area*. The values associated with these forms (e.g., A Ave. site sold for $755,000, $594,000 annual income generated by Downtown, Jack's annual sales of $1,400,000 and Joe's annual sales of $1,200,000, and the East PA trade area boundary) are analyzed by a market analysis service to predict values for behaviors (e.g., current demand of 900,000 meals per year, current supply of 500,000 meals per year, population of 65,000 and excess demand of 400,000 meals per year). When deciding whether or not to add a new fast food restaurant to a trade area, a market analyst would be most interested in the excess demand. To evaluate the behavior "excess demand" (400,000 meals per year) is compared with the function "minimum demand" (365,000 meals per year). In this example, excess demand (predicted behavior) exceeds minimum demand (function) and it is advisable to continue with analysis.

Figure 30 illustrates integrated and automated PPP using the concepts presented thus far. The following steps describe this process and are keyed to the figure:

1. During integrated and automated PPP, services are activated in sequence when the circle process arrives at their node.
2. Upon activation, a service (e.g., Market Analysis) imports from the SPM all required service objects.
3. The service then analyzes the forms of the service object(s) and calculates or predicts values for the behaviors of the service object(s). Where appropriate, behaviors are evaluated by comparison to functions.

4. After completing analysis, a service exports the service object(s) back to the SPM.
5. The next service is activated and the cycle continues.
6. When all services have acted on the SPM, all of the project forms have been proposed and all behaviors that correspond to those forms have been predicted.

Upon completion of a circle integration iteration for a project alternative, its behaviors can be compared to functions or behaviors of other project alternatives.

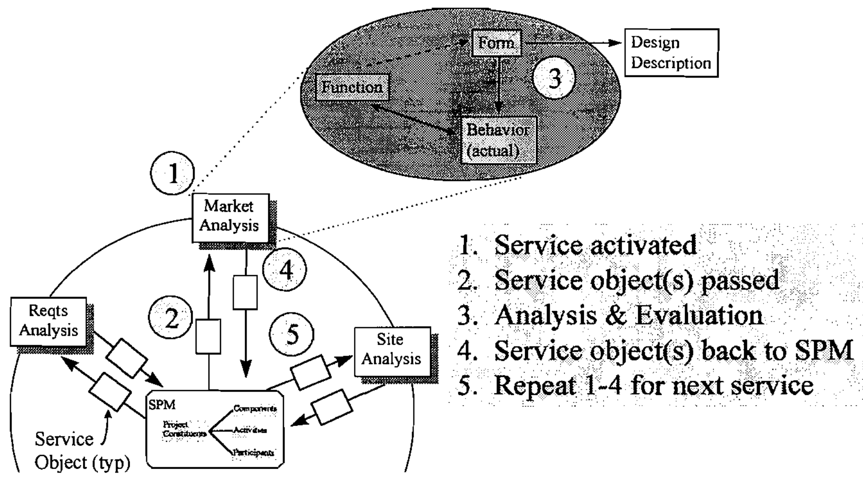


FIG. 30 Conceptual diagram describing automated PPP.

A Project Alternative

Using the PPP ontology, a project alternative is simply defined as a unique set of components, activities, and participants. This set is reified as a SPM consisting of a project object containing pointers to all of the service object instances.

We anticipate that the new circle integration mechanisms will help overcome the limitations of adaptability, incomplete information, and process automation now associated with integrated and automated PPP. Also, we expect the new PPP ontology to support functioning of the circle mechanisms and respond to the requirements of integrated and automated PPP for various types of facilities.

7.0 Discussion

PPP for capital facilities involves multiple types of analyses and is currently time consuming, costly, and often inconsistent. Circle integration of the software services that support PPP can make PPP analysis faster and more consistent while providing inherent version control. However, implementing circle integration and automation of PPP requires mechanisms for process control and an information framework that is sufficiently expressive to represent the essential concepts that support the PPP process. A PPP ontology that captures form, function, and behavior provides such an information framework and the circle broker, circle navigator, and circle explorer support integration and automation of PPP.

Referring back to the prologue, industry practitioners of PPP can benefit by having project information at their fingertips and by using a methodology to perform rapid analysis from multiple perspectives. Utilizing a computer-based shared project model that can be analyzed by various software services in a process-oriented manner provides this benefit. However, to support automated analysis and evaluation that involves computer reasoning, the shared model must go beyond representation of only form entities, as is common in current versions of industry product model standardization efforts. Form, function, and behavior of components, activities, and participants provides an information scheme that supports a consistent analysis and evaluation approach. The PPP ontology specifies the conceptualizations of this scheme. Using a SPM created from the PPP ontology makes it possible for heterogeneous software services, despite differing perspectives, to share knowledge and data effectively during integrated and automated PPP.

We are investigating additional building type cases to broaden and generalize the PPP ontology. We are experimenting with the circle navigator, circle broker, and circle explorer mechanisms in conjunction with the PPP ontology to explore the extent to which we can automatically analyze and evaluate project information during PPP using these new mechanisms. The key remaining challenges of this research involve collecting data from industrial PPP cases, conceptualizing a more general PPP ontology that sufficiently captures the essential elements of PPP, classifying the concepts into a form, function, behavior framework, and further testing and validating the circle integration and automation approach.

8.0 Acknowledgments

We would like to thank our industry partners who provided case study information, industry experience, and feedback regarding this research. We thank Reggie Brown, Clay Nicolsen, Steve Oratowski, Michael Thompson, and Fred Mathias of McDonald's Corporation for their contributions. This research was funded by a seed grant from the Center for Integrated Facility Engineering at Stanford University.

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