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INTEGRATION OF SUPPLY CHAINS AND CONSTRUCTION SCHEDULE ON HIGHWAY PROJECTS

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ABSTRACT

The supply chain methodology is a recent technology being developed and implemented for the manufacturing industry with many reported benefits. This paper presents a conceptual framework for the application of supply chain models in highway construction projects. The highway construction process is served by hierarchical levels of suppliers: (1) the materials’ plants and vendors who provide construction materials directly to the contractors; and (2) vendors who supply the “parts” or “ingredients” that these materials’ plants need to produce the construction materials. This implies a multi-echelon serial supply chain. Uncertainties in these materials’ characteristics (quality, cost, time, etc.), as generated at the interface of each supply chain with the construction process, will lead to uncertainties associated with the final project completion characteristics, i.e., project quality, cost, and time. The formulation of a mathematical model of the supply chains is demonstrated, along with impact of the supply chains on construction project completion.

KEYWORDS

Highway Construction, Supply Chain, Construction Materials, Probability Network Scheduling, Project Cost

1. INTRODUCTION

By industrial engineering definition, supply chain management is the incorporation or extension of production planning and control to suppliers and customers (Sipper and Bulfin, 1997). Normally, the supplier, producer, and customer exist as three separate entities but in the supply chain philosophy of management, these three entities are integrated in the production process. Stevens (1989) defines supply chain as: A system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via the feed-forward flow of materials and feedback flow of information." Supply chain management is further defined by Nahmias (1997) as: Logistics of managing the pipeline of goods from contracts with suppliers and receipt of incoming materials, control of work-in-process, and finished goods inventories in the plant, to contracting the movement of finished goods through the channels of distribution.

Supply chain is an integrated approach where a supplier becomes part of the team with improvement in the areas of expected delivery to specifications, and input from supplier in terms of realistic enforcement of the specifications (Sipper and Bulfin, 1997). The potential cost associated with supply chain inefficiency are much more than those costs attributed to manufacturing errors (Nahmias, 1997). The supply chain concept is currently being suggested and primarily applied to the manufacturing industry, as one of the modern production management technologies. There is widely reported success with the implementation of this concept, with many benefits (Nahmias, 1997).

Towill (1997) presented a schematic view of a simple supply chain for the manufacturing industry as shown in figure 1. The example supply chain in figure 1 consists of four echelons -- raw materials supplier, manufacturer, distributor, and end customer. The direction of material flow is defined as downstream while the information (orders) flows upstream. For each echelon or business unit, the unit upstream is its immediate supplier while the unit downstream is its immediate customer. Interfaces are also shown between suppliers/manufacturers, manufacturers/distributors, and distributors/end customers. The objective in the supply chain methodology is to study the interaction between these integrated units in terms of the materials and information flow, and optimize the system performance by virtue of quality, customer service level, total cost, and lead time of the final products (Towill, 1997). A study of the elements of production planning and control in manufacturing (Sipper and Bulfin, 1997) shows that the supply chain is a continuous process with feedback control loop to achieve a system optimization and minimize deviations in final product’s cost, time, and quality. Kruger (1997) further explains the basic requirements of a supply chain model, to provide planning, procurement of appropriate materials, evaluate the inventory costs versus the supplier response time, part lead times, and part delivery uncertainty.

