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PERT, CPM and the Tangled History of Network Scheduling

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ABSTRACT

The origins of two network scheduling techniques: The Program Evaluation Review Technique (PERT); and the Critical Path Method (CPM) are examined. Prior accounts hold that each are different and were created separately. PERT, developed within the U. S. Navy's highly classified POLARIS nuclear missile program which began in 1955. CPM, the creation of American industrial concerns E. I. du Pont de Nemours (du Pont) and Remington Rand UNIVAC. With the objective of settling "an acrimonious dispute over parentage," this research examines the literature and the original forms of PERT and CPM noting their 'dead ring' resemblances, synchronous development timelines, while introducing personal and corporate proximities between the two research teams. This study supports the notion that CPM was derived from the U. S. Navy's PERT system, and with only subtle differences, deliberately presented as an original concept to avoid the appearance of a leak from a highly classified nuclear missile program at the height of the Cold War. It also supports the possibility that CPM researchers played a role in the development of PERT. Regardless of which came first, PERT and CPM's place in history is secure as practically identical computer applications employing theories, models and terminologies provided prior to 1955 by various contributors and researchers identified in this study.

Keywords: Program Evaluation Review Technique, Critical Path, PERT and CPM

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INTRODUCTION

It is commonly accepted that two network scheduling methodologies; the Program Evaluation Review Technique (PERT) and the Critical Path Method (CPM) were the product of two unrelated research efforts of the late 1950s: PERT developed within the U. S. Navy's secretive POLARIS Fleet Ballistic Missile (FBM) program; and CPM within a private sector research venture of the E. I. du Pont de Nemours (du Pont) and Remington Rand UNIVAC (Astrachan 1959); (Fazar 1962); (Kelley and Walker 1959); (Kelley and Walker 1989); (Massey 1963); (Sperry Rand 1962). Also accepted is that the two methodologies are different enough to be considered as separate contributions to management science (Kelley 1961).

There is, however, debate over the timing of the creations. Although the U. S. Navy's first PERT publication preceded the first public presentation of CPM by 17 months -- PERT in July 1958, CPM in December 1959 -- several published accounts proclaim that CPM was actually developed before PERT.

> The DuPont (CPM) work is considered antecedent material for the development of PERT. (O'Brien and Plotnick 1999)

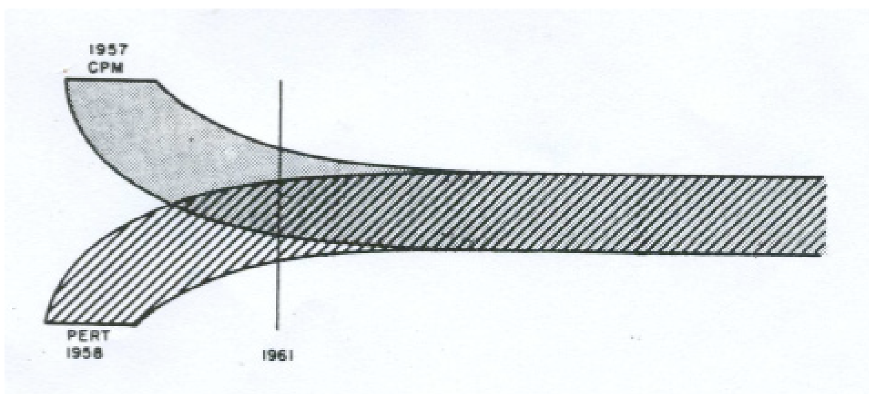

Figure 1. Sperry Rand Publication Illustrates CPM As Antecedent to PERT

> CPM had its inception in 1957… A year later, the U. S. Navy Special Projects Office implemented the PERT system. (Sperry Rand 1962)

Since their debut in the late 1950s, there is mention of a paternity dispute and bitter feelings amongst at least some of those involved. An Office of Naval Research study of the POLARIS program conducted by Harvey Sapolsky in the early 1970s exposed the rift.

> *With the actual birth of the PERT technique and its instant rise to fame, however, an acrimonious dispute arose over parentage. Given the size of the POLARIS program, it is not surprising that many people would be in some way involved in the development and application of a management technique that was in high demand. Paternity, then had a particular extra cash value that caused historical accuracy to be easily sacrificed in accounts of PERT's origins.* (Sapolsky 1972)

The objectives of this paper are to: (1) Identify PERT-CPM commonalities and shared concepts as PERT and CPM both relied upon pre-existing operations research; (2) Evaluate the synchronicity of PERT and CPM development; and (3) Identify proximities and relationships between the individual PERT and CPM researchers.

This study utilizes a detailed literature review of seven (7) key areas while exploring the PERT and CPM methodologies to meet the objectives of the study. It starts with an insight into the tangled history and the origins of both the methods while identifying influences of existing project management practices, Cold War events of the late 1950s, and relationships between the developers. In the end, each objective is reviewed against the facts identified through the analysis of the seven areas.

1. PERT AND CPM's TANGLED HISTORY

Absent from previous discussions is the fact that Sperry Rand Corporation was a member of both the PERT and CPM development teams. Or why the name "Remington Rand UNIVAC" was used as the name of du Pont's CPM collaborator despite the fact that that corporation had been acquired by Sperry Rand in 1955. Also unmentioned is that three of Sperry Rand's members -- John Mauchly, Grace Hopper, and a young mathematician named James E. Kelley – were simultaneously and directly involved in both PERT and CPM development teams. Prior accounts also neglect to mention that within a week of the Navy's discovery of the du Pont/Sperrry Rand CPM research effort in March 1959, Mauchly's research division at Sperry Rand was dissolved. Mauchly, Kelley, and du Pont's Morgan Walker resigned or were terminated by their respective employers and immediately started a CPM consultancy in Southeastern Pennsylvania by the name of Mauchly and Associates.

PERT and CPM reliance upon pre-existing operations research provided by scientists Warren McCullough and Walter Pitts (1943), John Von Neumann (1945), George Dantzig (1947), Selmer Johnson (1953), Charles Denhard Flagle (1954) and Melvin Salveson (1955) is also examined. Each of the aforementioned scientists provided fundamental concepts, theories, and models that became the basis of the work under the POLARIS and du Pont-Sperry Rand efforts. Some of the unique network topology, vocabulary and illustrations of PERT and CPM are indeed found in these earlier works. Here the research finds direct personal connections between these scientists and several individuals on the PERT and CPM research teams.

2. THE FIRST FLEET BALLISTIC MISSILE – The Beginnings of PERT

On September 13, 1955, President Dwight D. Eisenhower directed the U. S. Navy to develop, produce and deploy an Intermediate Range Ballistic Missile (IRBM) aboard a surface vessel within ten years and aboard a submarine within twelve. Carrying a single atomic warhead, the 'Fleet Ballistic Missile' (FBM) was devised to offset perceived Soviet advantages in the size of its atomic arsenal and delivery platforms. Eisenhower's FBM directive was prompted by recommendations made by the Killian commission, a classified American research study charged with assessing the balance of power between east and west. In the directive were recommendations to accelerate the U. S. Air Force's ATLAS Intercontinental Ballistic Missile (ICBM) program and initiate the development of two new IRBM systems, each with an operational range of 1,500 miles. One such IRBM would be a first of type 'Fleet' Ballistic Missile (FBM) deployed by the U. S. Navy.

Shortly after Eisenhower's FBM directive, Admiral Arleigh A. Burke, Chief of Naval Operations, created the "Special Projects Office" (SPO) as a singular command charged with overall responsibility and absolute authority for the management of the U. S. Navy's new FBM program.

> "The management structure of Special Projects is special and unique in the organization of the Navy - a Manhattan District type organization. The Office has a relatively small military and civilian staff which is essentially a task force with responsibility matched with authority to achieve specific high priority goals in the shortest time possible. ...The Director of Special Projects Office...reports directly to the Secretary of the Navy." (U S Navy 1961)

The choice of the name 'Special Projects Office' was deliberately non-descriptive, devised more to deflect attention from a highly classified military program than to connote importance. The word 'Projects' was deliberately pluralized to provide hope to the SPO's civil servants, many of whom had been handpicked from other federal agencies but who, in the move, lost any guarantee that their employment with the U. S. Government would extend beyond the FBM program (Baar and Howard 1960); (Sapolsky 1972). Burke tapped Rear Admiral William F. Raborn, Jr., a naval aviator serving on the command staff at the Navy's Second Fleet Headquarters in Norfolk, to serve as the Director of SPO. Since the end of World War II, Raborn had served at the Bureau of Ordnance in Washington, D.C., developing the REGULUS missile, commanded the aircraft carrier USS BENNINGTON and served on the Atlantic Fleet's command staff (Baar and Howard 1960).

President Eisenhower placed significant constraints on the Navy program. Rather than initiate a new design, he mandated the Navy team with either the Air Force or Army, to create the FBM from the stocks of one of four ongoing missile programs: ATLAS; THOR; TITAN or JUPITER. There was no overall increase to the Navy's annual budget, and the first fully operational FBM system was to be deployed within ten years (September 1965). The Navy joined the U. S. Army's JUPITER missile program at Huntsville, Alabama, a next-generation development of the Army's REDSTONE rocket, which, as of late 1955, was operational to the range of 200 miles.

