A Systems Analysis and Design Model to Initiate Scheduling of Construction Activities in Renovation of a Major Building

Dr. Bahador Ghahramani, P.E., CPE
Engineering Management Department
University of Missouri-Rolla, Rolla, MO 65409-0370 (USA)
Tel: (573) 341-6057
Fax: (573) 341-6567
E-mail: ghahrama@umr.edu

Abstract

A Systems Analysis and Design (SA&D) model is presented in this paper that is important for engineering management (EMGT) educators to help their students to solve complex project management and scheduling problems. The SA&D model discussed here was developed to provide a scheduling process for a large construction project in a major city in the United States. The paper will attempt to answer such critical issues as sequencing, timeline analysis, seasonal factors, and lead/lag time of the project. A scheduling model that makes use of SA&D is described. The model was required to incorporate sequencing, timeline analysis, seasonal factors, and lead/log time for the project. Also, this paper discusses the relevance of the SA&D in the EMGT education, and how students will benefit from this model.

1. Introduction

The primary goal of this paper is to educate engineering management (EMGT) educators in the basic understanding of the field of Systems Analysis and Design (SA&D), its application and how it can be used to solve practical technical problems. The paper also helps our educators better understand how their students can use SA&D to solve scheduling problems of a major theatre construction project.

The project's initial goal was to renovate a major building in a major United States city. As the result of this initiative, an SA&D model was developed that helped to renovate and remodel this major construction effort. The SA&D model had to satisfy the city as well as the contractor's requirements.

SA&D is an evolutionary and flexible process that fits very well with any model development. It can very well be adapted to any model development and project management application, and consists of a formal methodology for generating, analyzing, and implementing test specifications to evaluate various activities. It is a systematic and step-by-step approach that effectively helps EMGT planners in their development activities. Each part of the SA&D is unique but interdependent to other parts as shown in Figure 1. As Figure 1 shows, each part of the SA&D analyzes and evaluates the whole process as well as its own.