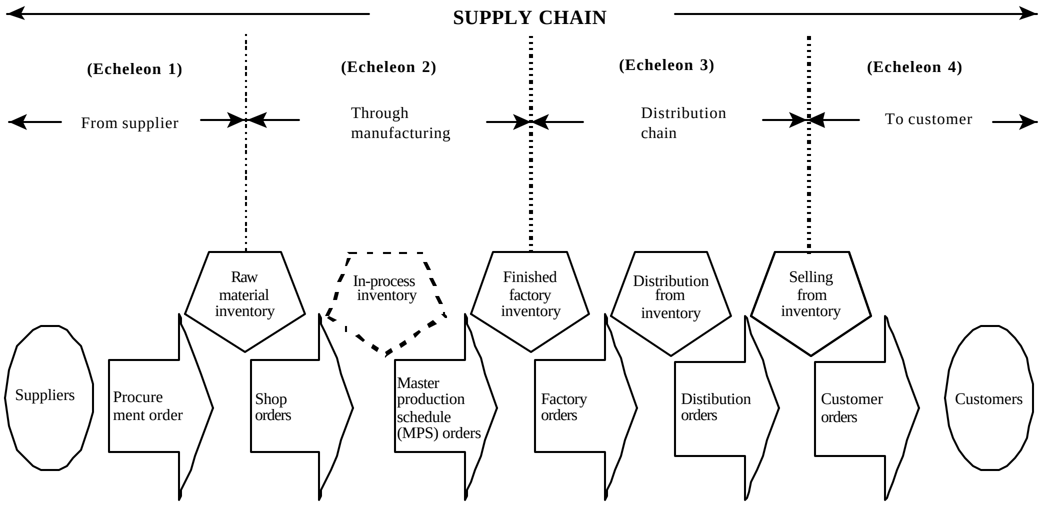


Figure 1: Schematic View of Material Flow in a Supply Chain (Towill, 1997)

2. SUPPLY CHAINS IN CONSTRUCTION

Looking at the similarities between the manufacturing industry and construction, it is reasonable to investigate the applicability of supply chain models to the construction process. First of all, the construction process (of buildings, highway, dams, etc.) is actually a manufacturing or assembly process where various materials are utilized or combined in producing a final constructed facility. The major difference between manufacturing and construction is the type and extent of uncertainties involved. Manufacturing is a continuous process in a factory environment which is relatively more controlled than the construction process, especially if you consider the extent of repetitiveness of activities, weather impact, etc. Also, inventory management is of a major concern in manufacturing and it is one of the areas addressed by the application of supply chains. Inventory issues are also of a concern in the materials management aspects of construction.

The construction process typically involves suppliers in the form of subcontractors or vendors providing specialty skills, supplies, or materials to the major contractor, who is actually responsible for the entire construction process, i.e., responsible for the production planning and control” equivalent in the manufacturing process. The customer will be the owner of the constructed facility a final product which must be delivered at a certain desired level of *quality, cost, and time efficiencies*. The supplies (from subcontractor) to the contractor in this case will typically include construction materials such as fabricated (structural) steel, reinforcing steel bars, Portland cement concrete, asphaltic concrete, pavement base materials, etc. The general project development process starts with the feasibility and design stage, through construction process, ending with the final product the constructed facility. Other input resources (supplies) to the construction process may include equipment rentals and labor supply for the contractor’s activities on the project.

The concept of supply chain management is deemed applicable to construction for two reasons: (1) there is a production planning and control system or an internal supply chain within each supplier’s own process, with the need to deliver supplies or materials to the contractor at a specified level of quality, cost and time; and (2) the production planning and control in the construction process, usually in the form of a time schedule and cost control model; the schedule and cost model which should show how the quality, cost, and time efficiency levels obtained from the supplier supply chains, i.e., the finished supplied goods, impact the overall construction time schedule, costs, and quality. These construction schedule time and cost parameters at project completion will determine the acceptability of the final constructed facility delivered to the customer or owner. In short, suppliers must deliver their goods to the construction process at good quality, cost, and on time. The construction process must also be controlled efficiently to obtain a good quality final facility at a good cost and on time.

Literature review showed several applications of the supply chain management in the manufacturing-related industry but until very recently, only a few related to the construction industry. Kroemker et al. (1997) reported an European project used to develop “CSCCM,” a computerized decision support system for the bidding process in small and medium-sized enterprises in the building industry. CSCCM considered a supply chain consisting of a tiler company, and a wholesaler and manufacturer of marble and granite. Goodwin (1997) discussed the benefits of information technology (IT) implementation in the construction industry, with consideration of some issues, including inventory from the supply chain. Hafeez et al. (1996) also presented the analysis and modeling of a two-echelon steel industry supply chain that services the construction industry; it was developed as a form of a Management Information System (MIS). Recent contributions also include O Brien (1999), Vrijhoel and Koskela (2000), and Akintoye et al. (2000). In the white paper by O Brien (1999), supply chain management was described in terms of a systems approach and its promise in improving facility construction. Through lessons learned from case studies, influence of supply chains indicate need for the management of scope, schedule, and costs. The supply chain should be modeled through an integrated analysis across the entire supply chain (from supplier through the contractor), with an optimal model of supplier-subcontractor costs with respect to changes in schedule and scope (O Brien 1999). As mentioned earlier, some studies have been conducted on supply chains in construction, but even these studies were mostly qualitative, rather than a needed quantitative model. Hafeez et al. (1996) studied the supply chains in steel reinforcing bars but they did not interface the steel supply chains with the construction process; the construction company was just indicated as an end customer. Also, no supply chain model has been established for highway construction.

