THE HISTORY OF MODERN PROJECT MANAGEMENT

PRECEDENCE DIAGRAMMING METHODS: ORIGINS AND EARLY DEVELOPMENT

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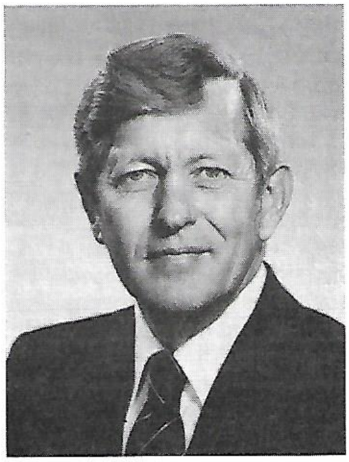

Professor Fondahl has served as Director of the graduate program in Construction Engineering and Management in the Department of Civil Engineering at Stanford University. *He is a registered Professional Engineer in the State of California and a Fellow, American Society of Civil Engineering. Mr. Fondahl was one of the earliest members of PMI, having become active in 1969. He has served in several capacities including Vice President, Director-at-Large, President (74-75) and Chairman (76-77). Additionally, he is quite active in the Northern California Chapter. John W. Fondahl was selected by the Project Management Institute as the 1981 recipient of its Honorary Life Member award.*

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In the first paper of this historical review, Jim Snyder stated that what we call "modern project management" had its beginnings in the 1950's. Certainly the introduction of the Critical Path Method (CPM) and the Program Evaluation Review Technique (PERT) in 1958-59 were two of the most important of the early contributions. As a contemporary researcher during this early period, I have been asked to describe my recollections and personal involvement in the development of an alternative approach which led to today's widely used Precedence Diagramming Method (PDM).

In 1955, I left the heavy construction industry to join Professor Clark Oglesby in the formation of a graduate construction program as part of Stanford University's Civil Engineering Department. Unlike most major engineering schools at that time which considered construction a vocational or sub-professional area, the environment at Stanford was favorable. Fred Terman, sometimes called the father of California's Silicon Valley was Dean of Engineering. He had been successful in achieving close relations between academia and industry in the electronics field and saw no reason why it couldn't be done in construction. Once our curriculum was successfully underway, we began to face the reality that no graduate program at a school like Stanford could survive without an active research thrust.

The Circle-and-Connecting-Line Diagram

In 1958 we made our first major research proposal. The Bureau of Yards and Docks (now Facilities Engineering Command), U.S. Navy, awarded us a three-year contract beginning July 1, 1958. One of several proposed topics under this contract stemmed from my experience as Project Engineer on a dam and powerhouse project immediately prior to coming to Stanford. This project was a highly successful one due, in my opinion, to very careful and detailed planning and scheduling. I felt that Cost Reduction, the overall topic of our contract, could be achieved by new and improved planning methods. Stating that a project could be broken down into a number of interrelated operations, I suggested that each of these operations had a time-cost relationship such that their performance could be at a rapid rate and high cost or a slower rate and lower cost. It was further suggested that there was some combination of performance rates that would result in the overall cost of the project, including indirect costs, being minimized. As it turned out, this elusive "time-cost tradeoff" problem had been defined and was under study by others. James E. Kelly and Morgan R. Walker were working on it, and their linear programming solution was to be presented at the Eastern Joint Computer Conference in 1959. However we were not aware of their efforts yet.

As a first step in my research I recognized that it was essential to represent the project operations and their interrelationships by a "paper model." At that time we had been stressing in our academic coursework the uses of industrial engineering techniques. We had been attempting to apply such tools as flow charts, process charts, and crew-balance studies to construction work. In a flow chart an operation, or activity, is represented by a circle. If another activity follows, it also is shown as circle with a line connecting it to the preceding activity. Therefore, when I broke a project down into component activities and attempted to represent their interrelationships, it was only natural to use a flow chart type of approach. I referred to the resulting diagram as a "circle-and-connecting-line diagram," a descriptive but rather uninspired label.

