The Foxboro Company
Adopting Object Orientation

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FoxAES is a manufacturing management software system under development for sale by The Foxboro Company in Foxboro, Massachusetts using state of the art object oriented technology. In April of 1997, eighteen months after the FoxAES project began, the director of the project, Randall Sewall, had to decide whether to terminate the project in the face of mounting obstacles or refocus the project by modifying its goals.

The Foxboro Company

The Foxboro Company was founded in 1908. The family-owned company manufactured machinery, machine tools, and developed a worldwide reputation for industrial controls. The company went public in 1958. In the late 1980s the company began developing products for industrial automation including plant monitoring, information management and automated manufacturing control systems. To increase available capital that would sustain its industrial automation thrust, Foxboro was acquired by Siebe plc of Windsor, UK in September, 1990 for $52 per share; a substantial premium over the selling price of $20 (see Exhibit 1 for Siebe's Financial Statements). Siebe incorporated Foxboro into its U.S. based Control Systems Division and reduced the Foxboro work force by 1600 workers; twenty-five percent of Foxboro's employees [Palmer, 1990].

Foxboro represents a major portion of Siebe's business. 50% of Foxboro's business is derived from the oil and gas sectors while pulp and paper represents about 13%, utilities 13% and general industries 24%. North America and Europe account for 30% of total revenues each, Asia with 25% and the remainder split between Latin America, Africa and the Mid East. Products spanning from fabrics, chemicals, semi-conductor assemblies, corn flakes, to Oreo cookies are produced in plants using Foxboro automation products.

Foxboro has 19 manufacturing facilities, 80 engineering offices, 216 service offices and 249 sales offices. Foxboro uses its products in its own operations and sells them to other manufacturers. Today The Foxboro Company is a leading developer and supplier of industrial automation [Noaker, 1993 #1183]. Foxboro has received industry awards for excellence in product engineering. Foxboro's management of complex integration projects like Nabisco have set industry standards.

Foxboro's commitment to training and developing employees was well known. Former Foxboro employees have started several successful control software companies, earning Foxboro the nickname "Foxboro University" [Berner, 1995 #1182].

Application Domain

Modern manufacturing is highly dependent on automated control systems to monitor and control the operations of equipment that is on the plant floor. Products are produced on plant floors by combining and processing resources through one or several units of machinery in a sequence which eventually yields the final product. Each unit may perform one or more steps of manufacture under the automated monitoring and control of a unit supervisory control system. Each unit consumes resources and partially completed product components via an input queue in packets called "batches." Unit automation provides the intelligent control and monitoring of the processing of each of these batches. The unit's "output" flows to its output queue (which in turn is the input queue of another unit). Units and their respective queues are often managed discretely with minimal, if any knowledge of their production relationship to other units in the sequence of manufacture. This sequence is sometimes referred to as a "train." Any particular plant usually includes several production lines or trains which may be reconfigured as is necessary to adapt to new production sequences, and thus, new products. In lesser "automated" environments, each unit is stewarded by individuals who are skilled and trained in the unit's operation and maintenance of production parameters that ensure required levels of quality based on weight, temperature, base or acidity, pressure, or any number of other automated measures. The product "path" through the plant is often marked by strips of colored adhesive tape on the floor which indicate the sequence of units in the product's manufacture.

Foxboro company provides products used to monitor and control individual pieces of equipment on the plant floor and plant information integration systems that collect, analyze, and present plant production information on production efficiency and product quality. Although Foxboro is a significant supplier of these manufacturing and plant management products, there are other vendors with whose products Foxboro also wishes to inter-operate. These vendors include Siemens, GE, and Honeywell among others. In fact, inter operability is an imperative in industrial controls marketing.

Application Product

Foxboro's FoxAMS group (Foxboro Advanced Manufacturing Systems), is the organization responsible for integrated manufacturing solutions. Where Foxboro's instrumentation products focus primarily on individual equipment calibration, automation, and control, FoxAMS focuses on managing a larger manufacturing arena including production lines and entire manufacturing facilities. Two layers of plant management systems

are currently under development: FoxBatch which focuses on production line management at the individual production unit, and FoxAES (Foxboro Agile Execution System) which focuses on managing the plant as a whole; from product demand to inventory control. Although FoxBatch is perceived as a primary component in the FoxAES domain, FoxAES is designed to inter-operate with production line management systems from other control system vendors as well.