Shortly after his appointment as Director of the Special Projects Office, Admiral Raborn requested permission to conduct research in solid rocket fuel, a technology that in 1956 had yet to be demonstrated as viable for anything beyond short-range applications. Such formality was necessitated by explicit limitations placed upon the Navy's FBM program by President Eisenhower; which included direction to employ a liquid fueled rocket system (ATLAS, THOR, TITAN and JUPITER each employed liquid fuel). Raborn's request, which was approved for a limited study, resulted in a technological breakthrough that resulted in the first solid rocket fuel feasible for strategic purposes. It was also a clear demonstration of Raborn's deliberate encouragement of iterations to his program's scope, cost, and schedule as a successful management strategy. After deliberation and evaluating constraints pertaining to deployment, Raborn decided to move ahead with a smaller solid-fueled missile system under naval control

Ultimately, Raborn was able to detach the FBM program from the U. S. Army JUPITER program. On December 8, 1956, having convinced Secretary of Defense Charles Wilson that with a smaller, submarine-launched solid-fuel missile, the Navy could deploy more warheads with greater mobility, stealth and enjoy a lower risk of mishap. The submarine option would also avoid technical complications that had emerged in the area of missile guidance, problems more pronounced on a surface ship even in the most moderate sea state. Raborn named the new missile POLARIS, envisioned deploying 16 missiles within each specially configured submarine, projected an overall savings of $500 Million and a time savings of at least two years (Potter 1990). With first efforts and a team in place, the development of PERT would follow.

Other influential decisions by Raborn included two separate accelerations of the FBM program which, together, saved over four years. He also re-directed an attack submarine already 'on the ways' at New London, Connecticut (USS SCORPION) and bisected it to insert a 130-foot missile section amidships. The larger vessel was renamed USS GEORGE WASHINGTON which became the U. S. Navy's first Fleet Ballistic Missile Submarine. SCORPION's conversion eliminated the need for the design and construction of an entirely new submarine platform and likely saved two years. SPO employed multiple management methods across the entire program and these approaches would be stitched together in the form of PERT. The next section describes how these methods came together.

3. THE INFLUENCE OF U. S. NAVY TIME MANAGEMENT METHODS

This section establishes the impact of the U.S. Navy's time management methods on the development of PERT. The Special Projects Office's use of milestone events for time management had already begun by mid-1956. These 'milestones' became the basis for the 'unambiguous' and 'measurable' basic stochastic events that were the basis of the PERT system, still yet to be formalized. "Prior to the advent of PERT, milestone reporting was the principal tool utilized by SPO to provide information on actual versus scheduled (i.e., planned) progress in all assigned areas of work." (U. S. Navy 1961). For example, "Start of Keel Construction" would be a milestone or 'event,' whereas "Assemble Keel" would represent a 'Job' and would not be illuminated within SPO time management systems. Some SPO members would later describe PERT as merely "an extension of the program evaluation system existing in the Special Projects Office at the time it was developed…(and that), these elements are codified in PERT." (Massey 1963).

According to the PERT authors, Admiral Raborn assembled a team of experts who considered themselves specialists in operations research and actively sought and considered the application of innovative management concepts (Malcolm et al. 1959). In mid-1956, while still part of the U. S. Army's JUPITER program, Admiral Raborn took key members of his team to the corporate headquarters of several major American corporations to explore private-sector program management practices with the hopes of gleaning innovative managerial techniques. Visits were made to entities like Chrysler Corporation, General Motors, and du Pont, but Raborn described the effort as disappointing, noting "nothing of value" was learned from the evolution and that notions of private industry innovation and cutting edge technique were "reputations unearned." (Sapolsky 1972). There is no record of this early encounter between du Pont and the U. S. Navy as influencing either the PERT or CPM research which had yet to commence.

In January 1957, one month after Secretary Wilson authorized the POLARIS program, Admiral Raborn established a "Steering Task Group" (STG) to recommend an "optimum POLARIS submarine system" and to "review and advise" on technical progress. STG members included "Lockheed, Aerojet, General Electric, Westinghouse, Sperry (Sperry Rand), Massachusetts Institute of Technology, Atomic Energy Commission, Chief of Naval Operations, Bureau of Ships, and Naval Ordnance Laboratories" (U. S. Navy 1961). The STG monitored program milestones on continuously updated wall charts, which tracked 'program management plans.' Incorporated within these plans were some 10,000 entities, primarily contractors, subcontractors, research laboratories, and suppliers.

Also, in January 1957, Admiral Raborn issued a seven-page memorandum to Special Projects staff describing, among other things, the need for integrated and reliable information for program control.

> It is now necessary that the elements of a completely integrated management control system be developed to obtain the full potential of the Management Center...I must be able to reach down to any level of Special Projects Office activity and find a plan and a performance report that logically and clearly can be related to the total job we have to do...

Raborn also addressed the importance of planning and scheduling:

> A common format of planning and scheduling work is as essential to interstaff coordination of work as it is to the establishment of relationships between the several levels of management authority. (Raborn 1957)

Raborn had SPO study the feasibility of further accelerations to the program during the spring and summer of 1957 (Baar and Howard 1960). His move was timely as the Soviet launch of the world's first orbiting satellite occurred some four weeks later, placing even more pressure on the FBM program schedule.

4. THE SPUTNIK EFFECT: The Birth of PERT

Raborn's acceleration studies preceded successful Soviet demonstrations of the world's first Inter-Continental Ballistic Missile and artificial satellites Sputnik I and II using the SEMYORKA R-7 platform (August, October and November 1957, respectively). After SPUTNIK, Secretary Wilson directed Raborn to shorten the POLARIS delivery schedule. Raborn proposed an emergency plan allowing the first FBM submarine to deploy with shorter-range missiles by February 1962 – a 5-1/2 years savings. It prompted SPO to embrace the idea that time was their "scarcest resource." (Miles 1963) (Fazar 1962).

At the time of the acceleration, Gordon Pehrson, Director of Plans and Programs at SPO, discussed formally establishing program management methodologies for time, resource and cost management with members from the management consulting firm Booz Allen & Hamilton and the Lockheed Corporation in December 1957. The discussions led to the award of a consulting contract to both firms (Sapolsky 1972). The name "PERT" was created while preparing the U. S. Government form, "DD-254 Security Requirements Checklist", which required a four-letter title. After considering several other options: "PET" (Program Evaluation Task), "PEP" (Program Evaluation Plan), "PEST" (Program Evaluation System Task), and "PEAR" (Program Evaluation and Analysis Research); "PERT" was selected (Fazar 1962).

PERT immediately caught the eye. The problem of designing a system of program evaluation was aptly described by "Program Evaluation Research Task." PERT was cute, catchy and bold. Our task was a bold venture that would require pert and skillful action. Based on this thinking, PERT was it. Project PERT will study the application of scientific research methods to facilitate the early spotlighting of situations requiring top management decision and action, and for the rapid determination of possible course of action.

Beyond Fazar, the immediate PERT development team included Donald Malcolm, John Roseboom and Charles E. Clark, and Lockheed's Richard Young and Everett Lennen. Other close participants were SPO's Fred Lewis, who developed PERT's computer routines, and Robert Pasek, who coordinated the flow of information among the participants. J. W. Pocock, W. F. Whitmore, L. T. E. Thompson, P. Waterman, and R. Miner, likewise from SPO, were also key participants (Malcolm et al. 1959). Work formally began under the PERT consulting contract on January 27, 1958, and "the general model specification upon which the analysis is based" took one month (Malcolm et al. 1959). This timing is corroborated in other accountings of this research effort, which together provide that PERT had in fact, been formulated in February 1958 and finalized into a final report by May 1958 (Fazar 1962, Massey 1963, U. S. Navy 1958a)

In July 1958, the U. S. Government Printing Office published Program Evaluation Research Task, Summary Report Phase 1, which provided a sixteen-page overview of SPO's new time management methodology. Included were detailed descriptions of PERT's approach to time management as well as key components such as the identification of 'unambiguous' and 'measurable' events, the establishment of the network 'system flow plan,' the elicitation of three time estimates for each interval between events, the conversion of three time estimates to one time estimate, the calculation of 'slack' (commonly referred to as 'float' in contemporaneous applications), and determination of the 'critical path.' This research considers the Navy's sixteen-page document of July 1958 as the first published account by either the PERT or the CPM development teams. A second, more detailed, PERT publication was provided by SPO in September 1958. By October 1958, Admiral Raborn reported broad implementation of PERT within the POLARIS program, specifically requiring that the POLARIS team update schedule information on a bi-weekly basis.

4.1 "Polaris, from ut of the deep…PERFECT"

The first successful 'full up' demonstration of the POLARIS missile system occurred on July 20, 1960, within the waters of the U. S. Navy's Atlantic Test Range, 30 nautical miles east of Cape Canaveral, Florida. Submerged aboard USS GEORGE WASHINGTON, Admiral Raborn sent an immediate message to President Eisenhower at Newport, Rhode Island. "POLARIS, FROM OUT OF THE DEEP TO TARGET. PERFECT." (Time 1960). Within minutes the demonstration was followed by a second missile shot, also successful.

> "The Fleet Ballistic Missile Program, and particularly its POLARIS component, is generally considered to be one of the nation's most successful weapon development projects. Certainly, it is the largest and one of the most important weapon projects ever undertaken by the Department of the Navy." (Sapolsky 1972)

In 1955 President Eisenhower ordered the Navy to achieve its first operational launch of an Intermediate Range Ballistic Missile (IRBM) from a mobile seaborne platform within ten years. It did so in just under five. By September 1967, the month President Eisenhower established for the launch of the first fleet ballistic missile submarine; the Navy had 41 such boats already in operation.

5. WHAT WAS THE PROGRAM EVALUATION RESEARCH TASK?

"Program Evaluation Research Task" was a network-based management and planning control system that appointed "time as the common denominator" while considering other resource variables (i.e., money, manpower, equipment, and material). PERT produced a measure of the POLARIS program's ability to meet end objectives by a specific point in time (Fazar 1962). In 1955, those end objectives for the U. S. Navy were to deploy an IRBM from a surface vessel by 1965, and from a submarine two years later. The methodology was renamed Program Evaluation Review Technique sometime in early 1958. The term remains unchanged some sixty years later.