Using the justifications already described earlier, this paper now presents a discussion of some specific supply chains in highway construction, and a quantitative approach of improved scheduling and cost modeling with emphasis on the uncertainty introduced by the supply chains into the overall project performance parameters.

3. SUPPLY CHAINS IN HIGHWAY CONSTRUCTION

Each of the plants or suppliers serving the construction process will have their own unique facility characteristics in terms of inventory, demand, production rates, etc., thereby constituting an internal supply chains within the overall supply chain. To illustrate the typical internal supply chains expected in the highway construction process, the manufacturing processes of some construction materials are discussed here. Typical construction materials include Portland cement concrete (used in highway pavement surfacing and bases, highway bridges, traffic barriers, etc.), asphaltic concrete (used in highway pavement surfacing and bases), aggregates (used in pavement bases), form work (used in highway bridges), fabricated steel girders and trusses (used in highway bridges), precast concrete pipes (used in storm drains, sewer), etc.

Portland Cement Concrete (PCC) can be produced at a ready-mix plant in a process where ingredients required by the plant include coarse aggregates, fine aggregates, Portland cement, water, and admixtures. The ready-mix plant is provided these ingredients by some suppliers. These suppliers of the aggregates to the plant, for example, will consider parameters such as strength, gradation, fineness modulus, polish values, etc. As measures of quality, the Portland cement suppliers will be concerned about properties such as strength, fineness, etc. These suppliers will also consider for the ingredients, parameters such as cost and delivery time to the ready-mix plant. The plant will mix these ingredients and obtain the final product Portland cement concrete (PCC), to be used in the construction process. The efficient use of PCC in the construction process will be influenced by parameters such as cost, quality, plant breakdowns, necessary rework to meet specifications, and delivery time to the construction site. The delivery time can be measured in terms of the scheduled time (early start date) of the related project activity, including lead times, if required. Other quality-related parameters to be monitored for the PCC will include the slump, and the strength, usually measured as 28 Days Compressive Strength. These parameters will have some uncertainties, as mentioned earlier, which may be adequately represented as probability distributions.

Similarly, *Asphaltic Concrete (AC)* is produced at a plant in a process where ingredients to be supplied to the plant include coarse aggregates, fine aggregates, and asphalt. The plant is provided these ingredients by some suppliers. Suppliers of aggregates to the plant will be concerned about similar properties mentioned above, for the PCC. Suppliers of asphalt will consider properties such as penetration, viscosity, density, etc. These suppliers will also consider for the ingredients, parameters such as cost, quality, and delivery time to the asphalt concrete plant. The plant will mix these ingredients and obtain the final product Asphaltic Concrete (AC), to be used on the construction site. Parameters to be considered during use of AC in construction will include: cost, quality, plant breakdowns, delays due to engineer’s inspections, necessary rework to meet specifications, and delivery time to the job site. Specific quality-related parameters for the AC will also include stability, flow, and percentage asphalt content. These parameters will have some uncertainties, as mentioned earlier, which may also be adequately represented as probability distributions.

Precast Concrete Pipes (from Portland cement concrete) pipes may be needed for drainage as storm drains on highways or as sewer pipes. In brief, the supply chain is as follows. Aggregates will be needed to be manufactured in the first stage, at an aggregate processing plant which is being supplied its raw material from a quarry or its equivalent. The aggregate will be processed and graded as required. At the second stage, processed aggregate is supplied to the PCC ready-mix plant a plant of which operations have been described earlier in this paper to be used in producing Portland cement concrete. The third stage, before interface with the construction process, will be the concrete pipe production plants where the precast pipes are produced, with the raw materials including concrete supplied from the PCC plants.