In June of 1959 a friend to whom I had described my research sent me a copy of an article that had appeared in the March 21, 1959 issue of *Business Week*. Its title was "Better Plans Come from Study of Anatomy of Engineering Job," and it described the CPM efforts of Kelly and Walker at duPont. The similiarities to my own objectives was obvious. One clear difference, however, was in the approach used to develop the paper model, or "network diagram." The CPM developed at duPont used a network where the lines, or arrows, represented the activities and the nodes represented events, the start or completion of an activity. In our diagram, the nodes represented the activities, and the lines represented the sequential relationships between activities. At about this time the PERT method of the Navy's Special Project Office also appeared. It too used the same diagramming method as CPM. However it used a different labeling system. PERT placed emphasis on the events and hence labeled the nodes. CPM placed emphasis on the activities and labeled the lines, or arrows. While our diagram looked like the historic PERT diagram, because we also labeled the nodes, it was basically different since the nodes represented activities. As time passed, the terms CPM and PERT became synonomous to many because the event labeling and the probabilistic duration estimates that were originally associated with PERT were seldom used.

At this time we took a close look at our "circle and connecting" line model and were prepared to change if we felt arrow diagramming had advantages. However, our conclusion was that we preferred the approach that we had developed due to its simplicity. The arrow diagram required the frequent use of artificial devices called "dummies" to achieve proper logic. This seemed to add an unnecessary complication.

A Non-Computer CPM

During the 1959-60 period, most of my time under our Navy contract was devoted to another topic: the development of short-interval time-lapse movies to analyze construction operations. However, I continued work on the time-cost tradeoff problem and eventually achieved a method that attempted to overcome some of the practical objections to the linear programming mathematical-type approach. It avoided the use of a batch-type method that required a complete set of data to be fed to a computer program all at one time, thereby eliminating any judgement control by the planner during the development of a solution. During the 1960-61 years, various implementations of the proposed methods were tried with the cooperation of industry firms. For example, when Kaiser Engineers bid on the construction of an underground command center for the Strategic Air Command at Cheyenne Mountain in Colorado, we tried an application of the time-cost method in the pre-bid stage. One new approach that came from this experience was the proposal of a different starting point for calculations. All procedures used the end of the time-cost curve, the so-called "Normal Performance" point determined by a schedule where every project activity is performed according to the least cost method regardless of time requirements. As a result of our pre-bid experience, we decided it was preferable to start with a feasible, "Conventional Estimate" solution that we would be able to submit as a bid and then, in whatever time was still available, to improve on this initial solution. This involved successive steps to achieve a better scheduling balance where each improved the cost and, given enough time, the optimum solution could be attained.

During 1961 as our contract time drew to a close, I made numerous presentations of our work. These were mostly to Navy audiences at BuDocks in Washington, D.C., at the San Francisco Naval Shipyard, at San Bruno, at Port Hueneme, at Davisville, Rhode Island, and at Pearl Harbor. By this time CPM and PERT had become relatively well-known and accepted procedures. There were many consulting firms including spinoffs from the original research teams. These firms were busy offering services and short courses. Three impressions had been conveyed to the potential construction users: (1) these were mathematically complex procedures, (2) these methods necessitated the use of computer, and (3) the services of a consultant were vital. Our own conclusion was that all three of these impressions were incorrect. Therefore, when it was time to write the final reports under the contract, I chose two objectives for the report on our planning and scheduling work. One was to sum up the work on our original time-cost tradeoff objectives, and the second, which proved much more important, was to offer a simpler approach to an industry that was ready for it. My 1961 report was entitled "A Non-Computer Approach to the Critical Path Method for the Construction Industry." It was also published by the Stanford Civil Engineering Department as Technical Report No. 9 under the same title and offered for sale. It featured the "circle and connecting line" method of diagramming. In the proposed time-cost procedure we featured the use of "Precedence" matrices and utilized the concept of "Lag" values.