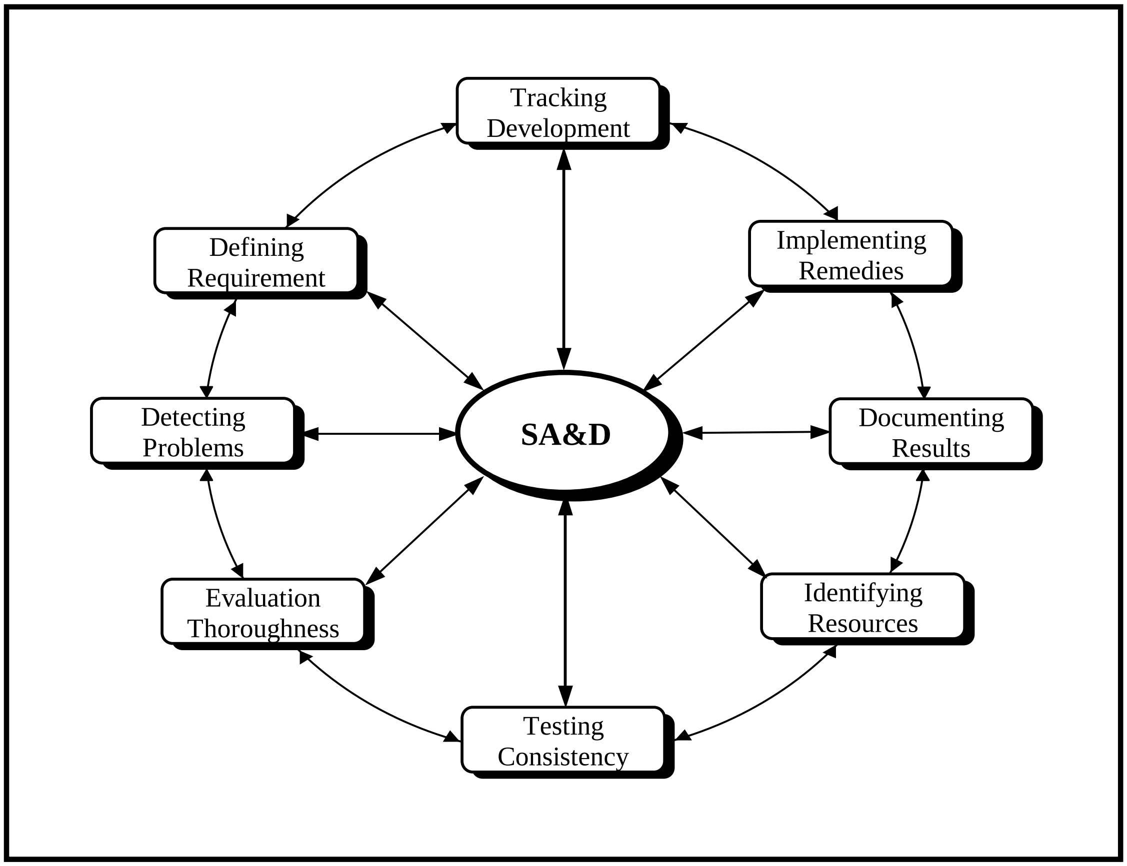

FIGURE 1, SYSTEMS ANALYSIS AND DESIGN PROCESS

2. Overview of the Construction Project

The major construction project (MCP) was a complete renovation of an old theatre building in the city. The building was to be completely remodeled and renovated according to the city's safety and zone specifications, including both exterior and interior rebuild. The project was part of a larger inner-city renovation and rehabilitation that covered most of the downtown area. This MCP was to serve as a comprehensive building renovation for downtown to attract new businesses, generate more income, and reduce crime.

The general contractor for the MCP portion of the project was a well-known construction company in the city. Although the contractor directly performed the concrete foundation work for the project, they were responsible for subcontracting all other work and finishing the project on schedule. The subcontractors were responsible solely to the contractor. The contractor, in turn, was responsible primarily to the owners group. However, due to the involvement of city tax dollars (the construction was located in a historic district), the contractor had to conform to city requirements above and beyond code regulations. The construction was estimated to cost approximately $40 million and take three years to complete. The project was started in early 1998 with the bidding for the subcontract work and obtaining permits. Actual work began in the winter of 1998.

3. Systems Analysis and Design Model

As part of this project, a Systems Analysis and Design (SA&D) model was developed that is capable of analyzing and developing the project's scheduling process, answering "what if" questions and performing sensitivity evaluation of the results. In the model, the life-cycle of the process was defined as that period of time from the inception of the construction to its completion. In the model it is assumed that, during the implementation phase, a variety of job functions are to be performed in the same time period.

An illustration of the development phases of the model is provided in Figure 2. As Figure 2 shows, the process's life-cycle development of the model begins with: first, defining and designing the process; second, implementing the process; and finally, testing and qualifying the process. If possible, that period of process time is again divided into its smaller periods of time called life-cycle phases [Fabrycky and Blanchard, 1991]. It is important to note that the SA&D life-cycle phases are circular because its phases are based on the continuous improvement and development process.

Following is the list of definitions for each of the life-cycle phases of the construction project that are presented in Figure 2:

- Define Process – the set of activities in which the idea for a new construction enhancement is analyzed for the owner's functional requirements.
- Design Process – the set of activities in which the new construction, its interfaces, its components, and their relationships are specified. This includes the specification of how they will be tested, and the detailed design of the components.
- Implement Process – the set of activities in which the components are built, integrated, and tested to form the final process.
- Test and Qualify Process – the set of activities in which the final construction is compared to its initial specification to validate that the requirements were met.

Each life-cycle phase is distinguished by two primary factors. First, the major area of technical effort is fundamentally different for each phase. Second, each of the construction development processes is initiated with a clear understanding of its specifications and customers' requirements for new construction.