4. FRAMEWORK OF THE SUPPLY CHAIN MODEL

The proposed methodology involves modeling the various production facilities for the materials utilized in the construction process as a serial supply chain, in addition to an interface model which will reflect the impact of the various chains on the outcome of the construction process. The construction cost-time schedule can be used to evaluate this interface and its impact. The supply chain management model for construction will therefore consist of a supply chain involving: (a) suppliers of ingredients to construction materials plants; (b) plants (suppliers) who produce the construction materials and supply them to the construction site; and (c) an integrated project cost-time schedule to incorporate the outcomes of each supplier s chain at its interface with the schedule. The model will estimate the impact of the uncertainties introduced by the materials supply chain, on the overall completion of the construction project, in terms of quality, cost, and time efficiencies.

In actually formulating and implementing a supply chain model, two phases are needed: first, a qualitative stage, where intuitive and conceptual knowledge about the system are acquired to understand the structure and operation of the supply chains; and second, a quantitative phase, in which there will be the development of mathematical models (Hafeez et al. 1996).

5. MATHEMATICAL MODELS

The second phase involves development of mathematical models, including the use of concepts such as the simulation models, derived probability distributions, and probabilistic scheduling techniques, to model the echelons of the supply chain and also estimate final project completion parameters. As mentioned earlier, the supply chains are made up of facilities or plants with their own production attributes. Figure 2 shows, as an example, the serial supply chain impacting or supplying the activity storm drain pipes,” indicating the facility attributes, i.e., facility’s production rate, rework time, and rework cost. These attributes can be manipulated for the most efficient operation of the individual facility. As discussed later, the attributes will have an impact on the project activity schedule.

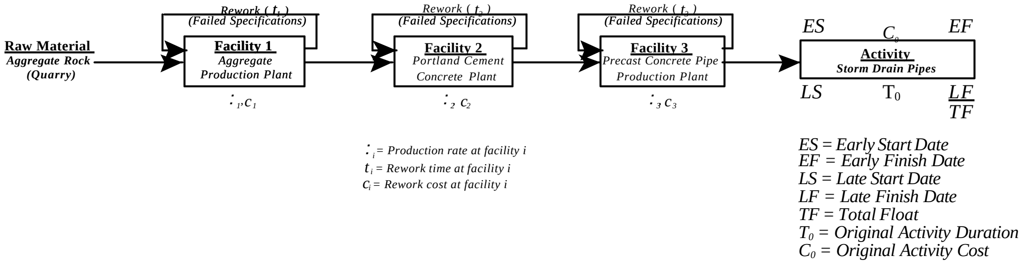


Figure 2: Supply Chain Attributes for Storm Drain Pipes (Precast Concrete)

An example highway construction project is shown in figure 3 to illustrate the conceptual framework of the methodology as discussed here. Major activities on such project may typically include excavation (road and bridge construction), storm drain pipes, main roadway pavement base, main roadway pavement surfacing, bridge substructure, bridge superstructure, bridge deck, and ending with the approach roadways for the bridge. The integrated project cost-time schedule with the interface with various supply chains is illustrated using Figure 4. Uncertainties are shown as probability density functions (pdf) but they can also be represented as fuzzy numbers. Fuzzy numbers are particularly useful when there is lack of historical data to generate pdf s and expert opinions can be elicited as fuzzy numbers. The schedule with fuzzy variables as input can then be analyzed using fuzzy sets theory.

Literature review shows previous work that described the processes and also studied these facility attributes on construction-related materials production facilities, especially aggregate processing plants, using mathematical techniques such as simulation and/or optimization (Beaman and Morrison, 1996; Peurifoy et al. 1996; Hancher and Havers, 1972). As part of the supply chain, there is interest in the integrated influence of the attributes, for instance, how the rework time in each facility affects the entire chain and subsequently, the scheduled activity dates on the project. Similarly, it is necessary to determine the effect of the cost of rework at each facility or plant, if any, in the chain on the impacted activity’s cost.