FoxAES provides a suite of plant management functions that are designed to simplify the centralization of manufacturing information gathering and subsequent plant operation control functions at the factory level. FoxAES provides information system support for the following functions:

- plant model management
  automated inventory of plant equipment, connectivity and operation personnel defining potential sequencing of processing on the plant floor

- master factory order management
  master factory orders specify the processing units and the required order of processing in a given plant model to produce a particular factory product

- unit management
  coordination of individual unit operations at each production station in the plant with the overall factory order production management and monitoring

- materials management
  order, inventory and distribution of raw and processed materials used in the manufacture of factory products

- electronic work instruction management
  a system of human operator dialogs synchronized with unit and materials management directing the operation of equipment or the movement of work in progress around the plant floor during production

- business information system interface
  corporate level product demand is received from the BIS composed of product orders from specific customers and product orders to maintain desired inventory levels

- intelligent factory order dispatch
  given the product demand from the BIS this function converts bulk product demand into individual factory order schedules by projecting plant resource utilization

and generating tailored factory orders based upon the master factory orders defined for each particular product

- dynamic unit management

once a factory order is released to the plant floor this function shepherds it through production starting tasks at units along it's processing path, monitoring these units activity and efficiency as well as forwarding information between units necessary to adjust product processing at downstream processing stations

- rules management

plant operation decisions may be automated in the FoxAES system by specifying production policy in automated processing rules dealing with issues spanning the size of product batches, the choice of processing units in a plant for production and/or the sequencing of factory orders through the plant to meet promised customer delivery dates

- system control integration

a series of operator interfaces, communication protocols, unit / product / schedule performance history, and access security and monitoring to pull all the individual functions under a centrally manageable umbrella

Plant Automation

The highest tier of the plant management pyramid is usually an enterprise system (or BIS, business information system) that feeds demand into the Agile Execution System to be scheduled and then produced. This demand may represent several days or weeks of future production and is used to project company inventories and revenues throughout the fiscal year. The demand is a mixture of specific customer orders and forecasted demand that must be fulfilled over the production period. AES converts the demand into batches of product production and schedules the batches through the plant to yield the required product quantities and varieties according to the enterprise system's demand.