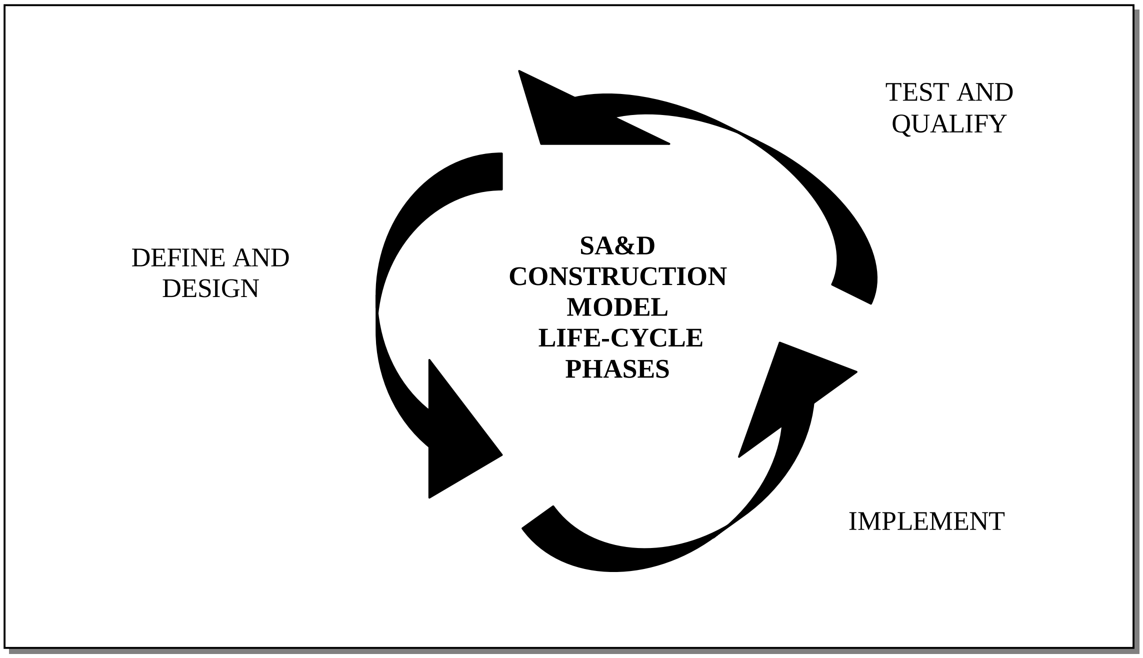

FIGURE 2, SYSTEMS ANALYAIA AND DESIGN PHASES.

As part of each life-cycle phase, several deliverables, such as blue prints, building codes, architecture's specification, software and hardware requirements, and other pertinent documentations, are included. Included in the life-cycle development process, an overview of each construction's function is documented and provided to the users. For each function, the SA&D overview includes a description of the type of activities, which includes a description of generic activities and explanation of specific activities.

The design and development of a system through each life-cycle phase requires input, direction, and cooperation of the following five job functions: project management, project assurance, development, verification, and configuration management [Fabrycky and Blanchard, 1991]. Figure 2 is also a presentation of the SA&D design and development phases of the process that was used to complete the model and the finish the construction project. The application process that is outlined in Figure 2 can be used by the EMGT educators in developing any SA&D model and application.

4. Reason behind the Systems Analysis and Design Model selection

The primary reason that the SA&D model selection this project, over the others, was its ability to constantly monitor all aspects of the system's life-cycle development process. This model continuously monitors development requirements through four effective and interdependent activities: defining the requirements; tracking the requirements; implementing the requirements; and testing the requirements. These four interdependent SA&D activities are presented in Figure 3.