The time was ripe for such a report. The construction industry was project-oriented and recognized the value of these project planning methods. Computers were not common in the industry, and their use either required resorting to employment of outside consultants or to service bureaus and employees with new skills. Contractors wanted tools that they could try out themselves before making the commitment to more sophisticated methods. In November and December, 1961, I published a series of two articles entitled "Can Contractors' Own Personnel Apply CPM Without Computers?" in *The Constructor*, the magazine published by the Associated General Contractors of America. These articles summed up our research results. In February, 1962, I was asked to present our approach to the National Convention of the Associated General Contractors which was being held in San Diego. Without these exposure opportunities, our research report, like most academic research reports, would probably have gone unnoticed. Instead, over 20,000 copies of this report have been distributed by our Department since 1961. A second edition was published in 1962. It involved the addition of "Appendix G" which recognized that our time-cost tradeoff method could produce a non-optimum solution under certain conditions.

The Navy renewed our research contract in 1961 on a year-to-year basis which eventually extended to 1966. In 1962 a programmer wrote the first computer program for the circle-and-connecting-line diagramming method on our Burroughs 220 in the Balgol language. In March, 1963, a graduate student at Stanford named Bob McLean published a much more powerful program written in Fortran

II for the IBM 7090 computer. While engaged in graduate studies, he worked with nine major contractors in the San Francisco Bay Area applying the computerized version of our research. Meanwhile by 1962 we had developed a graduate course in our construction curriculum on Project Planning, Scheduling, and Control, featuring the use of networking methods.

An Optimized Schedule

During this period I worked on the preparation of a second research report which was also to be published as a Technical Report by our Department at Stanford in 1964. It was entitled "Methods for Extending the Range of Non-Computer Critical Path Applications." We were obviously not blind to the benefits of computer processing as evidenced by our successful development of several programs. but I could see two objectives which I felt were important and that were not being served by computer processing at that time. One was the ability to update scheduling data whenever necessary at the field office site in order to achieve real project control. Computer processing at that point in time meant home-office updating, and a monthly cycle was considered a remarkable achievement. However, one doesn't achieve tight job control even with updating at monthly intervals. We wanted job site updating by practical manual methods to be applied whenever planning or schedule deviations took place, whether it was once a week or twice a day. The second objective was to achieve more effective applications of complex procedures such as time-cost tradeoffs and resource leveling. As mentioned earlier, batch-type computer processing effectively eliminated judgment control in the application of these procedures. The universal feeling was that such procedures were impossible without the use of computers. We were trying to show that for short-interval detailed planning they were not only possible but could produce better results, due to retention of judgment control, than so-called "optimum" batch-type algorithms.

In the resulting Technical Report No. 47, it was recognized that it would be necessary to work with networks of probably not over 100 activities. This meant that a subnetworking procedure was vital and that it should be time-period based. We developed what we called a "Dateline Cutoff" subnetwork. It allowed a subnet for any time period to be created that would permit calculations to be performed with the same results as though the entire master network was being used. This had obvious benefits. A 24-month project having a 1,000 activities might be converted to 1-month subnets having an average of 40 activities, and this might be done on a "rolling basis" as the job progressed.

We then developed methods for updating the data for such a network in the field office with only a few minutes of effort required. Originally our updating methods were aimed at the schedule compression required in the time-cost tradeoff procedure. However, further analysis indicated that the same methods were applicable to all types of updating. We found that all updating requirements would be satisfied if the following five changes could be handled: (1) duration changes, (2) schedule changes, (3) addition of activities, (4) deletion of activities, and (5) changes in sequential relations. Other conceivable changes are combinations of the foregoing. Moreover, we found that the methods that we had developed would accomodate all of these requirements. While the research for Technical Report No. 47 had originally been aimed at manual methods for the still elusive time-cost tradeoff method, once again we recognized that there was a more important immediate contribution, i.e. the ability to update conventional network scheduling data in a job-site environment. In the 1970's, of course, all of this would be taken over by the development of the interactive microcomputer processor, but such tools did not exist in 1964.