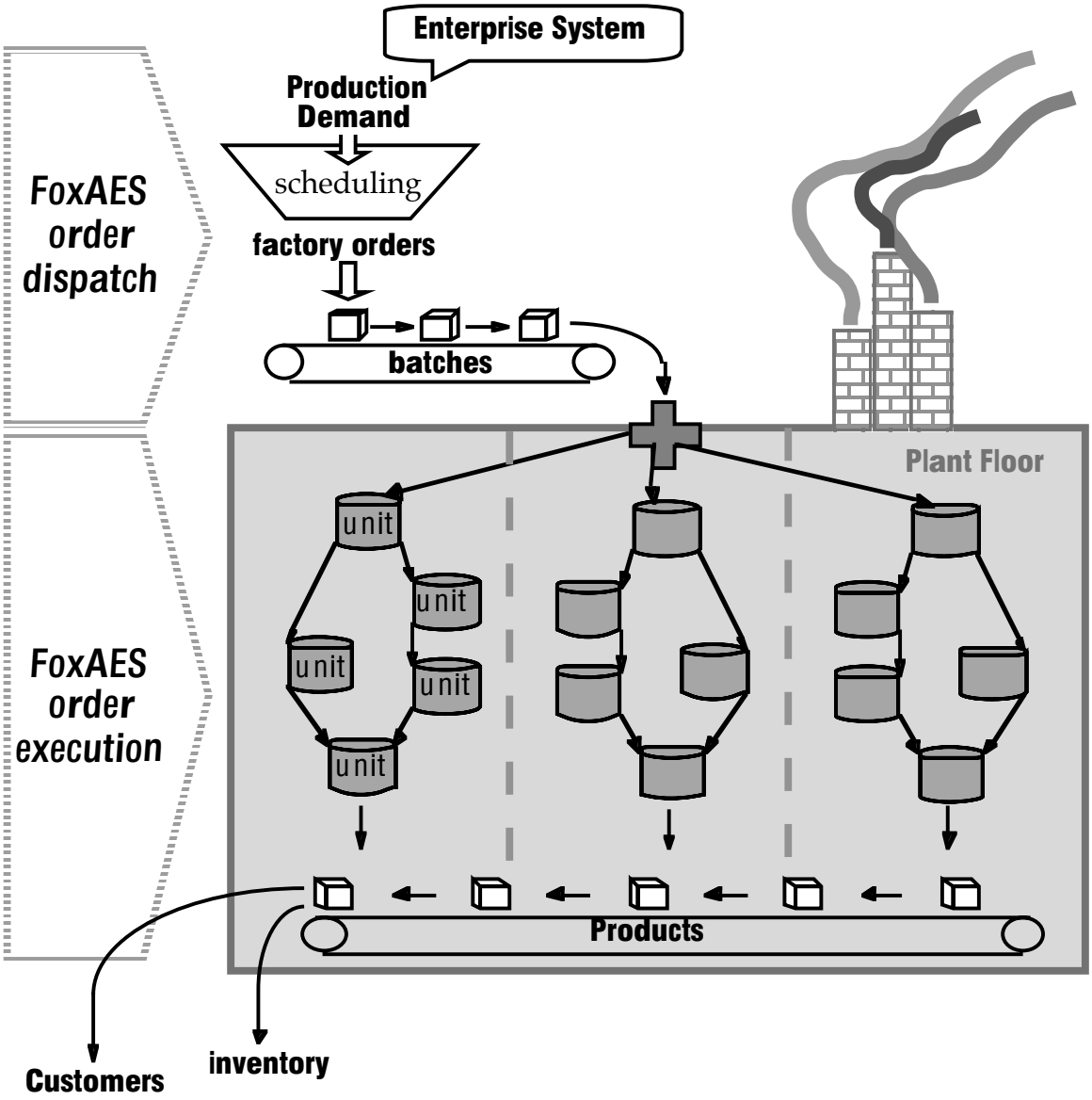

Figure 1 - Application Overview

FoxAES is designed to integrate the measurement and control of the entire "path" of manufacture by monitoring status from the various units and dispatching instructions to the units allowing them to perform processing on particular batches found in their work queues. At this level it is important to determine the various unit processing capacities and durations in order to manage each batch's life through production. In this manner, it is possible to project the emergence of finished batches and consequently schedule the production of particular batches in accordance with either factory orders pegged to particular customers or distribution to inventory. The facility to schedule and monitor the progress of batches allows marketing to maintain customer relations and respond to projected product demand.

An important feature of FoxAES is the ability to adapt the sequence of batch processing to mid-processing exigencies. Inevitably units fail or at least fall short of their production projections. In those cases it is important to adjust the sequence of batch processing to ensure that batches promised to particular customers emerge as scheduled. Such mid-course corrections are aggravated by differences in the unique processing that particular batches require at individual units. For example, one batch might require a different color of dye or a different mix of ingredient to produce a variant of the base product (e.g. sugar coated flakes vs. plain flakes). The sequencing of batches would have originally taken these special treatments into account. The mid course corrections may require an additional processing step such as purging a vat or rinsing a cauldron which must be accounted for in determining the "adjusted" projected time of product completion. FoxAES is expected to provide this agility and improve the plant's ability to please its customers.

Finally, FoxAES is intended to inter operate with a variety of enterprise systems and unit control systems from other vendors. The product is an "integration" facility to pull together various vendor products under a unified FoxAES control.

Management

Foxboro created a new business unit within the customer engineering services organization to develop new services and product offerings in the area of manufacturing execution systems, a new business for Foxboro (see Figure 2). Randall Sewall, program manager of Advanced Manufacturing Solutions (AMS), Foxboro USA, oversees the FoxAES product development. Sewall wrote the series of product concept documents outlining the FoxAES system functions (as described in Application Product above). In Spring 1996, FoxAES was launched as a corporate project (identified as a specific budget item in the annual plan) and specialists in the area of manufacturing information systems were sought to begin the requirements specification.

