DEFINING CONSTRUCTION MANAGEMENT EVENTS IN SITUATIONAL SIMULATIONS

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ABSTRACT: The challenge and promise of educational computer simulations are to provide user experiences that allow for immersion into a dynamic system in which users discover the ramifications of their decisions in a complex environment. Researchers at the University of Washington, in collaboration with Michigan Technological University, are developing situational simulations to meet the needs of construction management education. The simulation environment, known as the Virtual Coach, helps users to further develop their decision-making skills in a problem-based learning setting whereby they investigate, integrate and apply concepts in a participatory, contextually rich, educational, yet fun video game-like virtual environment.

This paper explores the development of this contextually rich and general-purpose environment and the user's experience as they progress from Project Awareness to Project Monitoring and into Project Management. In the Virtual Coach, users view project information in both Project Awareness and Project Monitoring. As the project and Simulation Events unfold, the user interacts with the simulation, making decisions that impact the project outcome. A Simulation Event includes the user's experience, variables altered by the event, and variables changed by the user. This paper defines the concept of Simulation Events within the context of the Virtual Coach, explains how the users become aware of an Event and how Events are triggered in the simulation, describes how users engage with the simulation (i.e., what variables are in play), and identifies types and formats of information available to a simulation developer to shape the learning outcomes.

KEYWORDS: Simulation models; Construction management; Engineering education; Computer aided instruction.

1. INTRODUCTION

The authors are engaged in a multi-year project to develop and facilitate the use of situational simulations for student-centered problem-based learning, which will be shared across institutions. The main objective of situational simulations is to help learners further develop their decision-making skills in an active-learning experience whereby they investigate, integrate and apply concepts in a participatory, contextually rich educational environment. Furthermore, situational simulations bring the excitement, attractiveness, and impact of video game-like environments to educational settings.

Educators and practitioners lament that we are not properly preparing students to solve the complex and multifaceted problems they will face in the industry after graduation. Students experience fragmented and specialized courses where concepts are presented as independent unrelated entities divorced from the complexities of real-world situations and problems (Chinowsky and Vanegas 1996, Fruchter 1997). Such decontextualized knowledge is intrinsically tenuous in nature. For example, Brown et al (1989) describe students who recall information on a test not being able to apply the very same concepts in the problem-based environment even when the situation clearly merits such an action. Course-centric, institution-dependent, and instructor-focused education prevents learners from integrating concepts, taking advantage of expertise found at different institutions, and expanding their educational experiences beyond traditional classroom settings. However, the increased availability of information technologies, the demand for more cost-effective education, and the emphasis on making students more responsible for their own learning, calls for alternative learning models.

The earliest approach to games and simulations as a training tool in construction was the “Construction Management Game” (Au et al. 1969) which simulates the bidding process in the construction industry. This model inspired a variety of research efforts in the area of games and simulations: CONSTRUCTO (Halpin and Woodhead 1970), AROUSAL (Ndekugri and Lansley 1992), SuperBid (AbouRizk 1992), Parade of Trades (Choo and Tommelein 1999), Simphony (Hajjar and AbouRizk 1999), STRATEGY (McCabe et al. 2000), The Construction Marketing Game (Bichot 2001), VIRCON (Jaafari et al. 2001), ER (Nassar 2002), and the Virtual Coach (Rojas and Mukherjee 2005a). These efforts provide stepping-stones towards creating interactive, participatory, and contextually rich educational environments in construction engineering and management.

Rojas and Mukherjee (2006, 2005a) demonstrated the potential of situational simulations to enhance learning with integrated concepts in an applied context. Achievement tests measured a statistically significant improvement in the decision-making skills of participants after being exposed to the simulation environment, or “Virtual Coach” (Mukherjee et al. 2004). The desktop-based Virtual Coach requires students to integrate concepts learned in different courses in order to solve authentic construction management problems (Rojas and Mukherjee 2005a, 2005b).

The research introduced here is an enhancement and extension to the original Virtual Coach system. This multi-year research project includes testing and evaluation of Virtual Coach at five universities throughout the country, and the creation of a Simulation Development Kit (SDK) allowing nonprogrammers to create and share their own simulation scenarios. Five participating universities will be the founding members of a Consortium dedicated to the collaboration, dissemination, replication, and sustainability of this project. The web-based Virtual Coach will provide an easy to use platform for faculty to develop situational simulations and share them with other members of the academic community; allowing learners to integrate concepts, take advantage of expertise found at different institutions, and expand their educational experiences beyond traditional classroom settings. This knowledge repository will be available free of charge to students interested on expanding their knowledge and understanding of construction engineering and management concepts.