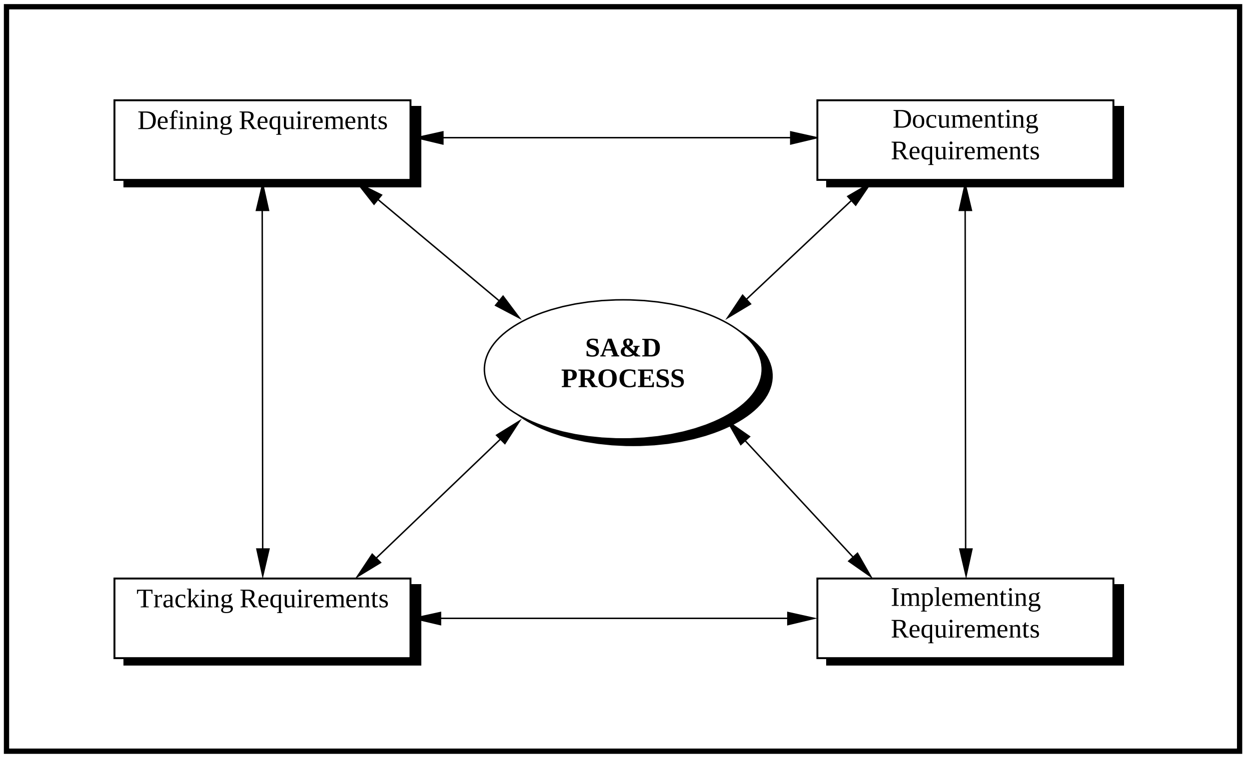

FIGURE 3, SYSTEMS ANALYSIS AND DESIGN PROCESS AND MONITORING ACTIVITIES

Another reason for selecting the SA&D model for this project was the ability of the process to effectively implement test requirements after completion of each development phase. The EMGT educators can relate to this process since the model executes each test requirement subsequent to its integration and actual performance. The implementation of a model requirement is then conducted according to the system configuration and its environmental constraints.

The final reason for selecting the SA&D model was its ability to continuously perform tracking of the requirement implementation results. System managers developing and monitoring the test requirements were able too pass rates as key elements of criteria to determine the completion time of each system development phase. System managers also were able to use function points and metrics to evaluate the test case implementation and results. The results were then compared with the standards specified in the system plan to rate progress of every phase of the model. The SA&D plan also indicated the implementation process, acceptance criteria, and pass rates to gauge model's phases and system readiness. Table 1 depicts the SA&D process incorporating the above outlined methodologies activities.

TABLE 1, SA&D PROCESS AND TESTING ACTIVITIES

PROCESS	INPUTS	STARTING TIME (AFTER)	RESULTS
Documentation: • Functional test cases • Unit test cases	Documents: • Feature definition • Internal requirement	Functional Test Cases: • Definition document inspection • Internal design document inspection	Test Requirements
Inspect Test Requirements: • Functional test case • Unit test cases	Documents: • Feature definition • Internal design	Functional Test Cases and Test Cases: • Documentation	Test--approved Requirements
Incorporating Test Requirements	Software Module	Completion of Code Inspection	Implement Results
Track Implementation Results	• Test case implementation results • Report generation tools	**Implementation Plan**	Implementation Report

5. Construction Problems and the Need for Better Scheduling

Renovation of the building proceeded normally into early 1999. However, the carpentry work on the building ran into serious overruns due to the demand for carpenters in the city. The city housing industry was going through the largest boom in construction in the past twenty years. As a result, all carpentry subcontractors had to balance the needs of large contracts versus the more lucrative small housing contracts. Also, delays by suppliers and undermanned construction teams added to the delays in the carpentry work. In fact, several of the carpentry subcontractors were in technical violation of their agreements with the contractor.