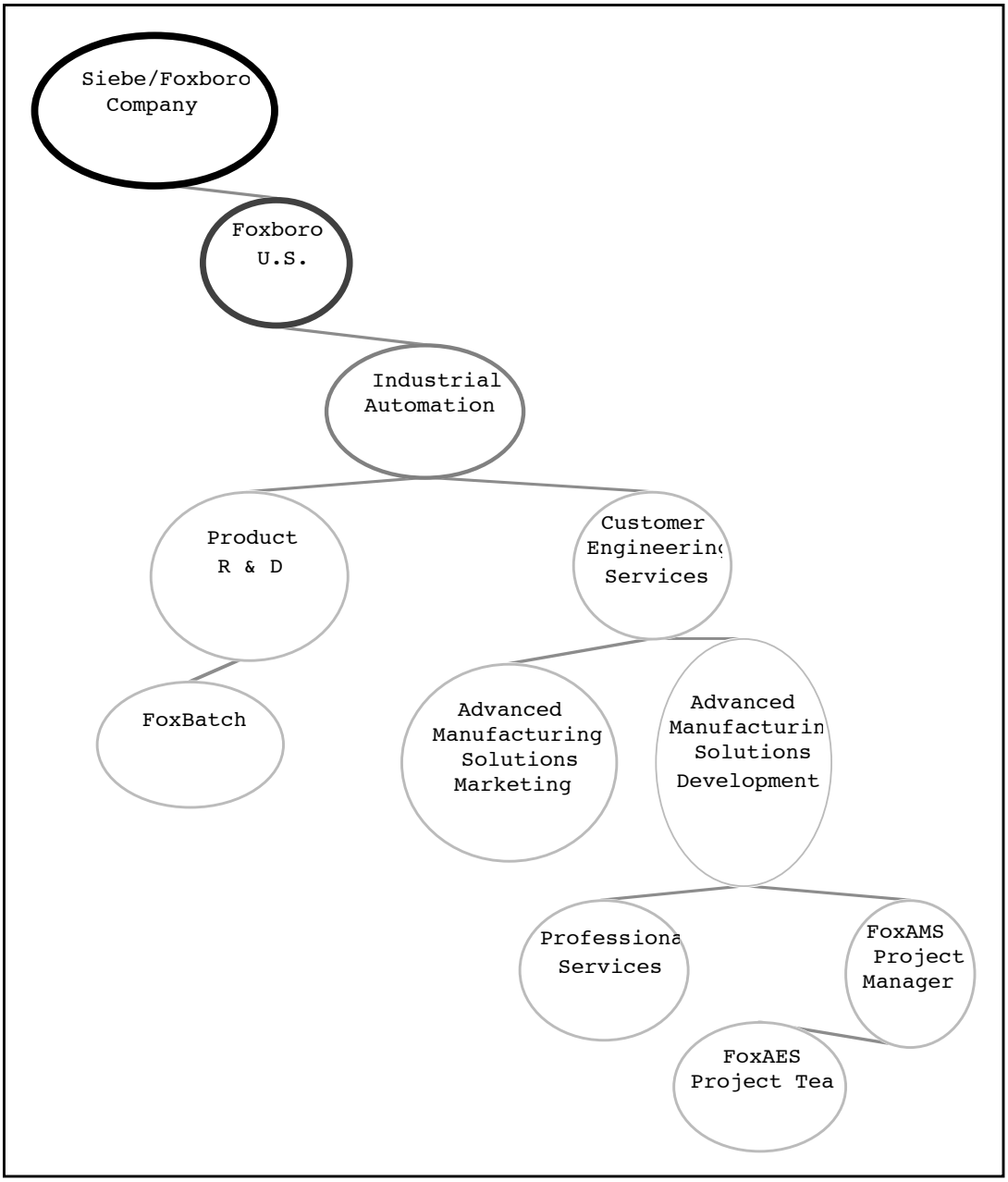

Figure 2 - Project Development Within Foxboro

The day the first requirement specialist arrived on site, Foxboro decided that the development of execution systems was a core technology and would be built in-house. Given that corporate direction, AMS quickly moved to assemble a software development unit within itself to develop not only the requirements but, also the actual system. Systems analysts, with extensive manufacturing experience at Foxboro and elsewhere, were gathered to develop the product specifications. The software developers were

hired mostly from outside Foxboro, as the existing OO experience available was contained within the R & D organization which included the FoxBatch project.

Foxboro had experience with object technology at least in object programming technology with the use of C++# in several engineering areas including the ongoing FoxBatch development effort. There was significant commitment to the object oriented buzzword# and it was decided that the FoxAES development would use OO technology and explore a "rapid prototyping" style different from the corporate development cycle standard which was classically waterfall.# The FoxAES unit is responsible for accomplishing the product development and demonstrating appropriate project progress to the upper level management who are more familiar with the waterfall project life cycle.