2. VIRTUAL COACH DEVELOPMENT

In this phase of development, researchers at the University of Washington (UW), in collaboration with Michigan Technological University (MTU), are focused on single-player project manager simulations to meet the needs of construction management education. In the first phase of this multi-year project, we are (1) creating an easy to use web-based system to run situational simulations in construction management, (2) developing innovative techniques to integrate and visualize construction management information, and (3) partnering with the construction industry in the development of situational simulations that accurately reflect authentic context. This section will discuss research methods and management strategies used in a multi-faculty, multi-institutional, multi-year project, centered on the development of a shared simulation system. We also present initial findings from the process of developing content-rich scenarios.

One challenge that we have found more prevalent than expected is that of a common vocabulary. We have found the need to discuss and define specific user types and terms such as "developer" - sometimes we might discuss the development of a simulation, whereas other times we are discussing the development of the Virtual Coach software. To mitigate confusion, we have defined the following user roles:

> *Developer*: faculty and graduate students involved in designing and programming the computer systems that create the Virtual Coach simulation system.
>
> *Author*: individual or group of individuals that create a simulation for public distribution (available to anyone) or private use (available to selected users only).
>
> *Instructor*: individual or group of individuals that coordinate the application of simulations with other pedagogical activities.
>
> *Player*: individual that plays the simulation.

2.1 Research Methods

This project builds off or previous Emulation Engine development (Rojas and Mukherjee (2006, 2005a), such that we are focusing on the visualization engine. The research questions here are how to best represent the complexity of a realistic construction project in an accelerated simulation virtual environment to support the learning objectives in a fun and exciting way. To this end, we have focused our initial efforts on defining the user experience and the simulation scenarios. We have employed schematic design meetings, industry advisory meetings, and developed a specification for the single-player Virtual Coach.

Regarding pedagogical guidelines, the National Engineering Education Delivery System (NEEDS) provides useful criteria for education simulations, (http://www.needs.org/needs/public/premier/2007/2007-criteria-prelim.pdf). The NEEDS criteria reflect the values associated with good teaching practices and pedagogy and are divided into three categories: instructional design, software design, and engineering content. Each category is described by a set of components and sub-components. Using our previous work with educational simulations, and the NEEDS guidelines, we developed the specifications for a single-player web-based Virtual Coach.

2.2 Virtual Coach Specification

Using web-based widget technology, a single player will view, monitor and manage simulated project information displayed in a variety of charts, graphs, 3D models, 4D models, and spreadsheets. As described in more detail below, players will monitor the project as time elapses. Then, to modify project variables, the player stops the clock by pulling up the project manager window. Each player's time-out time is limited, and a higher score will be given to those students to spend less project management time. In this way, we simulate the day to day pressures on a jobsite that managers face. As Events occur, the Virtual Coach system will interject and guide players through project management steps. A single player is responsible for all activities performed by the general contracting company for a project.

Before we get into the game play details, we address the Virtual Coach capabilities and requirements for the first release:

- Players will be able to play a variety of simulations created by authors and customized by instructors.
- Several players will be able to play the same simulation simultaneously.
- Each simulation will be limited to one player (project manager) overseeing the construction of one project. Other participants in the project (owner, architect, subs, etc.) will be simulated by the system.

- Construction planning (schedule, budget, site layout, safety plan, etc) will be provided to the player. Therefore, the player's role is limited to managing the actual construction phase of the project.
- Simulated projects include both self-performed as well as sub-contracted activities.
- Simulated projects will be built following the traditional design-bid-build delivery system.
- The Virtual Coach platform will run on typical desktop computers.
- Complete history of all player actions, simulated events and results will be recorded and stored on a server to be used in the future for data mining.
- Players have a limited amount of time to make decisions improving the construction process or taking care of events as determined by the instructor. A countdown timer is always present on the screen letting the player know how much time they have left to complete the game.
- Where there are images, video and other opportunities, simulated events will portray minorities and members of underrepresented groups in positions of leadership.