The contractor also had to conform to numerous city regulations that were specific to the historical area. This was the first time that the contractor had operated in an environment such as this, and several unforeseen delays were incurred due to unique regulatory requirements. By mid-1999, most of these delays had been overcome and the chance of future delays of this type was considered small.

The contractor had been scheduling activities by the use of calendars and "job lists." Job lists merely represented the proposed start date and the deadline for certain aspects of the projects. The lists did not specifically link certain activities to others and, therefore, there was no clear consequence of the effect of delay in one activity on others. The contractor project manager for the MCP determined that they needed to have a better graphical representation of the project with which they could better manage overruns and changes in the project. Also, linking and sequencing the activities properly needed to be better represented. The model also had to be flexible in order to include unforeseen tasks and changes in the sequencing of activities. A delay in one activity could have a ripple effect in activities for up to one year.

6. Software Requirements

The modeling software would have to meet several requirements in order to satisfy the specifications of the contractor.

a. The software must be able to link different activities on the project and automatically update one area due to a change in another.
b. The software must be able to graphically present the project in a way that would represent linkages and progress to date. The best and most common graphical representation is the common Gantt chart.
c. The software should be able to model the data to determine the critical path of the project. The software should be able to produce a PERT chart or other project management tools.
d. The software should be able to produce calendars which could be distributed to outside sources who are unfamiliar with project modeling techniques such as PERT or Gantt.
e. The software had to be also compatible with the contractor PC-based computers.

7. Overview of Off-the-Shelf Software on the Market

Market research indicated that demand for project software was strong but not overwhelming. There existed only two well-known software packages that would meet the requirements put forth by the contractor. The Primavera software package was one of the oldest, was common throughout the industry, and was able to construct Gantt and make PERT charts utilizing simple commands. The PERT charts modeled activities on the arrow (AOA), as opposed to the more common activity on the node (AON). Also, the Primavera package began as a DOS-based program, and had not fully integrated all aspects of the more current Windows operating system.

The other common project software package on the market today was Microsoft Project. This program was fully Windows optimized (as could be expected). Also, the software was able to do Gantt, PERT, CPM, and calendars based on one set of data, and the interface for the package was easier to use. Finally, Microsoft Project was widely available in the educational environment. Thus, Microsoft Project was the software package selected to model the SA&D.

8. Assignment of Project Beginning and End Times

The assignment of beginning and end times was the next step in composing the project specifications. The project manager for the contractor provided the majority of the beginning and ending times. The model had to be flexible enough so that the subcontractors could adjust the beginning and/or ending times to account for delays. The majority of the delays came from the carpentry subcontractors due to reasons previously stated. Each activity was assigned an Original Duration (OD) time. The OD's for each of these activities were all estimates based on the most likely duration.

Each activity was also assigned an optimistic and pessimistic time. Linked activities beginning times were contingent on the end times of the preceding activities. As delays in one activity manifested themselves, the beginning times of all following activities had to be delayed. The computer could not automatically delay critical path activities. This feature was done on purpose, so that any change in the project end time would have to be done by a deliberate action of the project manager.

9. Issues Related to the Project

The contractor wished to have the model reflect all past activities on the project in addition to the future ones. This was to provide managers with an easy overview of the entire project. All activities done in 1998 and early 1999 were easy to model based on historical records of the contractor and the input of the project manager.