PERT consisted of a 'system flow plan' or network representation of the POLARIS program's milestones connected to one another using arrows to represent interdependencies and estimated time between events.

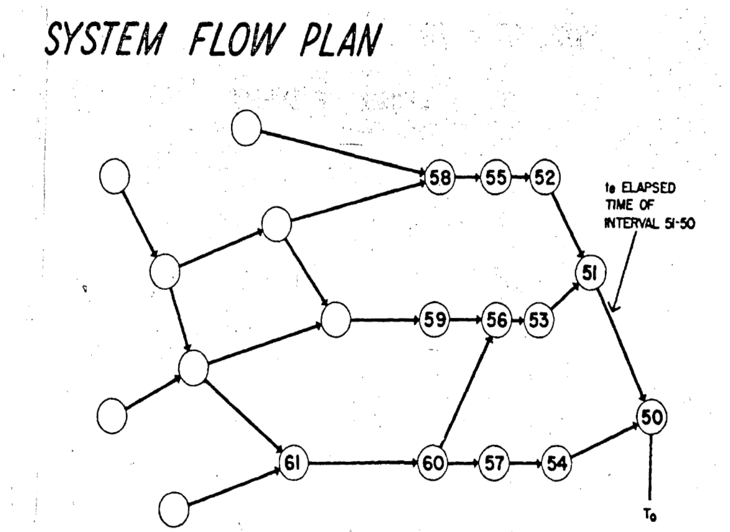

Figure 2. PERT's Network of 'Expected Time' Between Events. (U. S. Navy 1958a)

Once the network of events and interdependencies were established, a two-step process was used to assign a time value to each arrow. To assign time values, the Special Projects Office elicited three-time estimates – "optimistic," "pessimistic," and "most likely" durations -- from small working groups composed of contractor and government engineers. The membership of these groups changed depending on the subject matter. With three estimates for each arrow, PERT schedule data was provided to the Naval Ordnance Research Calculator (NORC) computer staff at Dalgren, Virginia. The NORC computer converted the three-time estimates to a single time estimate ("estimated time"), identified the program's "critical path" (i.e., the path through the network that controlled the duration of the overall endeavor) and computed the likelihood of program completion on or before a point in time. Contrary to popular notion, the term 'critical path' was coined by the members of the U. S. Navy's POLARIS program in early 1958. Once PERT's details were published, the term earned immediate popularity within the management science community and remains in use to this day. (U. S. Navy 1958a)

The PERT technique also identified 'non-critical' paths, or the network paths with events that had "slack" and did not immediately affect the duration of the overall endeavor. Together, knowing which path could immediately delay POLARIS, and which paths did not, gave the Navy team the ability to target the work necessary to accelerate the program, rather than across the board "crash" efforts which were popular up until this time. PERT also offered a second important feature, a quantitative expression of the likelihood of the endeavor's overall completion on or before a specific point in time (e.g. "as of Week 69, the probability of the program's overall completion on or before week 175 is 32.01%.").

PERT's details were first released to the general public under two separate publications from the U. S. Government Printing Office in July and September 1958 (U. S. Navy 1958a); (U. S. Navy 1958b). Describing PERT in April 1959, nine months after its first public release, several of the principal team members provided five fundamental PERT concepts:

> (1) The most important requirement for project evaluation…(is) the provision of detailed, well-considered estimates of the time constraints on future activities;
>
> (2) The qualifications of a person making such an estimate must include a thorough understanding of the work to be done;
>
> (3) Time estimates for some activities…are highly uncertain. This uncertainty must be exposed;
>
> (4) Each activity…should have a probability distribution of the times that the activity might require;
>
> (5) Precise knowledge of the sequencing required or planned in the performance of activities (is required).

Observing these five fundamental concepts, it was possible to construct a network of events and calculate "the time at which each milestone…can be expected" (Malcolm et al. 1959).

Next, the PERT development team theorized that if the three-time estimates for each interval between events were converted to one, a far less intensive computer algorithm could be realized. This single time estimate ("expected time," t_e) was established as the mean value of a 'beta' type probability distribution through the following approximation:

$$t_e = (a + 4 m + b) / 6 \qquad (1)$$

where,

t_e = expected time

a = optimistic time estimate

m = most likely time estimate   3 Time Estimates

b = pessimistic time estimate

Converting three-time estimates to a single expected time (t_e) between events created a deterministic solution to what was otherwise a stochastic problem. This nuance has been largely ignored in the traditional PERT-CPM debate, which contrasts PERT's stochastic first step to CPM's deterministic approach as evidence of separate intellectual subject matter. Indeed, PERT was set up as a stochastic problem, but when its algorithm converted three-time estimates into one, its topology was solidly deterministic.

With a single time value between each event, the portions of the PERT solution address the 'expected' completion time for the overall endeavor (T_{0E}), identification of the network's 'critical path,' and 'slack' values for individual events, was deterministic.

The PERT methodology also produced a statement of subjective probability regarding the overall likelihood of program completion (T_{0E}) "on or before" a certain point in time (e.g. "the likelihood of the program's overall completion on or before week 175 is 0.3201 or 32.01%"). In this calculation, the 'optimistic' and 'pessimistic' time estimates across each interval produced the variability of the time estimate between individual events (t_e) using the following approximation:

$$\sigma^2(t_e) = ((b - a)/6)^2 \tag{2}$$

where, $\sigma^2(t_e)$ = variability of expected time

a = optimistic time estimate

~~m = most likely time estimate~~ 2 of 3 Time Estimates Used

b = pessimistic time estimate

Finally, the variability of POLARIS's overall schedule ($\sigma^2(T_{0E})$), was calculated by summing the variability of the time estimates (t_e) along each path. The probability of completing the overall endeavor "on or before" a certain 'scheduled date' (a required, desired, or 'what if' date) described as (T_{0S}) was calculated using the 'expected' completion time for the overall endeavor (T_{0E}), the schedule's overall variability ($\sigma^2(T_{0E})$) and published tables for a normal probability distribution.

6. ACCOUNTING FOR HUMAN FACTORS

While understated at best, it is important to observe the Navy's treatment of human factors in its design and implementation of PERT. POLARIS's three time estimates for the interval between each event -- the 'optimistic,' 'pessimistic,' and 'most likely' time estimates, were indeed deliberately intended to "disassociate the engineer from his built-in knowledge of the existing schedule. Also, the fact that the time estimates were obtained during a formal 'interrogation process' overseen by U. S. Navy Progress Officers; and that the time estimating groups were made up of both contractor and government engineers, intended to reduce the influence of corporate or personal bias on PERT results.

Following its initial release and publication in July 1958, the U. S. Navy SPO was inundated with requests from the private sector for additional details. Open houses were held in Washington, D.C., to demonstrate PERT and other aspects of the POLARIS program to the general public (Kelley and Walker 1989). Within months, PERT was adopted by other major

U. S. Government procurement programs such as the Department of Defense and the National Aeronautics and Space Administration. However, these new users struggled with PERT's use of stochastic concepts. PERT's requirement for a robust computing capability, which was still somewhat limited to only the largest government and corporate concerns, also limited the ability of smaller entities to adopt the system. Consequently, many users simply tailored the methodology to suit their own needs, and/or adopted an *a la carte* approach towards spin-off approaches both within and beyond the U. S. Government (Sapolsky 1972).

One spin-off was John W. Fondahl's "Precedence Diagramming Method" (PDM), a non-computerized form of network scheduling advanced within a classified research project for the U. S. Navy's Bureau of Yards and Docks which began in 1961 (Fondahl 1964). The Navy's interest was to see Fondahl create a non-computerized approach for U. S. Naval Construction Forces operating in remote locations. Ironically, Fondahl's PDM, devised as a simplified, handwritten approach to network scheduling, was incorporated into IBM's network scheduling algorithm in 1965. It has since become the standard coding methodology for network scheduling software applications.

7. A ROAD BUILDING INITIATIVE AT du PONT

On June 29, 1956, President Eisenhower signed into law the National Interstate and Defense Highways Act. This first interstate highway bill authorized just over $33 Million towards road building. It was the first in a series of appropriations in what was expected to deliver over a half-million miles of interstate highways and secondary roads throughout the United States. It was generously described as "the greatest public-works program in the history of the world" by U. S. Secretary of Commerce Sinclair Weeks (Morris 1956). Anticipating an accompanying demand for highway design and construction, American construction contractors such as E. I. du Pont de Nemours (du Pont), whose engineering division oversaw an annual budget of $500 Million in 1956, set about on a search for operational efficiencies (Kelley and Walker 1989). On December 20, 1956, du Pont's Philip Hayward and John A. Robinson provided a preliminary analysis of a 'construction scheduling problem' suggesting significant operational efficiencies could be realized using the Universal Automatic Computer I (UNIVAC I). Du Pont's UNIVAC I was under lease from the Sperry Rand Corporation. (Kelley and Walker 1989); (Murray 1997) Subsequently, Morgan Walker, a member of du Pont's Integrated Engineering Control Group was assigned the responsibility of furthering this initial research.

Walker contacted John W. Mauchly, then head of Sperry Rand's Remington Rand UNIVAC Applications Research Center and co-inventor the UNIVAC I. Mauchly assigned mathematician James E. Kelley, Jr. to the du Pont research project. By January 1957 work had begun on an approach dubbed the 'Kelley-Walker Method,' then 'Main Chain Technique' and finally, the 'Critical Path Method' (Kelley and Walker 1989). In late January 1957, Kelley presented a conference paper at the Case Institute of Technology in Cleveland, providing that scheduling may be 'put as a linear program and handled by standard methods' and described the utility of the computers towards identifying optimal solutions to both roadwork 'cut and fill' operations and project scheduling (Kelley 1957).