The UW team has defined the general requirements for the current Virtual Coach project and is focused on developing the Visualization Engine. Each simulation (game) running under the Virtual Coach will have the following:

- Learning objectives will be clearly stated and presented to the player at the beginning of each simulation. They will be grouped into four main categories: awareness, competency, proficiency, mastery.
- Instructors will be able to select the level of difficulty for each event before players begin the simulation. Three different levels will be available: novice, intermediate, and expert. For more information, see the events section.
- Players will be able to review pedagogical materials regarding the learning objectives at the end of the simulation to reinforce important concepts if needed.
- Each simulation will have three modes:

<u>Project Awareness</u>: This mode introduces the player to the project they will manage, familiarizes them with the construction plan and issues of interest. The information is static (does not change over time), but can be multimedia rich. A web-page will show videos describing the project, 3D models will be available for the students to navigate, as-planned schedules and budgets will be available for the player to study.

<u>Project Monitoring</u>: Provides players with the ability to follow the construction process and monitor a variety of variables necessary to evaluate the progress of the project. Project monitoring is a "view only" mode, where players can view but not alter any variables. The provided information reflects four different states of progress: baseline, history, current, and forecast. Baseline refers to the original plan plus any required changes. History refers to the actual data from day 1 to the current date and it changes as the project advances. Current refers to information about an instantaneous point in time. Finally, forecast refers to the information regarding projected values of variables from the current date to the calculated finish date.

<u>Project Management</u>: This mode allows players to make decisions and implement changes to the project by either optimizing the process or responding to events, and is not necessarily keyed to an event as shown below, but an event occurrence would be the most likely time the player would modify project variables.

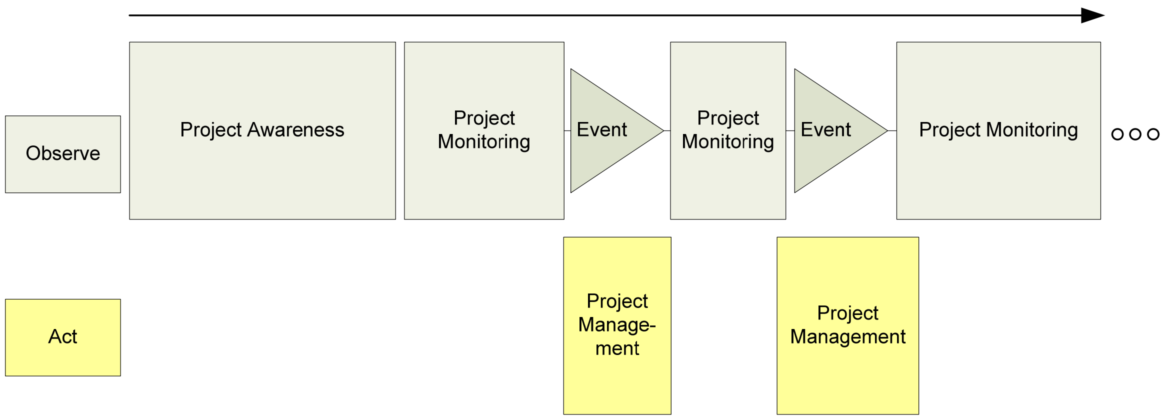

Figure 1. Virtual Coach Simulation Map

Project Awareness	**Project Monitoring**	**Project Management**
<u>Owner</u> • Business Plan • Motivation (mission, value, team, goals) • Definition of project success • Environment <u>Contractor</u> • Construction plan • Schedule • Budget • Site layout • Procurement plan • Safety plan • Quality plan • Cash flow • Organization chart <u>Designer/Consultants</u> • Drawings • Specifications • Geotechnical report & design <u>Market</u> • Location & conditions • Codes & regulations • Labor, material, equipment, trades	• Schedule information (baseline, as-built) • Cost (baseline, as-built) • Space usage (material storage) • Cash flow • Profit • Earned value variables (schedule performance index, cost performance index, productivity index) • Productivity values • Weather • Safety report (accidents, incidents, non-compliance) • Quality report (punch list, rework, inspection log) • RFI log • Submittal log • Change order log • Market information (wages for craftsmen and laborers by trade, subs quotes, material costs, equipment costs)	• Change labor allocation (number of workers, crew) • Change in work calendar (hours per day, days per week) • Change of subcontractor or supplier (name, cost, productivity, availability, quality) • Change technology (equipment/construction methods) • Issue a change order proposal • Timing for delivery of materials and equipment • Timing on payment to subcontractors and suppliers • Wage & incentives • Start dates, durations, end dates • Add rework activity • Weekly (quality, safety, other) tasks (toggle on and off)

Table 1. Select List of Possible Data Types for the Three Simulation States

We will develop the user interface components as "widgets", taking advantage of the Google Web Toolkit (http://code.google.com/webtoolkit). A widget encapsulates 3rd party controls that will display the simulation information in graphical formats. This allows for maximum flexibility when configuring interfaces, allowing instructors and/or players to customize their own interfaces while running a simulation. We will utilize third party controls for the graphical display portions of the interface for this release, which will save significant development time. All simulation project data will be stored in a PostRegres database.