Precedence Diagramming

When the 1964 Report was published, the matter of diagramming nomenclature was examined. My label of "circle-and-connecting-line" was not an attractive one. Our graduate student, Bob McLean, in his work had used the title of "operation and interrelation line" which wasn't any improvement. Moder and Phillips published the first edition of their book "Project Management with CPM and PERT" in 1964. They suggested a logical nomenclature. CPM-type arrow diagramming was to be called "Activity on Arrow" diagramming. The type of diagramming that I had promoted would be called "Activity on Node" diagramming. We were about to adopt this nomenclature but reconsidered for two reasons. The nodes in our diagram could represent events (equivalent to activities of zero time duration) if it were desirable to include events in the diagram, such as might be the case with the use of selected "milestone" events. However, the more important reason for the selection of a different title was an announcement by IBM in early 1964 of their Project Control System for the 1440 computer. IBM had started work on this system in 1962 with the H.B. Zachry Co., contractors in San Antonio. Their 1964 announcement described a computer system that had the alternative of using arrow diagramming data or using data based on what they described as "precedence diagramming." This was the same system that we had been using. Their system also incorporated the use of lag factors, but primarily for a different purpose than we had used our "lag values." They used them to simplify handling of overlapping activities. We made the decision to also adopt the title "precedence diagramming" since we felt that with usage by IBM the label would probably prevail.

Due to the active efforts of the early consulting firms in the field and the contract specification requirements by government agencies for its use, arrow diagramming, at an early date, became the "standard" method in the U.S. Most specification writers, who perhaps had been exposed to one of the numerous short courses of CPM or PERT, assumed that "network diagramming" and "arrow diagramming" were equivalent terms, and were unaware that an alternative existed. Based on our work, the Navy wrote a spec for a drydock project in Charleston, S.C. in 1962 which required the use of our first research report for the scheduling method. However, the specification writer proceeded to further comment on the system, and actually described the use of the PERT-type arrow diagramming method.

Overseas the situation was different. During a sabbatical leave in 1963, I gave many presentations of our research in countries including France, Switzerland, Denmark, Sweden, and England. When I returned to Denmark for a sabbatical leave in 1970, I found that "block," or precedence, diagramming was much more standard practice than arrow diagramming. In 1964 on a three-week U.S.A.I.D.-

sponsored lecture assignment, our approaches were presented in Africa. In 1966, I spent three months in South America, giving presentations in Venezuela, Argentina, Chile, Peru, and Columbia. Precedence diagramming received an enthusiastic response in all of these locations.

In the U.S. the arrow diagram had been considered a necessity for computer methods, and alternate methods were viewed as suitable for manual applications only. With the introduction of computer programs based on precedence diagramming this began to change. Certainly IBM's PCS program was a factor. In 1965 a computer science graduate student, C. Wilson Baker, working under my direction, published a very sophisticated program package called SPRED-CPM. His report appeared as Stanford Civil Engineering Technical Report No. 56 entitled "SPRED-CPM, A Computer Program for the Solution of the Precedence Diagram Using Critical Path Methods." He continued work on this program, adding a resource leveling capability, and in May 1966, published a revised edition of Technical Report No. 56 entitled "SPRED and LEVEL-CPM." At that time he left Stanford to become President of a software company in Vancouver, Canada. Baker has used his program over the years since and eventually licensed Computer Science Corporation to market SPRED in the U.S.