According to recollections of Kelley and Walker provided in 1989, as of April 1957, "…a completed write-up of CPM was available including a statement of assumptions, a non-trivial, worked example – but no proofs." They also claim that by September 1957 the du Pont – Sperry Rand team had conducted analyses on the "George Fisher Works," a simulated project consisting of a network diagram of circular nodes and connective arrows. "Project A," "Project B" and "Repauno Works" followed, and in late 1958, CPM was applied to plan a future maintenance shutdown of a du Pont plant in Louisville, Kentucky (Kelley and Walker 1989).

8. WHAT WAS THE KELLEY-WALKER METHOD?

CPM was presented as the creation of the E. I. du Pont de Nemours Corporation (du Pont) and computer consultants from Remington Rand UNIVAC (by 1955 a subsidiary of Sperry Rand) within a secretive corporate research project titled 'the construction scheduling problem' which ran from December 1956 to April 1959 at the two companies. Originally called the "Main Chain Technique" or "Kelley-Walker Method" in recognition of James E. Kelley, Jr. (Sperry Rand) and Morgan Walker (du Pont), it was subsequently renamed 'critical path method', sometime after the Navy's first PERT publication in July 1958 (Kelley and Walker 1989); (Sapolsky 1972). "The Critical Path Method" was a wholly deterministic approach to the time problem. It employed a network of an endeavor's job tasks as alphabetized arrows representing individual work tasks connected to one another from project beginning to project end.

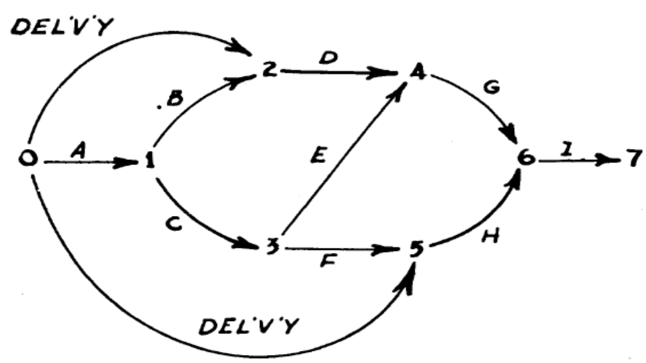

Figure 3. CPM's "Typical Project Diagram" (Kelley and Walker 1959).

Kelley and Walker described five CPM concepts: (1) Project Structure; (2) Calendar Limits on Activities; (3) the Project Cost Function; (4) Manpower Leveling; and (5) An Accounting Basis for Project Work. Concerning "Project Structure,", the first of these five fundamentals, they provided:

> Fundamental to the Critical-Path Method is the basic representation of a project. It is characteristic of all projects that all work must be performed in some well-defined order…(t)hese relations of order can be drawn graphically. Each job in the project is represented by an arrow…(t)he result is a topological representation of a project. (Figure 3) typifies the graphical form of a project.

Kelley and Walker then described their second concept, (2) “Calendar Limits on Activities,” which was summarized by assigning time durations to each task and performing network calculations to determine the critical path.

> In order to schedule a project, it is necessary to assign elapsed time durations to each job. Mathematical computations are then performed for each task producing an “Earliest start time,” an “Earliest Completion Time,” a “Latest Start Time” and a “Maximum Time Available” for each activity. Where “maximum time available for a job equals its duration the job is called critical. A delay in a critical job will cause a comparable delay in the project completion time…If a project does contain critical jobs, then it also contains at least one contiguous path of critical jobs through the project diagram from origin to terminus. Such a path is called a critical-path.”
> (Kelley and Walker 1959)

In defining a “Project Cost Function,” the authors asserted that the optimal duration of each job within the network would be driven not by the job itself, but the overall project schedule scenario that achieved the lowest total project cost. To account for the variable cost profile of each work task, Kelley et al. defined two separate cost scenarios for each job, a total cost associated with the duration of the job under proper, non-crash conditions (the “normal limit”), and a higher total cost associated with the shortest feasible duration for the job under the most aggressive crashing scenario (the “crash limit”). The term ‘crashing’ describes attempts to shorten the duration of an endeavor through the manipulation of resources within specific work tasks or jobs. Next, an approximation was devised to identify costs for the ‘job’ durations between these two scenarios employing a curve of simplified, convex shape, between the two points. Finally, a total project cost could be calculated under multiple schedule scenarios.

‘Manpower Leveling,’ Kelley and Walker’s fourth concept, identified two primary concerns. First, that the schedule may be impacted by the lack of available manpower and/or equipment; and second, ‘violent’ fluctuations in the manpower and equipment requirements dictated by a CPM schedule may prove impractical in most work settings where employers are seeking a uniformly sized workforce over the course of an endeavor. Noting that to date their considerations of manpower and equipment within their CPM studies had only been treated manually (“...thus far computer routines have not been prepared”), Kelley and Walker described an intensive process of examining manpower and equipment requirements first along the critical path, lengthening job durations where necessary, then along ‘non-critical’ paths, moving individual job start dates earlier or later where necessary to ensure that the desired manpower and equipment profiles are optimized (Kelley and Walker 1959).

Kelley and Walker’s fifth and final concept, “Cost Accounting,” briefly discussed cost accounting and financial requirements, allowing the user(s) to assign monetary amounts to each work task to realize “early” and “late” cash curves for the project. This capability provided what could be described as a cost control function, allowing for the identification of revenue and expense projections (Kelley and Walker 1959).

Like PERT, the Main Chain technique identified the longest duration path between project start and finish. Unlike PERT, which elicited three-time estimates before converting them to one, CPM started with a single time estimate for each work task or ‘job’. A further distinction between the two was that CPM assigned descriptive job titles to the arrows of its time network, and PERT did not. Instead, PERT assigned descriptive titles to the 'events' at each network node. In the PERT system, an inter-nodal arrow in fact, did not represent a 'job', only a time-period between two events. The different labeling method, largely unacknowledged in PERT-CPM comparisons, may be attributed to the different purposes for which each platform was developed: PERT to facilitate an owner's oversight of deliverables through the satisfaction of discernable performance criteria (i.e., monitoring 'unambiguous' and 'measurable' events), and CPM devised to facilitate a contractor's planning and execution of its work tasks or 'jobs' on a single construction project.

In its March 21, 1959 issue, Business Week, a weekly American business news magazine, featured an article on du Pont's CPM use in planning the Louisville plant shutdown (citing interviews with both Kelley and Walker). By April 9, 1959, nineteen days later, Morgan Walker, James Kelley, and John Mauchly each departed their respective employers to establish Mauchly Associates, a management consulting firm dedicated to the proliferation of the critical path method within the construction industry. The three would spend the next few months refining the CPM methodology and preparing their introductory paper, "Critical-Path Planning and Scheduling," for presentation at the Eastern Joint Computer Conference (EJCC) held at Boston's Statler Hotel in December 1959 (Kelley and Walker 1989). It was disqualified from the EJCC conference's 'best paper' competition for reasons that remain unclear (Kelley and Walker 1989).

The first formal publication of CPM appeared in the January 1961 edition of Operations Research. The subject matter of that paper, however, was limited to mathematics and referred the reader to the EJCC paper for a more detailed accounting of CPM's development timeline (Kelley 1961).

RESULTS

The results of this research effort are summarized under four principal observations.

PERT and CPM Both Relied Upon Existing Concepts

There are perhaps an innumerable set of works within the field of science, and more recently, within management science, that could be mentioned as influential predecessors to PERT and CPM. One stimulus for applying network based approaches to a host of professional fields was offered in the mid-1940s by Warren S. McCulloch's and Walter H. Pitts' 'neural network' model, wherein a human being's central nervous system was described using calculus and logic (McCulloch and Pitts 1943; McCulloch and Pitts 1948). "Later, neural networks were more broadly defined as architectures based on connections among a set of neuron-like models, and a variety of different architectures were proposed and studied" (Gass and Assad 2005).

Subsequently, Jon Von Neumann's application of McCulloch and Pitts concepts to the early computer systems in 1945 is significant, because the neural network became the basis for Von Neuman's design of a stored memory concept for the EDIVAC computer. Von Neumann's work, performed with at least some association with the University of Pennsylvania's Moore School during World War II, brought him in direct contact with John W. Mauchly, who would oversee the CPM research team at Sperry Rand in the late 1950s (Von Neumann 1945). The algorithms that formed the basis of the PERT and CPM computer programs may also be thought of as extensions of the 'Simplex Method', devised by George Dantzig in 1947 wherein optimal solutions to scenarios having multiple variables are sought through a coded algorithm (Dantzig 2002). Reference to Dantzig's work is indeed noted by James Kelley, who provided that scheduling problems could be "put as linear programs and handled by standard methods" (Kelley 1957).

Selmer Martin Johnson of the Rand Corporation ('Rand Corporation' and 'Sperry Rand Corporation' represent two separate corporate entities) is also significant to these discussions. Johnson's 1953 report "Optimal Two- and Three-Stage Production Schedules with Setup Times Included" described work scenarios wherein a manufactured product required the execution of multiple tasks under two separate "stages," or machines. Johnson sought the identification of "a simple decision rule for the optimal scheduling of the problem so that the total elapsed time (was) a minimum." His work appeared in the March 1954 issue of Naval Research Logistics Quarterly (Johnson 1954).