Another key aspect of the scheduling was that certain jobs would require a significant amount of money in order to shift. The high-money jobs were not necessarily on the critical path, but would cause the company severe monetary distress if they had to be moved. These jobs were also assigned alarm nodes in order make the manager aware of any changes to their beginning times. The company kept track of these jobs by assigning them with numbers beginning with "CS" or Contractor Special. Management approval was needed in order to change any job that began with this special code.

The company was primarily concerned with the activities of their carpentry subcontractors; therefore, the model had to give special emphasis on all activities related to carpentry. The solution to this problem was a color-coding of carpentry activities separate from the rest. Carpentry was assigned an orange color, common activities were black, and critical activities (regardless of type) were red. The use of color-coding provided the project manager an easy way to see the critical aspects of the project.

The company also used a much higher margin of error than what was typically seen in an academic setting. These error margins were seen as necessary due to the real world constraints such as weather, supply backorders, machine breakdowns, maintenance, etc. The company also varied their margin of error according to the type of job. For instance, carpentry jobs typically had a 20% margin of error. However, with the recent problems in this area, the percentage was increased to 35%. Some activities had a very low safety margin. For instance, demolition work had only a 5% time margin of error. Also, the critical points of the demolition work could not change due to the large number of permits and the coordination with the city government. The margins of error were given by the contractor project manager and were incorporated into the end times of the project. The pessimistic times for the project were the most likely times multiplied by the highest margin of error for that type of job.

One special area of the project scheduling was coordination with the artisans to perform the specialty wood and masonry work that would make up a good portion of the interior of the theater. Typically, this type of contracting work is done separately from the primary contract. However, the contractor was tasked with coordinating this as well as the sound system installation. This work had a high margin for error due to the nature of the people performing the work. This work was given a margin of error of 50%.

Finally, the area for materials storage on-site was very limited due to the fact that the theater was located in a downtown historical district. Therefore, the flow of materials had to be strictly regulated to prevent work stoppages or overcrowding of the project site. Therefore, the project manager added some extra requirements linking the start dates of certain activities to a single node activity of materials delivery. The materials delivery node was then linked to a resource listing which incorporated the bill of materials (BOM) for the activity. The project manager had to maintain constant awareness of these deliveries in order to ensure that the suppliers were made aware of any changes. Consequently, an “alarm” was linked to these supply nodes which would alert the user should any changes be made in the beginning times of those particular nodes.

10. Final Model Results

The final model represented a timeline stretching from April of 1998 to June of 2000, which had two levels of detail. The entire project including delivery nodes and minor jobs was deemed necessary but too “busy” for easy use and presentations to the contractor managers. Therefore, two levels of detail were completed. The Level 1 detail included only the major items and critical activities to be performed on the project. It also utilized a Gantt chart by month. The Level 2 detail included all activities in Level 1 in addition to delivery nodes, small jobs, and non-critical events. The Level 2 chart utilized a weekly timeline although it could be broken up into days by changing the scale. Level 1 detail included 85 activities while Level 2 included 225 activities. The product was delivered to the construction manager on 22 July 1999. He was provided with a software version as well as the proposed hardcopy. Figure 4 is a presentation of the SA&D flowchart from the concept phase (defining the goals) to the completion phase (validation) of the project.