3. EVENTS

Events are unexpected occurrences that change the course of a construction project. We have developed an initial list of generic events that can be included in a simulation. This list currently has more than 20 different events including (1) strike of concrete truck drivers, (2) concrete delivery re-schedule, (3) poor concrete quality, (4) incomplete design, (5) defective design, (6) different site condition, (7) design change (no re-work involved), (8) design change (re-work involved), (9) unforeseen (adverse) weather condition, (10) accident, (11) low productivity, (12) equipment shortage, (13) material shortage, (14) price escalation, (15) fire, (16) vandalism, (17) funding delay, (18) estimating error, (19) decision-making error, (20) subcontractor default, and (21) equipment malfunction among others. We will select 3 to 5 of these events to be fully developed and implemented as part of our initial sample simulation.

To make the generic events more realistic, the writers met with industry advisors to capture, discuss and brainstorm narratives for these types of events from actual field experiences. Not only did the industry advisors provide interesting stories, but their focus and feedback on the educational significance of specific issues was invaluable.

3.1 Event Simulation

For each event, we have analyzed and defined how the player will become aware of the event, what kind of guidance the simulation might provide, what types of variables will trigger automatic changes to project data, and what types of variables the player can modify in response to an event. These can all vary according to the level of difficulty set for the simulation, player and event. Events are defined by the following characteristics:

- *Event Trigger*: To reflect the realistic nature of events, we have designed a number of ways that the events can be triggered: random, variable, concurrent, and cascading. A *random* trigger will run stochastically, and will trigger the event at random time during that simulation. For example, a general labor strike shuts down the project for a month. A *variable* trigger will cause the event when a particular variable meets or exceeds a specified value. For example, when the structural steel is 50% complete, trigger steel workers strike. We also allow for *concurrency*, where one event happens at the same time as another event. For example, an equipment malfunctioning happening at the same time as a delay in material delivery. The fourth event trigger type is *cascading*, where actions taken by players when dealing with events can create other events. For example, when a player postpones an activity because of unavailability of labor, he or she may run out of room for laydown space in the future.
- *Event Awareness*: how the player finds out about the event in the simulation. e.g. email, video, photos, voice mail, text message or highlighting the relevant data in the project monitor.
- *Event Guidance*: type of help (hints, tips and suggestions) system will provide to the player. The higher the level of expertise, the less help will be provided.
- *Event Variables*: the variables that the event will alter in the simulation.
- *Event User Variables*: the variables that the player can modify to keep the project under control given the event at hand.

As an illustration, the following three examples show how these characteristics define particular events:

<u>Event 1: Concrete Delivery Truck Drivers Strike:</u>

- *Event Trigger*: A concrete strike would likely be triggered by the variable concrete quantity reaching a particular value different than zero as a concrete strike makes sense as an event only if there is still concrete to be poured in the project.
- *Event Awareness*: In the event of a concrete strike, the player might be notified via voicemail with a follow-up via email informing him or her that concrete delivery truck driver are on strike.

- *Event Guidance*: At the novice level, the simulation will provide guidance on how to identify activities impacted, how to find alternative vendors for concrete, and how to evaluate the impact of changing the vendor. The simulation will also guide the player in issuing a change order request asking for more time and money. At the intermediate level, the system may propose changing the concrete vendor and issuing a change order proposal. At the expert level, no specific direction would be given.
- *Event Variables*: The activity variables related to concrete availability and the quantity of available concrete would be changed to zero.
- *Event User Variables*: The user might control variables such as concrete vendor, schedule of activities, and change orders (including time and cost).