Charles Denhard Flagle, a Westinghouse engineer, turned graduate student at The Johns Hopkins University in Baltimore between 1950 and 1955, also made substantial contributions. There has been no mention of him, however, in mainstream PERT-CPM literature. While a graduate student, Flagle worked as a researcher within Johns Hopkins' Institute for Cooperative Research and its Operations Research Office. His 1954 paper titled "Probability Based Tolerances in Forecasting and Planning." Flagle offered a variation of the basic Gantt chart schedule (i.e., a bar chart), observing that individual bars (i.e., jobs) could be assigned several time estimates instead of one. The various time estimates for each task, further, could also be assigned a probability of occurrence. Combining the probability distribution from one multi-duration Gantt task with those from all others, a cumulative distribution function (CDF) could be constructed for the entire endeavor and the probability of the project's overall completion "on or before" a specific point in time could be measured. Flagle's conversion of a Gantt chart to a probabilistic model, if not his most fundamental observation: "the forecast of completion on any given day is generally of less interest in a schedule than completion on or before that day," (emphasis added) must be considered significant as these ideas form the basic PERT concept.

Flagle's work was formally established four years before these same ideas were employed within the U. S. Navy's PERT methodology. Yet Flagle's 1954 master's thesis has remained beyond the realm of mainstream discussion (Flagle 1954).

In his subsequent doctoral dissertation, Flagle would acknowledge Johns Hopkins faculty members Robert H. Roy, Acheson J. Duncan, Ellis Johnson, George Pettee, Paul Meier, Charles E. Clarke, James Mouzon, Paul Dunn, Phillip Hicks, and Sidney Davidson as key contributors to his research (Flagle 1955). in 1958, thirty months after his graduation, Professor Charles E. Clark, one of Flagle's supervising faculty members at Johns Hopkins would be acknowledged for his contributions as a principal member of the U. S. Navy PERT team.

> "...a major share of the credit must go to Dr. C. E. Clark, the mathematician, who initiated the network and three-time estimate concept, and who developed the PERT logic and mathematics. By the second week in February 1958, Clark

> presented the PERT team with his early notions on the subject. He drew a series of circles on the blackboard…and stated they represented the things that must be done to meet an end objective…drew connecting lines or arrows to represent their sequence and interdependency and the effort or work-in-process that must be performed between the circles. He also pointed out that the time required for each of these efforts was variable, with different degrees of uncertainty or margins of error. In addition, he was seeking a method for estimating the chances or probability for achieving each circled event in such a flow diagram…
>
> (Fazar 1962)

Another early contribution to network scheduling methods was the introduction of the concepts of 'precedence' and 'slack time' by Melvin E. Salveson, an engineer with the General Electric Corporation and Director of the University of California's Management Sciences Research Foundation. His work was presented at the annual conference of the American Society of Mechanical Engineers of 1954 in New York and subsequently, within the May-June 1955 edition of The Journal of Industrial Engineering. Salveson described a concept of "precedence" while establishing a time management model devoted to 'balancing' a manufacturer's assembly line.

Because of technical considerations, it is necessary and/or desirable to assemble the component parts of which the commodity is comprised in some specified sequence or

> set of sequences; that is, there is an ordering upon the sequence in time in which the parts may be assembled...now let us consider the effect of the precedence relations…(f)or this purpose, we develop the concept of a "precedence graph.
>
> (Salveson 1955)

Salveson's accompanying "Precedence Graph" is identical in appearance to PERT's 'System Flow Plan' and, in the very least, wholly consistent with CPM's 'Typical Project Diagram', both developed several years after Salveson's publication.

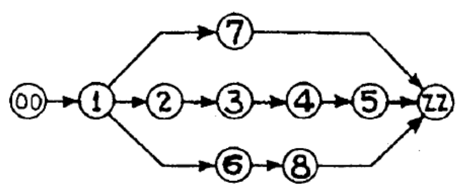

Figure 4. Precedence Relations in a Manufacturing Setting (Salveson 1955).

Salveson's paper also offers the first usage of the term "slack time" to refer to the additional time available for individual tasks that may be afforded a longer duration because they do not immediately affect the cycle time of the overall process. Later, the Navy POLARIS team employed this same term, defining slack "as a measure of the scheduling flexibility that is present in the flow plan" (U. S. Navy 1958a). The du Pont – Sperry Rand CPM team employed the term 'float' to describe the concept: "Jobs that aren't in the critical path have some leeway, or 'float,' between the earliest and latest times for starting and finishing" (Astrachan 1959).

Salveson's concepts of 'precedence' and 'slack', his recognition that some network tasks affect the overall duration of an endeavor (and some do not), his distinctive circle and arrow representation of the time problem and broader study of time optimization in a work setting were subsequently embodied, if not replicated, within both PERT and CPM. The venues where Salveson presented his research, further, are fairly considered as mainstream discussions subject to peer review, allowing for a conclusion that his work was formally offered to the management science community no later than 1955. Donald Malcolm of Booz Allen Hamilton, technical director and first author of the U. S. Navy's PERT methodology, likely witnessed Salveson's concepts while President of the American Institute of Industrial Engineers from 1954-55. The Journal of Industrial Engineering, AIIE's principal publication, published Salveson's article during Malcolm's presidency (Massey 1963).

Considering the earlier works of Johnson, Flagle and Salveson, the connections to PERT researchers Charles Clark and Donald Malcolm and the wide dissemination of Johnson and Salveson's works as early as the summer of 1955, it is perhaps reasonable to consider PERT and CPM more as first of type computer applications of existing models than as original theory or concept.

PERT and CPM Maintain Dead Ring Similarities

Both PERT and CPM employed a network arrangement of individual work tasks and/or events constructed for the same purpose: to identify a single, 'critical path' controlling overall duration and achieving an optimal solution. Where one considers a distinction between PERT's focus on program 'events' and CPM's focus on contractor 'jobs' or 'tasks' as trivial, a further resemblance is realized; that both utilize the same network diagram composed of circular nodes having zero time value and connective arrows representing the intervening work periods. Further study of the U. S. Navy's methodology reveals that PERT's three-time estimates for the interval between each node were in fact, converted to one-time estimate and then, just as with CPM, solved as a network of single time estimates. This point compromises a popular notion that PERT was thoroughly probabilistic and therefore fundamentally different from CPM's deterministic approach. It was not. Once PERT's three-time estimates across each interval were converted to one 'expected time', the two solutions were indistinguishable from one another. Prior suggestions that it is also feasible to draw distinctions between PERT and CPM with regard to the purposes for which each methodology was developed: (1) programs versus projects; (2) monitoring versus oversight vs. planning versus execution; (3) construction projects versus research and development (Kelley 1961). Considering the identical network topologies and terminology, it is difficult to consider these points as valid theoretical distinctions between the two applications.

It also is notable that both developmental teams considered the same variables within their studies. Discussion of the CPM team's treatment of time, cost, and resources (in the forms of manpower and equipment) has been provided previously. The PERT team noted these same variables (Malcolm et al. 1959).

The status of a developmental program at any given time is a function of several variables. These variables are essentially of three kinds: *Resources*, in the form of dollars, or what 'dollars' represent – manpower, materials, and methods of production; *technical performance* of systems, subsystems, and components; and *time*.

Integrating these three variables might provide an optimum solution.

Ideally, we should like to evaluate a given actual schedule in terms of all three variables. In this way it would be possible to arrive at an 'optimum' schedule that would properly balance resources, performance, and time. The existence and determination of such an optimum requires that some criterion be analytically maximized or minimized. To do this it is necessary to establish a criterion that integrates time, resources, and performance into meaningful utility.

Malcolm et al. stated that the identification of such an integrated utility function went beyond the PERT study and that "an approach dealing only with the time variable was selected." Recognizing that both PERT and CPM discuss the same variables before both devising computerized routines focused on the time variable, substantive distinctions in this area appear dubious.

With the exception of two PERT elements not found within the original CPM platform, specifically: (1) the provision of a statement of probability as to the likelihood of overall completion 'on or before' a certain point in time; and (2) the accounting for the subjective, and possibly biased, judgments of otherwise 'competent engineers'; it is reasonable to consider PERT and CPM as indiscernible from one another.

Both Research Teams Were in Close Proximity

Sperry Rand's responsibilities on the U. S. Navy's POLARIS missile program were significant. Beyond serving as a member of Admiral Raborn's Steering Task Group, a position that would have made them privy to any time management methodology developed or employed within the POLARIS program. Within the POLARIS program, Sperry Rand was responsible for establishing the gyroscopic compass and supporting navigations systems for both missile and submarine. So prominent was Sperry Rand's role that Admiral Raborn constructed the program's dry land 'mock-up' of the ballistic missile submarine at Sperry Rand's plant in Syosset, New York (Baldwin 1959). Also of note are the significant positions within the POLARIS program held by General Electric, Westinghouse and the Johns Hopkins University's Applied Physics Lab, each with at least remote connections to Melvin Salveson (General Electric) and Charles Flagle (Westinghouse and Johns Hopkins).

While other elements of his company worked on POLARIS, Sperry Rand's James Kelley performed his CPM research for du Pont directly across the hall from fellow employee Grace Murray Hopper in the company's Philadelphia office (Kelley and Walker 1989). Grace Hopper, then a Vice President at Sperry Rand, served as an officer in the U. S. Naval Reserve during this period. Her Naval Reservist duties included oversight of the Navy's Naval Ordnance Research Computer at Dahlgren Proving Ground, which was used by the Special Projects Office for the PERT calculations (Malcolm et al. 1959). Before returning to active duty naval service in the 1970s, Hopper had established herself as one of the pioneers of the computer era, responsible for the creation of COBOL (Common Business Oriented Language), devised as the first common computer language. Notwithstanding her immediate proximity to the CPM researchers at Sperry Rand, her extent of communication with them remains unknown. Biographer Kurt Beyer coined the concept of "distributed invention" as a deliberate Hopper methodology employed throughout her career (Beyer 2009).