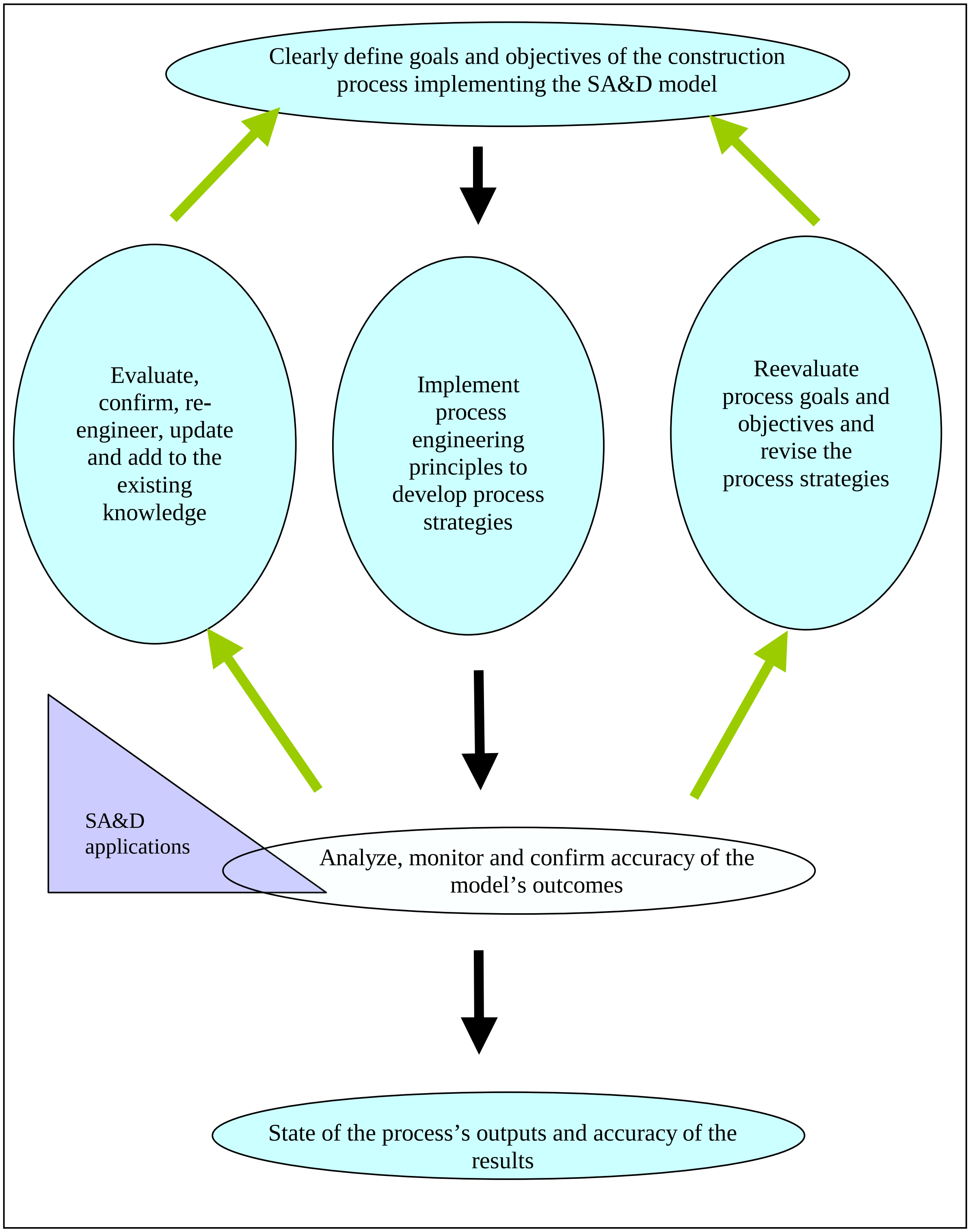

FIGURE 4, SYSTEMS ANALYSIS AND DESIGN APPLICATION PROCESS

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Biography of the Author:

Dr. Bahador Ghahramani is an Associate Professor of Engineering Management in the School of Engineering at the University of Missouri-Rolla (UMR). Prior to joining UMR he was a Distinguished Member of Technical Staff (DMTS) in AT&T-Bell Laboratories. His work experience covers several years of academics, industry, and consulting. Dr. Ghahramani has presented and published numerous papers and is an active participant and officer of various national and international organizations and honor societies. He holds three patents the "*Eye Depth Testing Apparatus*", "*A Method for Measuring the Usability of a System and for Task Analysis and Re-engineering*", and " *A Method for Measuring the Usability of a System*". He has another patent pending "*Emergency Marker System, Marker Device, Components Therefore and Methods of Making the Same*". Dr. Ghahramani also maintains copyrights on five other AT&T designs. Dr. Ghahramani received a Ph.D. in industrial engineering from Louisiana Tech University; an MBA from Louisiana State University; an MS in industrial engineering from Texas Tech University; M.S. in applied mathematics from Southern University; and a B.S. in industrial engineering from Oklahoma State University.