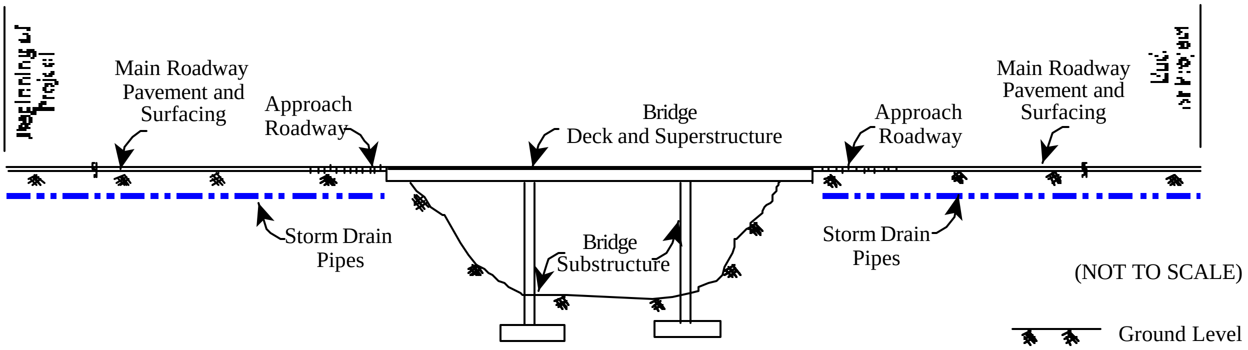


Figure 3: Sketch of an Example Highway and Bridge Project

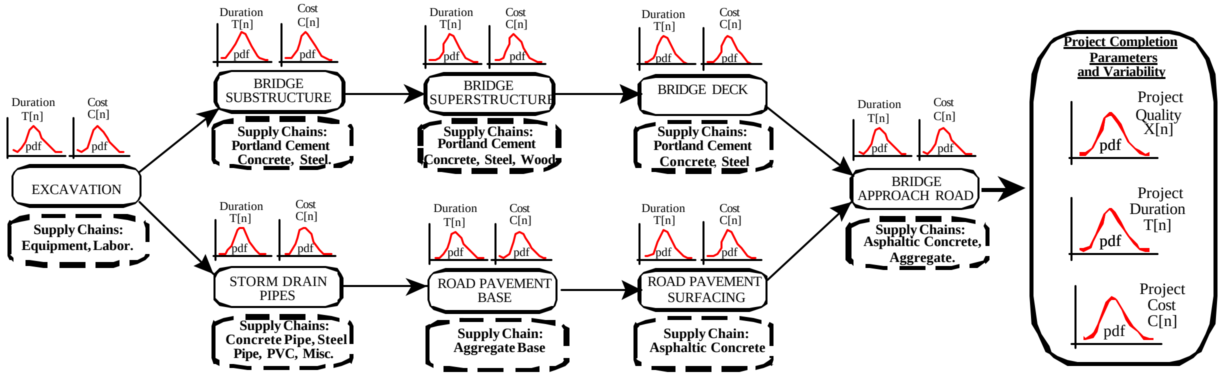


Figure 4: Integrated Cost-Time Schedule with Supply Chains Interface

Eventually, each activity affected by the supply chain attributes will impact the project construction schedule; various delays and inefficiencies within each facility on the supply chain result in costs and time durations which are reflected upon the total project completion parameters in terms of quality, cost, and time efficiencies.