> Hopper's dynamic representation of her invention is matched by an evolving approach to innovation, which I refer to as *distributed invention.* This term describes Hopper's unique style of program development, wherein prototypes were farmed out to an ever-widening circle of programmers and users. This growing network of invention crossed organizational boundaries and provided Hopper with a variety of feedback that she then incorporated into more advanced prototypes.

Beyer's theory suggests that it may be impossible to define a bright-line separation between CPM research and PERT research and that credit might also be shared with other Sperry Rand employees who will probably remain unknown.

John W. Mauchly, the Sperry Rand supervisor to both Kelley and Hopper at this time, factors in to these discussions as does the fact that the Kelley-Hopper relationship extends back to at least 1955, when Kelley, a graduate student at American University, contributed to a Hopper research project at the Office of Naval Research and used the work as the basis of his master's thesis. Of note is that POLARIS schedules material may be found amongst Kelley's working papers, which likely confirm his involvement in the development of PERT.

PERT and CPM Development Was Synchronous

Despite the commonly accepted notion of the separate and independent development of CPM and PERT, the synchronicity of their development timelines provides pause. Both research efforts began in December 1956. The same month that the POLARIS program was authorized by Secretary of Defense Charles Wilson and du Pont's Morgan Walker (du Pont) contacted John Mauchly (Sperry Rand) to explore solutions to "the construction scheduling problem."

In January 1957, Admiral Raborn appointed Sperry Rand as a member of the POLARIS Steering Task Group (STG), and James Kelley (Sperry Rand) began his research on behalf of du Pont's Morgan Walker (Kelley and Walker 1989). The PERT team formally convened in late January 1958, established PERT the following month, and codified it in a final report to Admiral Raborn by May 1958. During this same timeframe, the du Pont-Sperry Rand team reported that it had prepared an analysis of du Pont's Repauno project (February 1958) and then presented these results to du Pont Director Granville Read (May 1958). Subsequent to the Navy's July 1958 release, the Sperry Rand team analyzed a future shutdown at du Pont's Louisville plant, described by Kelley as the first application of the critical path method (Kelley and Walker 1989).

Business Week reporter Tony Astrachan has been credited with alerting the U. S. Navy to the existence of du Pont-Sperry Rand's parallel effort. When the basic PERT concepts were demonstrated to the reporter by SPO's Willard Fazar in late 1958, Astrachan remarked, "Well gee, that's just like what they are doing at du Pont." Astrachan already visited du Pont and had seen Kelley and Walker's CPM system. Expressing surprise, Fazar invited du Pont's CPM team members to the Special Projects Office to "compare notes" (Fazar 1962). The first visit between the two teams occurred on April 2, 1959, less than two weeks after Business Week's publication of its article. Three members of du Pont -- Morgan Walker, George Fisher, and John Sayer – traveled to Washington to meet with the Navy's Gordon Pehrson and Willard Fazar (Kelly and Walker 1989). To insulate the POLARIS program from the appearance of a leak from a classified nuclear weapons program, no representatives of the Sperry Rand Corporation were in attendance. From this meeting SPO's Willard Fazar would state:

> There was no communication, collusion, or knowledge between the boys who were working at du Pont on a system for production and us who were working on a system for controlling R&D projects. There was no communication. I honestly believe they were using the networking approach concurrently with our using the system.
>
> (Massey 1963)

Fazar's remarks were made in a 1963 interview with American University graduate student Robert Massey. Kelley would corroborate Fazar's remark in 1989, expressing his belief that PERT was "cut from whole cloth" and did not rely upon the work of the du Pont – Sperry Rand research team (Kelley and Walker 1989). But Kelley and Walker did not address whether the same "whole cloth" remark could be applied to CPM.

While there is no evidence to contradict SPO's statement that PERT was not influenced by the CPM researchers, the same cannot be said for CPM's development. What is known is that The U. S. Navy Special Projects Office was extremely concerned over Sperry-Rand CPM's appearance in the mainstream media and, on April 9, 1959, no less than one week after du Pont's met with the SPO, Sperry Rand canceled Mauchly's entire research program and he, James Kelley and du Pont's Morgan Walker resigned or were terminated (Kelley and Walker 1989). No explanation of Sperry Rand's absence from the April 2nd meeting with the SPO is yet available.

It is indeed possible that Willard Fazar and other members of the Special Projects Office noticed a possible transfer of information to the CPM team through either Sperry Rand's participation in Admiral Raborn's Steering Task Group, Sperry-Rand's work on the POLARIS gyroscopic navigation systems, or by way of U. S. Navy Commander Grace Hopper. Hopper served simultaneously as a U. S. Naval Reservist and as a Sperry Rand executive with John W. Mauchly and James Kelley. Her naval duties included overseeing the operation of the NORC computer, which ran the PERT calculations. Fazar's choice of words during the Massey interview – "the boys who were working at du Pont" (emphasis added) – were devised to accommodate the likely back-channel communications involving the female Hopper and her Sperry Rand colleagues. SPO's concern over the CPM development appears obvious, however, as the Special Projects Office produced a PERT publishing blitz following the release of the Business Week article describing Sperry-Rand's CPM. (Fazar 1959a); (Fazar 1959b); (Hamlin 1959); (Malcolm et al. 1959).

CONCLUSION

This research supports four notions: (1) that rather than new concepts, PERT and CPM are perhaps best described as the first computerized applications of pre-existing operations research. An innumerable set of contributors in this work include Warren McCullough, Walter Pitts, John

Von Neumann, George Dantzig, Selmer Johnson, Charles Flagle and Melvin Salveson. Notably, pre-1955 contributions by Charles Flagle and Melvin Salveson represent prominent features of PERT and CPM; (2) PERT and CPM share key concepts, characteristics and terminologies and that dead ring resemblances between the two suggest commonly held distinctions between their original uses have limited meaning since the two network topologies are identical; (3) that PERT and CPM maintained synchronous development timelines and (4) that dead ring similarities between the two techniques may be explained, at least in part, by the previously undisclosed proximities between the two development teams by way of Sperry Rand being directly involved in both PERT and CPM efforts, and the personal relationships between individual team members from both programs.

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Role of Infrastructure in the Success of Residential Developments in Michigan

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ABSTRACT

Infrastructure systems are critical for the success of a residential development. These systems include the infrastructure within and around the development as well as facilities and amenities in the surrounding area. Most of the residential development literature tend to focus on the planning, layout, social aspects, and the residential units itself, but lack emphasis on the infrastructure systems.

This paper identified supporting infrastructure for residential developments based on the review of research and industry literature, and several case studies nationwide. The availability and absence of infrastructure systems were investigated in each case study. The review led to the identification of 13 major categories of infrastructure systems and 40 subsystems. The success of a residential development was defined in the context of a success criteria developed by the researchers.

These infrastructure systems and subsystems were then prioritized based on their importance for the development as viewed by the developers and the municipal officials in the context of the success criteria. In addition, their preferred distances from the development was determined. Detailed interviews were held with six developers and five municipal officials in Michigan. Since the data collected by interviews was qualitative in nature, an analysis method known as the ELECTRE III method was used as it is a multi-criteria analysis method that effectively helps in prioritization or optimized ranking of alternatives.

The results reflect that the top five infrastructure categories were: Education, Utilities, Employment, Digital and Transportation Infrastructure. All infrastructures are preferred within the distance of 2 to 7 miles. The authors believe that this analysis will be valuable in guiding the developers and the municipal officials in prioritizing the infrastructure for a successful residential development, especially in situations with budget limitations.

KEYWORDS: Infastructure Systems, Infrastructure Subsystems, Residential Development, Developers, Municipal Officials

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INTRODUCTION

Infrastructure is an essential component of a residential development. Infrastructure can be explained as the facilities, structures, amenities, equipment and similar physical assets; that are important for people to thrive as individuals and participate in the economic, political, civic, household, and other roles in ways critical to their own well-being and that of their society. (Beeferman & Wain, 2016). Developing a residential neighborhood is a long-term investment for any community. A well-functioning infrastructure necessary to serve the proposed development is essential for the growth of a new community (Beauregard Small Area Plan 2012).

The demand for housing is experiencing a growth in both urban and suburban areas since the great recession of 2007-09. Suburbs refer to primarily low-density residential areas, located within metropolitan areas (not rural), but outside the central cities (not core). The key features distinguishing a suburb are presence of substantial open space and scattered employment (Forsyth, 2013). The decentralization of job centers to the suburbs, the availability of automobiles combined with expressways, and the quest for single-family homes have attracted individuals to outlying areas for housing. These forces have resulted in the development of what previously used to be classified as agricultural and rural areas. This points to the need for more infrastructure to support the residential developments in suburban areas (Suen 2005).

In addition to growing housing demand, urban neighborhoods are presently encountering a dramatic transition, with condominiums, townhouses and apartments, supplanting parking lots, industrial sites, and underutilized commercial areas. As indicated by US Census, residential building permit data for 209 metropolitan areas analyzed over a 5-year period (2005 to 2009) shows a noteworthy increment in the share of new residential construction built in focal urban areas and older suburbs. Infill residential construction exceeded 50% of the total construction only in four metropolitan regions, whereas 205 of the total 209 regions studied had more residential developments on greenfield sites. Even with current strong economic fundamentals, several large-scale development projects require optimization in infrastructure investments to move forward (US-EPA 2010).