Event 2: Concrete Delivery Re-schedule:

- *Event Trigger*: A concrete delivery re-schedule would likely be triggered by the variable concrete quantity reaching a particular value different than zero following the same reasoning used in event 1.
- *Event Awareness*: The player might be notified of a concrete delivery re-schedule via email, where the concrete supplier explains that the demand for concrete is of such magnitude that they need to schedule delivery for clients at specific dates of the week. Therefore, from this point forward the project will receive a specified maximum quantity of concrete delivered on Tuesdays only.
- *Event Guidance*: At the novice level, guidance could be provided via a video-mail where a senior project manager gives some advice to the junior project manager in charge of the project. This advise would include instructions for identifying pouring activities, setting hard dates for those activities in the construction schedule, evaluating the impact of the hard dates (negative float), modify the schedule to eliminate negative float by either delaying or accelerating activities (increasing number of workers, number of days/hours worked, etc.), At the intermediate level, the senior project manager may propose evaluating the scope of work, evaluating overall project delay, and the consequences of the re-scheduling of concrete deliveries. At the expert level, no specific direction would be given.
- *Event Variables*: The activity variables related to concrete availability and the quantity of available concrete would be changed to zero, except for the days where concrete is available (Tuesdays).
- *Event User Variables*: The user might control variables such as start date of activities, number of workers assigned to an activity, number of days a week working on an activity, and number of hours a day working on an activity.

Event 3: Change Fireproofing Columns from Drywall to Paint – No Rework Required:

- *Event Trigger*: This event would likely be triggered by the variable concrete columns completion reaching 100%. The event may happen a few days after this milestone is achieve, but before the beginning of the fireproofing activity (in order to avoid rework).
- *Event Awareness*: The player might be notified via voicemail with a follow-up via email.
- *Event Guidance*: At the novice level, once again, guidance could be provided via a video-mail where a senior project manager gives some advice to the junior project manager in charge of the project. This advice would include instructions for identifying the activities impacting, identifying the contractors involved, requesting RFQ (cost and duration) to each contractor (deduction for the drywall contractor and addition for the painting contractor), substituting contractors, and issuing a change order request. At the intermediate level, the senior project manager may propose substituting contractors and issuing a change order request. At the expert level, no specific direction would be given.
- *Event Variables*: A follow up inspection will be trigger to verify the change in scope..
- *Event User Variables*: The user might control variables such as quantity of drywall, quantity of painting, fireproofing activity duration and cost, subcontractor associated to the activity, and change orders (including time and cost).

In addition, we will include the ability for instructors to set the level of difficulty specific to an event. There may be pedagogical reasons to have some events at the novice level, while other events are at the expert level. For instance, if an instructor is using a simulation throughout a course, he or she may want to add events at the novice level, but as the course progresses the older events become expert level events, while new events are introduced as novice events. Consequently, we have included the level of difficulty as a variable of the event. The instructor can select the event level that will override the simulation level. When starting the simulation, the player selects a level of difficulty. Let's assume the player selects the novice level as the simulation level. As the player plays through the simulation, when they encounter an event the instructor set as intermediate, this event will play at the intermediate level, even though the player will experience novice level support for other events.

3.2 Challenges

Implementing a realistic situational simulation, however, is a complex problem. Rojas and Mukherjee (2003, 2005b) have published the mathematical theory that supports the Virtual Coach simulation as part of the Emulation Engine. For example, productivity can be defined as a function of the number of workers, quantity of activity as originally planned, and the original duration, with factors for overtime and efficiency. Theoretically, once the equations are developed, creating events is characterized by a change in variables; whereas, the player can change other variables to react to the issues at hand.

Construction management is a social endeavor, and many activities a player may encounter include social components. For example, in reaction to an event, a project manager might write a letter to notify the owner of the issues. In a real world setting, the owner, designers, and contractor might have a project coordination meeting to discuss alternatives and make decisions. As we continue to develop scenarios, we seek to incorporate some social interactions through video, audio, and written materials that support the events. The challenge for our simulation team is to determine if and how we can have players create documents such as letters, memos and change orders that trigger a change in the simulation variables. In the concrete strike event example discussed above, one of the player variables is change order where the contractor predicts the impact on the schedule and budget. To simulate interpersonal interactions, we would need a multiplayer game as discussed below. In the single player version, we might have the player submit a template type document, where cost and time are entered in specific boxes that are linked to simulation variables.