These facility attributes as defined, for example, in figure 2 are utilized in formulating the supply chain models. Assuming there is no delay or extra costs (other than originally estimated) associated with transportation or distribution of goods between the facilities, or to the construction site, the revised schedule parameters of an impacted construction activity

$$C_{NEW} = C_0 + \sum_1^n c_i$$

$$T_{NEW} = T_0 + \sum_1^n t_i$$

will be
where

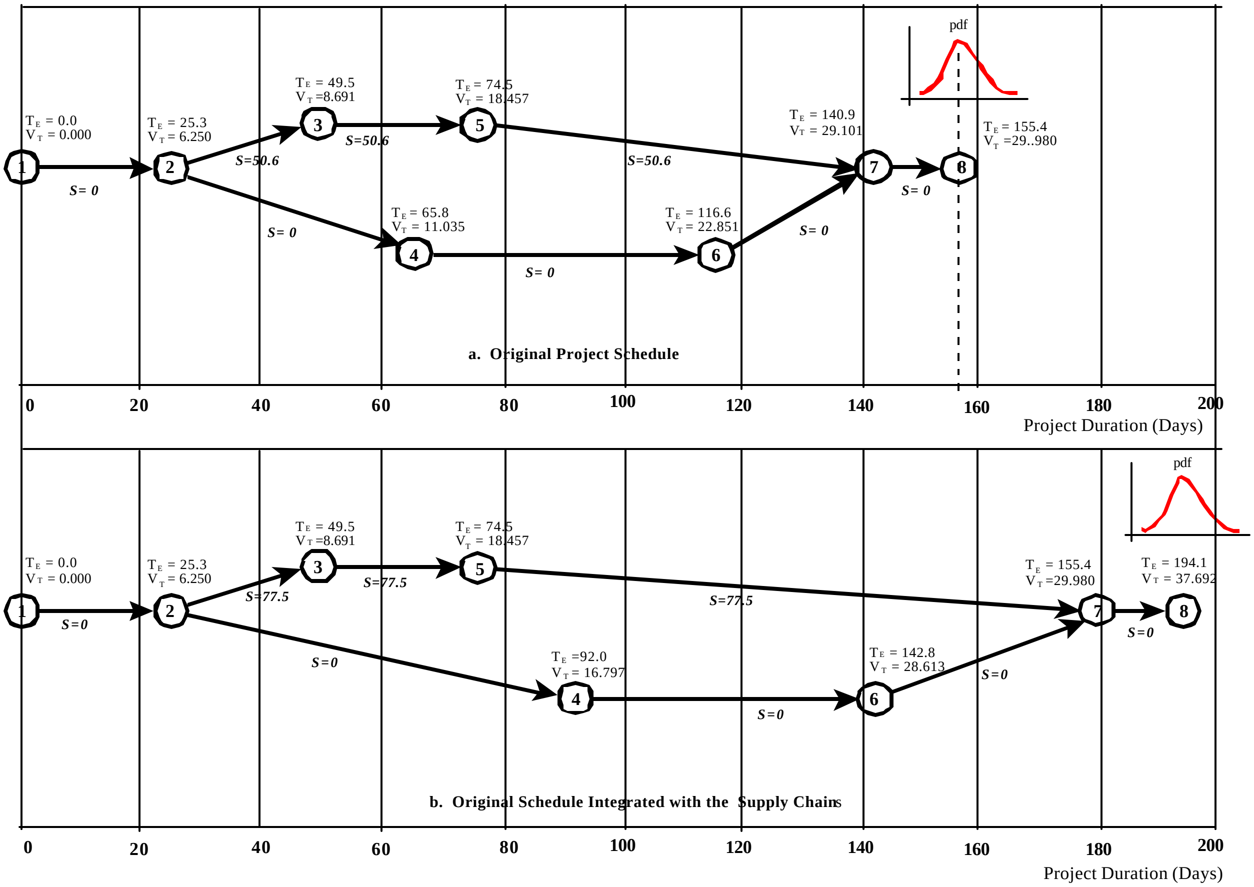
C_{new} = New or revised activity total cost; C_0 = Original activity cost; c_i = Estimated cost for rework at each facility on the supply chain; T_{new} = New or revised activity duration; T_0 = Original activity duration; t_i = Estimated time for rework of material at each facility on the supply chain; and n = number of facilities on the supply chain.

The last terms in these two equations (summation terms) represent respectively, the quantitative attributes of the supply chain in terms of: (1) delay in the expected delivery time (to the construction site) and (2) additional costs due to necessary facility rework in producing the material. The facility rework time, facility rework cost, construction activity duration, and construction activity cost are random variables which can be adequately represented as pdfs. Based on the normal Critical Path Method (CPM) algorithm, the floats and scheduled dates of any activity impacted by a supply chain can be computed by using the revised activity duration.