Managing FoxAES Product Development

Felix Dunleavy was the requirements specialist who arrived that first day. He had extensive experience in manufacturing systems development before coming to Foxboro Company and had worked with Randall Sewall. Sewall assigned Dunleavy as project leader as well as lead analyst. Dunleavy was assigned two analysts: Jimmy Salvaggio and Fenwick Twitchell (see Figure 3). These two analysts each had more than a decade of experience with manufacturing and plant management systems. Salvaggio had worked on the development of other Foxboro plant floor control systems, but neither had any object orientation experience. Dunleavy professed himself to be a "zealot" of the waterfall life cycle model and set about developing comprehensive requirements specifications. In addition, Dunleavy, early on, had expressed a mistrust of object technology and rapid prototyping. He pledged not to support any application development until all the requirements documentation was complete.

The FoxAES software development team was then assembled around the newly hired lead developer, Michael Steine. Steine was experienced in and committed to object oriented development in Smalltalk# . He hired four additional developers from inside and out of Foxboro bringing his team to five, including himself.

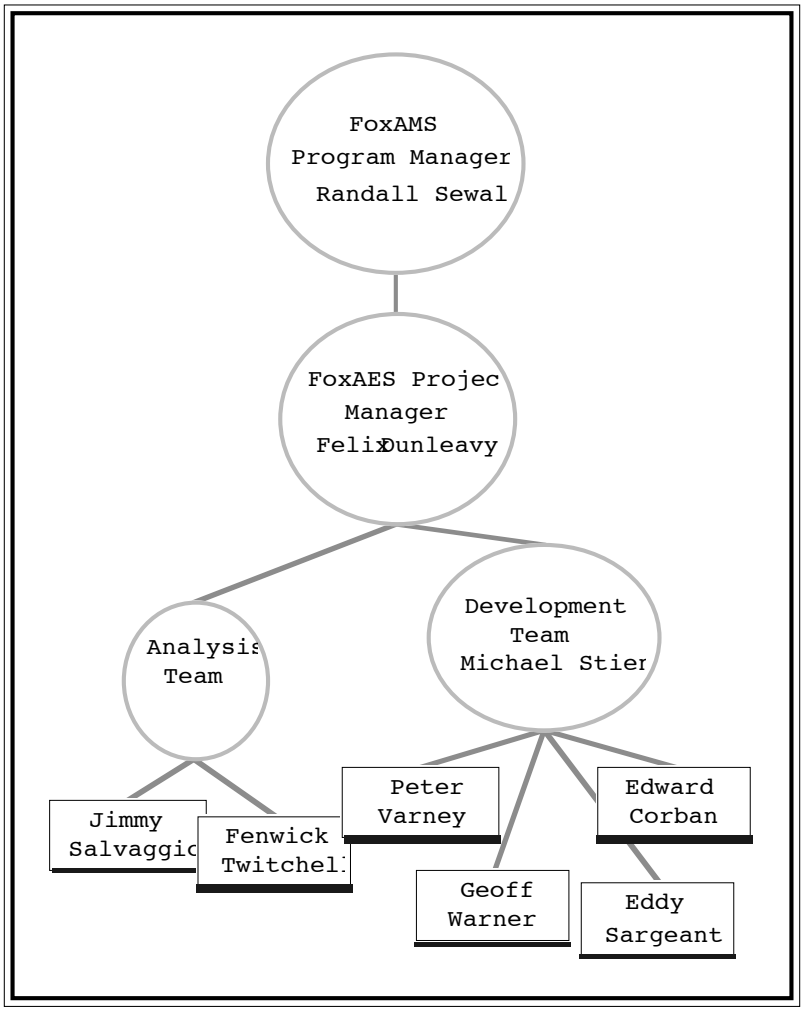

Figure 3 - FoxAES Project Team

Two had three or more years of Smalltalk experience and the others were highly reputed developers, but without any object technology experience. The development team set about researching a variety of Smalltalk environments and object oriented database tools. Their choice of development platform was constrained by a combination of operating system platform and distributed object communication requirements. Although the major processing of FoxAES would reside on one or two larger workstation servers, the ability to communicate and control a wide variety of plant floor workstations for unit management and equipment operator instructions dictated that the interconnection capability be as flexible as possible. They presumed that CORBA# support would be necessary to handle distributed object management, so vendor support for the CORBA standard was an important evaluation criteria. They settled on the Objectivity database system and VisualWorks from ParcPlace (now ObjectShare) and began prototyping. They constructed a mock up of the system with order scheduler and unit man-

agement screens based upon the initial product concept specifications that Sewall had used to sell the project to management.