This paper begins with a brief overview of the literature reviewed and several case studies that were investigated. It then identifies 13 infrastructure categories for residential developments based on the review of research and industry literature, and the case studies. Each system is further divided into subsystems leading to a total of 40 infrastructure subsystems. The success of a residential development is defined in the context of a success criteria developed by the researchers based on the literature review and the case studies analysis. Using this success criteria, developers and municipal officials in Michigan were interviewed and were asked to prioritize the infrastructure systems and subsystems for the success of a development. In addition, the preferred distances of key infrastructure amenities from the development were determined.

INFRASTRUCTURE SYSTEMS FOR RESIDENTIAL DEVELOPMENTS

Infrastructure systems are critical for the success of a residential development. These systems include the infrastructure within and around the development as well as facilities and amenities in the surrounding area. Most of the residential development literature tend to focus on the planning, layout, social aspects, and the residential units itself, but lack emphasis on the infrastructure systems. Adequate infrastructure and services serve as a backbone for growth and are essential for community health, safety, and quality of life (Humboldt County General Plan 2007). Research has demonstrated that the availability of goods and services within neighborhoods enable residents to better participate in the society. This contributes to economic and social sustainability locally (Yigitcanlar et al. 2015). The benefits of infrastructure can be summarized as: enhanced quality of life, improved safety of residents, improved health and aesthetics, reduced household expenditures, creation of new employment opportunities, and enhanced neighborhood vitality (Chakraborty 2020).

In addition to the research and industry literature, review of single-family, multi-family and mixed-use residential developments across the United States assisted this study in defining key infrastructure systems for successful residential developments. The availability and absence of infrastructure systems in the case studies were investigated. Table 1 lists the name, location, and type of the development. The determination of the success of these case studies is based on the analysis done by the Urban Land Institute between 2006 and 2010 (ULI 2006; ULI 2007; ULI, 2008; ULI 2010).

Another important aspect of the background work was the review of market analysis literature. When developers initially consider a site for development, they usually begin with gaining a sense of general market conditions including preferences of potential customers. As entrepreneurs, they keep themselves updated with the current trends, observing current and past developments, and searching for new niches to fill in the market. They would generally seek the following information from the market analysis (Novak 1996):

- Employment trends in the market area.
- Population growth rate in the market area.
- Best configuration and size of units for the proposed development.
- Number of units that the market can absorb, the price for those units and the length of time required for development.
- Percent of market demand expected by the project to capture.
- Strategy for the units be marketed to the target customers.
- Operating revenue or income expected to be generated by the project over a certain time.
- Regulatory controls placed on type of development.
- Position of communities on the potential development in the proposed location.

Table 1: List of Case Studies of Successful and Unsuccessful Developments

(Based on the availability and quality of infrastructure)

No.	Name of the Development	Location	Type of the Development
Successful Developments			
1	Maple Grove at College Fields	Okemos, Michigan	Single-family
2	Wild Sage Cohousing	Boulder, Colorado	Single-family
3	Wild Meadows	Medina, Minnesota	Single-family
4	Prairie Trail	Ankeny, Iowa	Single-family
5	Bailey's Grove	Kentwood, Michigan	Single-family
6	Aurora Square	Anchorage, Alaska	Multi-family
7	Burbank Senior Artists' Colony	Burbank, California	Multi-family
8	Chestnut Commons	Austin, Texas	Single/Multi-family
9	Eco Village	Loudoun County, Virginia	Single/Multi-family
10	The Benton	Alameda County, California	Mixed-use
11	Mill Creek	Kane County, Illinois	Mixed-use
12	Prairie Crossing	Grayslake, Illinois	Mixed-use
13	Stonebridge	St. Helena, California	Mixed-use
14	Curran House	San Francisco, California	Mixed-use
15	Cotati Cohousing	California	Mixed-use
Not So Successful Developments			
16	Garden Green	Boise, Idaho	Single-family
17	Oak view	Marine County, California	Single-family
18	Philippi Park Condominiums	Boise, Idaho	Multi-family
19	Oak Park Village/Brampton Square	Boise, Idaho	Single/Multi-family
20	Fountain Grove	Santa Rosa, California	Single/Multi-family

Another important aspect of the background work was the review of market analysis literature. When developers initially consider a site for development, they usually begin with gaining a sense of general market conditions including preferences of potential customers. As entrepreneurs, they keep themselves updated with the current trends, observing current and past developments, and searching for new niches to fill in the market. They would generally seek the following information from the market analysis (Novak 1996):

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required for development.

- Percent of market demand expected by the project to capture.
- Strategy for the units be marketed to the target customers.
- Operating revenue or income expected to be generated by the project over a certain time.
- Regulatory controls placed on type of development.
- Position of communities on the potential development in the proposed location.

The construction of effective infrastructure has long been an impetus for advancing and supporting economic development. Developers, businesses, and potential customers are attracted by adequate "on the ground" infrastructure. This implies ample water, electricity, transportation, communication resources and other supporting civil infrastructure (Colorado 2016). Another broad category of infrastructure is "inbuilt infrastructure", that is a part of residential development, such as waste management, utility lines etc.

Based on the review of the above-mentioned literature and case studies, 13 infrastructure categories were identified as key infrastructure that is necessary for the success of a residential development. Each infrastructure category was further divided into its constituent sub-categories or infrastructure systems leading to a total of 40 subcategories (ASCE 2017; Beauregard Small Area Plan 2012; Beeferman & Wain 2016; Buckman et al. 2017; Chakraborty 2020; Colorado 2016; Humboldt County General Plan 2007; Novak 1996; Robinson & Robinson 1985; Suen 2005; ULI 2006; ULI 2007; ULI 2008; ULI 2010; Yigitcanlar et al. 2015). The proposed 13 infrastructure categories and 40 subcategories are provided in Table 2.

STAKEHOLDERS AND ASSOCIATED PARAMETERS OF SUCCESS

The two main stakeholders involved in the process of development in addition to the end users are the developers and the municipal officials. Each stakeholder will consider a development to be successful based on varied parameters, depending on their perspectives. For example, developers are generally driven by monetary goals and profits; whereas municipal officials generally focus on the zoning fit and the potential tax revenue. It is important for developers to understand as to what draws in potential customers to locate and remain in a new development. Potential customers are generally attracted to a residential development by the pricing versus the housing preferences and the infrastructure and amenities, in the development itself and in the neighborhood (Buckman et al. 2017; Robinson & Robinson 1985).

Developers display entrepreneurial characteristics, reflecting a behavior of profit-seeking, risk-taking and innovativeness. For a typical private organization, development involves substantial investments of time and money without a guaranteed return. The entire process requires the developer to consider availability of land, zoning, policy regulations, occupant preferences, land characteristics and monetary risks. No developer will want to lose money after going through this tedious process (Novak 1996; Shaw 2003, Maruani and Amit-Cohen 2011).

Table 2: Infrastructure Systems Needed to Support a Residential Development

1	**Transportation Infrastructure**	Local Road Network
		Footpaths & Cycle ways
		Public Transport
		Community Transport
		Parking
2	**Waste Management**	Waste Collection
		Recycling
3	**Utilities**	Water Supply
		Wastewater Management
		Electricity Network
		Gas Network
		Telecommunications
4	**Renewable Energy:** **a) Unit level** **b) Community level**	Solar Energy
		Wind Energy
		Others: Biofuels, Geothermal, etc.
5	**Education**	Early Years Education
		Primary Education
		Secondary Education
		Colleges
6	**Community Infrastructure**	Community Centers
		Libraries
		Sports Facilities
		Pools
7	**Social Infrastructure**	Children's Day Care
		Religious spaces
8	**Emergency Services/ Safety**	Police Service
		Ambulance Service
		Fire & Rescue Service
		Street lighting
9	**Health**	Primary Health Care
		Hospitals
		Senior Citizens' Care
10	**Green Infrastructure**	Open Space
		Arboretum/Biodiversity
11	**Digital Infrastructure**	Internet Access
		Cable Access
12	**Retail**	Restaurants
		Banks
		Grocery stores
13	**Employment Infrastructure**	Local Employers
		Office Spaces

Municipal officials also look at broadly similar aspects to measure success of a development but from different angles. For example, both sides consider profitability as a criterion for success where developers look at sales and profits and municipal officials look at zoning fit and tax revenue. Often, municipal officials will also look at secondary benefits such as infrastructure enhancements and increased tax returns from business district spurred by the proposed residential development as well as addition to local schools' enrollment.

Having developed a detailed understanding of the development process and the stakeholders, researchers worked on defining parameters that can be used to assess success of a residential development by the developers and the municipal officials. The plan was to interview developers and municipal officials about their ranking or prioritization of the infrastructure systems towards the success of a residential development in the context of this success criteria. Based on the literature related to developed success parameters (Chou et al. 2003; Adriannnse 2007; Novak 1996; Maruani & Amit-Cohen 2011; Wei et. al. 2012) and understanding from the development literature and case studies, the proposed success criteria are shown in Figures 1 and 2 for developers and municipal officials, respectively. Both these criteria are based on four major elements - Organization Success, Profitability, Project Success, and Branding; and associated parameters.