An appropriate tool for integrating the supply facilities attributes, i.e., the supply chain, with the project schedule, and thereby formulating an integrated model, is the Project Evaluation Review Technique (PERT). Under PERT, the activity durations are treated as pdfs instead of a single deterministic value used in the CPM schedules. The durations of impacted activities will be estimated in the form of beta distributions and inserted into the PERT project schedule. The probability of meeting a scheduled project completion date can then be computed. PERT simplifies this type of analysis by employing the central limit theorem to treat the resulting pdf as a normal distribution, which is relatively simpler to handle mathematically. A more rigorous and detailed stochastic analysis, will involve use of advanced probabilistic techniques to add the original pdfs along the supply chain before incorporating the resulting pdf into a probabilistic network schedule.

The normal PERT algorithm which is well documented in many scheduling texts (Moder et al. 1983) involves first estimating the activity's duration based on an assumed beta distribution for the pdf. Moder et al. (1983) defines the three times estimates of an activity duration, i.e., the optimistic, most likely, and pessimistic estimates. The optimistic estimate indicate that this activity duration will only be lower at about 5% of the time; the most likely estimate is the modal value of the time distribution; and the pessimistic estimate will only be exceeded only about 5% of the time (Moder et al. 1983). Assuming a beta distribution, the facility rework times and facility rework costs can also be handled the same way, i.e., using the optimistic, most likely, and pessimistic estimates. Equations are then used to compute the mean and variance respectively. In PERT, the activity durations are summed along the various network paths to obtain a probabilistic estimate of the project completion time. To incorporate the supply chain parameters, the same PERT steps are followed except for some modifications. The activities impacted by supply chains should first be identified, their activity durations and costs modified accordingly to reflect the impacts of rework times and costs from each facility on the supply chains. Monte Carlo simulation approach can also be applied to the stochastic network model. Another alternative to a stochastic network model (e.g., PERT, Simulation) is to portray the facility attributes as fuzzy numbers and then use a fuzzy network (Ayyub and Haldar, 1984) to model the construction schedule. In this fuzzy supply chain-CPM network, the facility attributes, activity durations and costs may be subjectively estimated based on expert opinions. Concepts under fuzzy sets theories may then be applied to manipulate the data involves and estimate the project completion parameters.

Using the same highway example project presented in figures 3 and 4, an arrow diagramming equivalent network schedule was constructed to illustrate the integrated supply chain-schedule network computations. Using some hypothetical but reasonable set of time and cost data for the facility attributes and network activity data, the pertinent equations and basic PERT network steps were applied to the network schedule. First, results were obtained for the project network in its original form, without any supply chain impact. Then the network was modified with the supply chain parameters to produce an integrated supply chain-schedule. Figure 5 illustrates the results of both PERT schedule analyses, indicating impact of the supply chains. The cumulative probability plots can also be generated for the project completion times and costs. The expected project completion times and costs will be indicated, as well as an estimate of the probability of finishing the project within a particular desired time or total costs, or the probability of zero slack on the critical path.



a. Original Project Schedule

b. Original Schedule Integrated with the Supply Chains

Figure 5: Project Completion Times Showing Impact of Supply Chains

6. CONCLUSIONS

A conceptual model has been presented in this paper to demonstrate the application of supply chain methodology to highway construction projects. The applicability of this new technology was discussed, along with a framework for the formulation of quantitative models to integrate the supply chain flows with the network schedule of the construction process. It can be concluded that this methodology is feasible for application to highway construction. Implementation of the methodology will involve gathering data on uncertainties of the variables involved. Most of the analytical tools utilized in formulating the models have been demonstrated in this paper to be simple and already available in the construction industry. The supply chain methodology is a new concept of great potential benefit to the construction industry in general. Supply chain models should also aid in providing better construction cost effectiveness, by improving the efficiency of completing highway construction projects in terms of its project quality, cost, and time goals.

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