Meanwhile, at Stanford we maintained a version of the program for the benefit of the members of our industrial affiliates program, the Stanford Construction Institute. Former graduate student Bob McLean and a PhD student named John Arrington extensively modified the program to take advantages of some of the more efficient methods from Bob's 1963 program written for the IBM 7090. The modified version was called CODASY (after an organization established to maintain the program for the Stanford users, Construction Data Systems Corporation). It was used, for example, by the Guy F. Atkinson Co. on the construction of the giant Mica Dam project in British Columbia and later on the construction of Kootenay Powerhouse Project also in British Columbia.

Engineering News-Record published an article in their May 6, 1965 edition entitled "Contractors Shift from Arrow Diagramming to Precedence Diagramming for CPM." In my 1964 Technical Report I had devoted a chapter to a comparison of arrow and precedence diagramming. While many points of comparison could be developed, the key bases for selection seemed to narrow down to Simplicity vs. Standard Practice. Certainly in the U.S. in the 1960's, arrow diagramming achieved the distinction of being standard practice where networking was utilized. However, I continued to feel that *Simplicity* was much more important. This was reflected in an article that I wrote for Western Construction magazine in May 1968, entitled: "Let's Scrap the Arrow Diagram."

One point of comparison was omitted from both my 1964 comparison and the 1968 article. This was the matter of *Lag Factors*, which many consider the major advantage of the precedence diagramming method. At one of the professional meetings that I attended, I found myself in a heated discussion concerning the merits of arrow diagramming. It was particularly upsetting because my opponent was upholding arrow diagramming on the basis that it was much simpler. This was striking at the very basis of my convictions. Suddenly I realized that he was probably correct. The computer applications of precedence diagramming were using lag factor relationships to such an extent that logic errors sometimes developed, and an analysis of the computational procedures utilized was extremely difficult. Lag factors had destroyed the simplicity of the method.

Sometimes a distinction is made between "Node Diagramming" and "Precedence Diagramming." Precedence Diagramming in this context is Node Diagramming with the additional application of Lag Factors. To this day I tend to remain a "purist" and really am an advocate of Node Diagramming, or of Precedence Diagramming only when there is a very careful and limited use of lag factors.

In summary I suspect that the precise origin of Precedence or Node Diagramming cannot be identified. As indicated, my original use was the natural result of having experimented with flow diagramming procedures for construction planning. Apparently a Frenchman named Roy also developed a similar networking approach called the Metra Potential Method (MPM) during the same general time period. In 1970 an approximately 150-page long dissertation was published by Dr. Wolfgang Rosch in West Germany entitled "Roy-Typ Und Fondahl-Typ." It discusses the networking methods of the two types and traces their geographic infiltration. According to a global diagram presented by Dr. Rosch, at the same time that I was disseminating my research in Europe, with subsequent flows to some of the Eastern bloc countries and to Israel, Roy was spreading his work to Berkely, California. At the same time that I was lecturing in Santiago, Chile, Roy was in Concepcion, Chile. Unfortunately, I never met Mr. Roy or knew of his work until Dr. Rosch's dissertation appeared.

At least one other set of players who may be involved were three researchers from Carnegie Tech named F.K. Levy, G.L. Thompson, and J.D. Wiest who wrote a chapter in a book called "Industrial Scheduling," edited in 1963 by Muth and Thompson. They stated that the diagramming method that they used on a contract for the Office of Naval Research and the Bureau of Ships "avoids the necessity (and complexity) of dummy jobs, is easier to program for a computer, and seems more straight-forward in explanation and application." I have never been in contact with them on this matter to know whether their work was based on mine, on someone else's, or whether they too may simply have used a flow diagram approach.

Recent software developments seem to confirm the importance of the PDM or Node Diagramming approach. I am glad to have had at least some impact on the development and growth of those methods, along with my students and associates. Our editor-in-chief's invitation to prepare this article was a motivation to finally look back over these early years and bring together some scattered experiences. I look forward to similar contributions from some of the other participants.

Editor's Note: Contributors to this column are sought who can shed light on the development of Modern Project Management. If you have a contribution, or know the whereabouts of a possible contributor, please inform *Project Management Journal, ATTN: History Editor.*