Sewall, the program manager, developed a time line to satisfy upper management's need for familiar milestones. This consisted primarily of a series of prototypes that would demonstrate technology feasibility. The milestones were scheduled approximately at three month intervals with the beta version of the product expected at that end of the first year. Much of Sewall's time was filled with communicating the FoxAES vision to various echelons of Foxboro's management outside the marketing arm. Sewall was often called in to help woo potential customers. In addition he was occupied developing and staffing a separate group of consultants dedicated to implementing an integrated control and information management system. He was encouraged to promote the FoxAES system since Foxboro was anxious to extend its customer portfolio both by extending their relationship by selling FoxAES to existing customers of other Foxboro systems, as well as luring new clients to Foxboro with the promise of a fully integrated factory and manufacturing management system.

In the ensuing twelve months, the development team, with dogged tenacity and long periods of "slash and burn" coding, developed two prototypes of the system's structure and operator interface screens to satisfy upper management's requirements for progress demonstrations. At several points when the demonstration deadlines were obviously in jeopardy, outside Smalltalk experts were hired to augment the development team's software production. Although the outside help was very effective, they could not be made continuously available because of the budget (the outside help was about $1,000 per person per day). How much of the software they developed would be reusable in the actual product was unclear, but the developers were gaining valuable experience by overcoming a variety of configuration problems as they integrated several object oriented products and tools into their development platform.
The requirements specification team simultaneously developed an extensive and detailed description of the FoxAES system using System Architect (a C.A.S.E. or computer assisted system engineering tool) to produce an "object model" of the system. The model when printed, spanned three walls of a conference room and included several hundred "objects," each with a half dozen or more attributes and not a single method or service in any object or class.# Early in the year of parallel work, the two teams met biweekly or so to review the progress of the requirements specification and gain insight into the eventual product details. The Smalltalk developers often expressed their difficulty in understanding the requirements as a basis for an object oriented implementation of the system. Dunleavy would often dismiss their questions as issues of implementation and insisted that when the specifications were complete, all would be clear. After repeated attempts to influence the style and spirit of the requirements documents

(and several sessions that deteriorated into shouting and personal attacks on each other's professional ethics), the joint meetings between the analysts and Smalltalk developers basically ceased. Not only did formal meetings between the analysis and programming team become more and more infrequent, but the analysts were avoided in general. Steine decided that the best way for his developers to make progress was to insulate them as much as possible from Dunleavy. Salvaggio and Twitchell found working with Dunleavy a growing burden as well. The developers began to develop their own "interpretation" of the requirements based upon Sewall's concept documents in order to proceed with Smalltalk prototype development necessary to meet Sewall's milestones for upper management.

Enter the Consultant

In the Spring of 1997, Steine and Sewall agreed that a consultant experienced in project risk management and object oriented modeling should be brought in to assess the prospects for meeting the proposed product target dates. The consultant was told to assess the status of the overall project from an object paradigm and rapid prototyping perspective. As a matter of course, the consultant asked several times for a sketch of the administrative structure of the project and its position within Foxboro. No one on the project, including Sewall, seemed to be up to date on the organizational structure, and several indicated that they answered only to Sewall and "that's all that mattered." The diagrams above are the best understanding that the consultant gained. After two site visits, including all the developers and analysts, and a three hour meeting with Dunleavy, the consultant submitted a report indicating that the development team would be hard pressed to complete the application at all unless more appropriate object model documentation could be developed. The report suggested implementing a dedicated week of object paradigm training for the analysis team and a phased re-specification of the existing FoxAES requirement documents (which he described as revisiting each of the major system functional areas and modeling them one at a time). Phased re-specification was proposed to accommodate the rapid prototyping life cycle by identifying a sequence of releases with expanding functionality and robustness. In a late Friday afternoon meeting on April 18, 1997 between Sewall, Dunleavy, Steine and the consultant, these issues were discussed. Dunleavy expressed no confidence in the spiral approach, object technology, or Steine's competence, and asked to leave the meeting. He did.

Acknowledgement

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