Since computers are numerical machines, they deal very well with variables such as productivity, cost and time. However, issues related to safety and quality are more challenging to model mathematically. The development team's challenge is to incorporate safety and quality related events. Some preliminary strategies focus on quality reviews, safety walks, and other activities that a project manager might do. The more safety and quality management activities the player defines, the higher GC cost and time become. But, if safety and quality management activities are not performed in the simulation, accident and rework rates will increase. These types of simulation challenges will be addressed over the project development.

4. MANAGEMENT STRATEGIES AND FUTURE WORK

The project team, consisting of 5 faculty and 5 graduate students from two universities, required the development of some structure and communication protocol. Some of the initial logistical activities include the setup and configuration of the technological platform, as well as a project web site (http://depts.washington.edu/vcoach). Two groups, an Industry Advisory Panel and an Academic Advisory Board both support the project. Industry support provides real world projects and events to create content rich scenarios. Academic advisors provide feedback on pedagogical issues and in later phases support testing of the Virtual Coach.

Regarding the UW and MTU partnership, we found it to be very helpful to establish a faculty collaboration agreement. Above and beyond the standard subcontract that is developed and managed by the offices of research, this collaboration agreement outlines responsibilities, authorship, ownership, credit, contingency and communication. Discussing these issues at the beginning of the project forced the faculty to come to terms with their expectations, and fostered dialog between team players.

In working with industry, we have found the establishment of partnership agreements to be very worthwhile. Strategic Partnership agreements allow both parties to establish expectations and outline very clearly what the academic researchers will do with the data collected. Once the agreements were in place, we received 3D models, geotechnical reports, schedules, budgets and change order documents for two exemplary projects. These projects will provide the context for initial simulations. Our industry advisors have also supported the development of scenario narratives.

To support the tightly collaborative development and communication for all 10 research participants, we conduct bi-weekly conference call meetings during the academic year where the entire team gets together to discuss project scope, accomplishments, and future work. Furthermore, since many individual emails are sent between participants outside of these all-hands meetings, we have established a system to archive all e-mail communications among project participants that are related to the Virtual Coach project. This record of communication allows us to review discussions and agreements made, and bring others up to speed on a discussion if they were not originally included in the email distribution.

4.1 Virtual Coach Master Plan

This paper describes our initial development of the interface (the Visualization Engine) for the Virtual Coach system. In the long run, we seek to create a multi-player system where players take rolls as Project Executive (Construction Company level – multiple projects), Project Manager (single project), and Subcontractor Project Manager (specific trade on single project). Future versions of the Virtual Coach may have the following capabilities: (1) Multiple players may be able to play the same simulation taking on different roles (owner, GC project manager, trade contractor project manager, etc.). This is downward vertical expansion (Figure 2). (2) A player may be able to oversee the construction of several projects by taking on the role of a construction company executive. The executive will interact with other players who are managing projects (project managers), will be in charge of monitoring all projects and will allocate resources among projects as needed within the boundaries of company constraints. This is upward vertical expansion (Figure 1). (3) A player may be able to perform the planning of the construction process in addition to the management of the process. This is up-stream horizontal expansion. (4) Facilities Management simulations may be supported by the system. This is down-stream horizontal expansion. (5) The Virtual Coach platform may run on virtual reality environments (immersive or semi-immersive) in addition to desktop computers. (6) Several alternative delivery methods (design-build, build-operate-maintain, etc) may be supported.

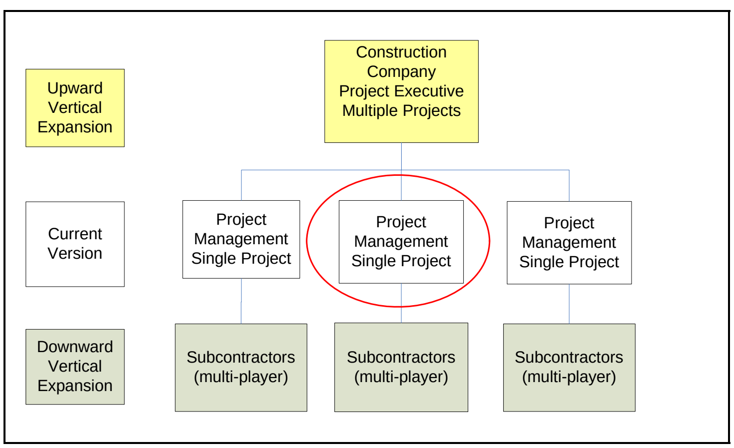

Figure 2. Virtual Coach Master Plan

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