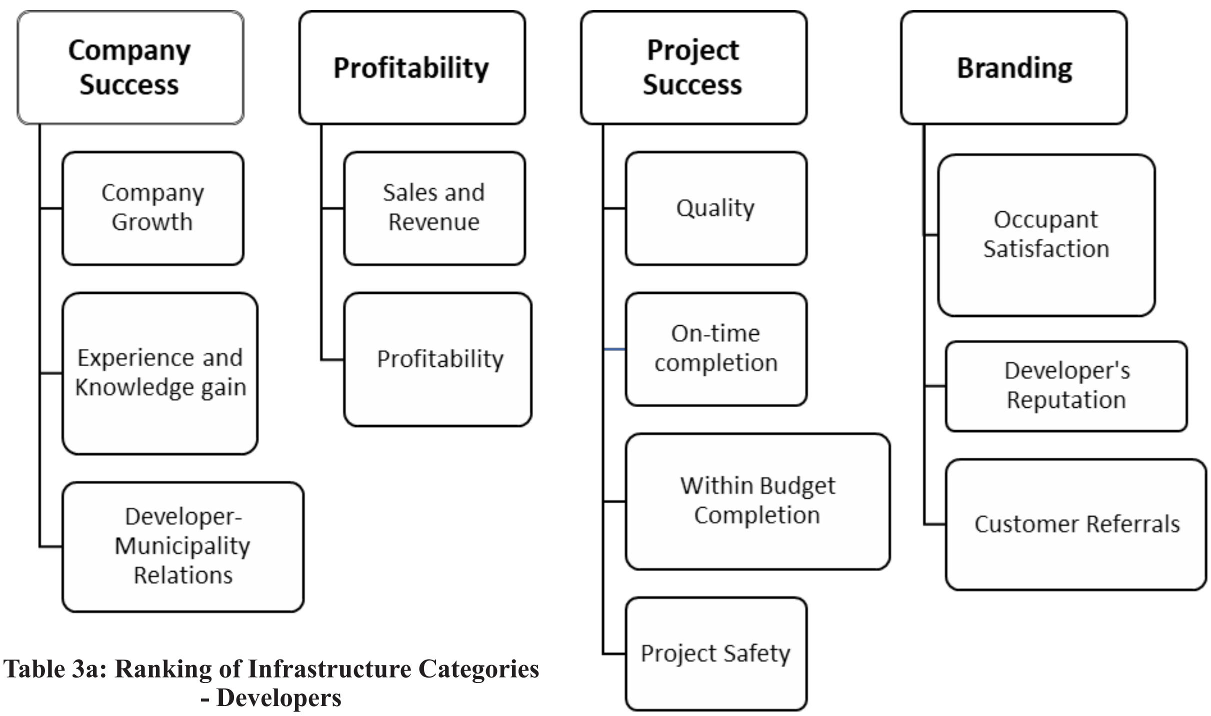

Table 3a: Ranking of Infrastructure Categories - Developers

Figure 1: Project Success Criteria from Developers' Perspective

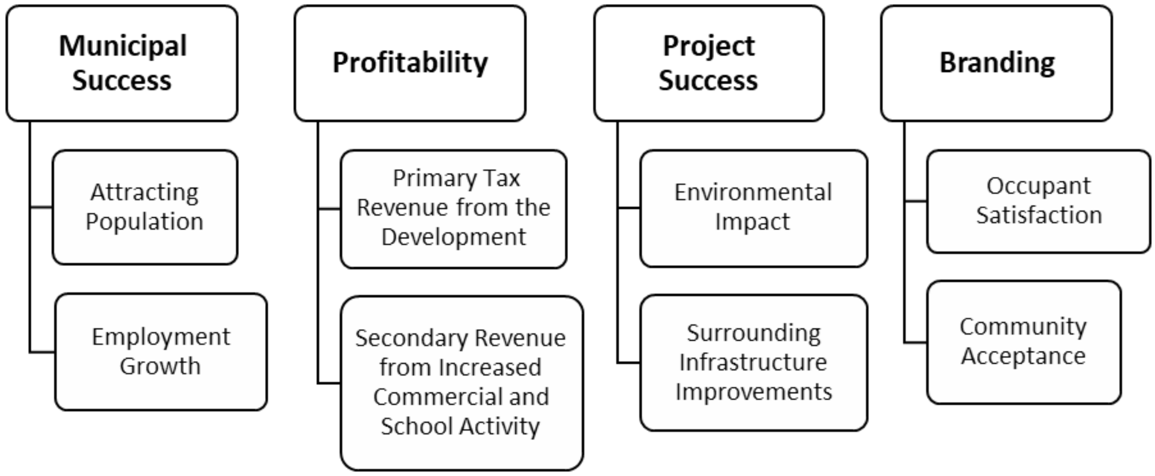

Figure 2: Project Success Criteria from Municipal Officials' Perspective

In addition to the availability of infrastructure systems, the market analysis literature emphasizes the proximity and accessibility of these systems. Literature suggests that a large number of potential residents select a development based on its access to different amenities such as restaurants, retail spaces, print centers, gym facilities, etc. Residents also care about the proximity to interstate highways, distance to employment sources and availability of schools in the neighborhood. Therefore, not only availability, but also an appropriate distance is required for the infrastructure to contribute positively to a residential development (Smersh et. al 2003; Romkaew 2011; Allen 2015; Novak 1996).

DATA COLLECTION AND ANALYSIS

A structured interview process was used to find the overall and relative importance of infrastructure categories in the success of a residential development. The data collection was focused on the developers and the municipal officials but both groups were asked to keep in mind the future residents' perspective also when answering the interview questions.

Residential developers can be either part of a private or non-profit organization but for this study, private developers were contacted. Municipal officials included either city council members, county commissioners, planning board members or other similar elected officials. Due to the qualitative nature of the information needed, it was determined that in-person interviews were needed to explain the questions to the experts. Ten local developers and nine city officials from Michigan were contacted and out of those contacted, the researchers were able to successfully interview with six developers and five municipal officials. Five of the six developers interviewed had extensive experience in single-family, multi-family and mixed-use residential developments in Michigan and the sixth developer has done multiple projects in Michigan as well as North Carolina, South Carolina, Texas, Ohio, and Florida. Four out of five city officials interviewed had more than 10 years of experience each. Similar questionnaires with some customization were used with both groups. The overall structure of the questionnaires was very similar, except the variation in the criteria of success for a developer and a municipal official, as shown in Figures 1 and 2. A scale of 0-10 was used for infrastructure systems rankings, with 0 being extremely unimportant, 5 being neutral, and 10 being extremely important. The questionnaire was divided into four sections:

Section1: Background of the Developers/ Municipal Officials

Section 2: Comments on Proposed Infrastructure Categories and Subcategories

Section 3: a. Prioritization of sub-categories

b. Prioritization of broad categories

c. Acceptable Infrastructure Distance (miles)

Section 4: Other comments

This research requires the understanding the role of infrastructure systems on the success of a residential development. The researchers explored various data analysis methods, starting from quantitative statistical techniques to qualitative methods, in order to find the most appropriate approach which will yield accurate outcomes. Quantitative statistical methods including Multivariate Linear regression and T-Test method were discarded as this research involves limited set of data whereas a parametric data analysis method yields best results only with a larger sample size. Considering the limitation of inadequate sample size, the researchers focused on qualitative methods.

The easiest way was to ask the interviews to rank order the list of infrastructure categories and the final ranks can be calculated as an average of the ranks given by all 11 interviewees. However, this aggregating value provided a comparison of all options together rather than reflecting the preferences between any two categories. Moreover, the role of the four different success criteria on the infrastructure would not be clear through the ranks provided by the interviewees. The researchers suspected profound data loss as the interviewees would try to assess a final rank assimilating all the success criteria to impact their decisions. Therefore, researchers decided to search further.

Another very popular ranking method is Analytical Hierarchy Process (AHP), developed by Saaty (1980), which helps in the analysis of qualitative data. It utilizes a hierarchical framework to characterize a decision-making problem, compares the decision elements using the pairwise method, and computes the relative weights of the decision elements. AHP can be an acceptable option as it builds in the preference by comparing two categories at a time, however the condition of analyzing the impact of all success criteria remained unfulfilled. The only way to introduce the success criteria, was to have the interviewees record their decisions separately for each criterion. The process would have been extremely laborious and cumbersome.

A further search into qualitative methods, brought into focus, the ELECTRE, which is a multi-criteria decision analysis method that helps in prioritization of alternatives. This method eliminated all the shortcomings as discussed for the previous options. ELECTRE III, which is an improved version of ELECTRE to incorporate the fuzzy (imprecise and uncertain) nature of decision making, by using thresholds of indifference and preference. The underlying principle for outranking in ELECTRE III is the preference of a decision-maker for a given set of alternatives.

An alternative 'a' is said to outrank an alternative 'b', if the decision-maker's preference supports the conclusion that 'a' is at least as good as or better than 'b'. ELECTRE III is fundamentally non-compensatory, meaning, a very bad score on a criterion cannot be compensated by good scores on other criteria. ELECTRE III models also allow for incomparability, which occurs between any alternatives 'a' and 'b' when there is no clear evidence in favor of either 'a' or 'b.' The procedure is also built with less effort and can be easily clarified to the interviewees. Therefore, ELECTRE III is utilized for analyzing the ranked order for infrastructure in terms of their impact on success of a residential development project method (Buchanan et al. 1999; Velasquez & Hester 2013).

RESULTS

Three different sets of results were obtained for the ranking of the infrastructure categories, the sub-categories, and the acceptable infrastructure distances. Results were compiled separately from the perspective of the developers, the municipal officials, followed by combined results. These results are presented in the sections below.

Ranking of Infrastructure System Categories

The ranking of the broad categories of infrastructure obtained through data analysis in ELECTRE III considering the opinions of the developers and the municipal officials respectively are shown in Tables 3a and 3b, and Table 3c shows the combined rankings.

> The categories occupying ranks 1-5 for both the developers and the municipal officials are almost similar. When these results are viewed individually to consider the perspectives of the developers and the municipal officials, some differences are observed. For developers, the topmost rank is filled by Employment Infrastructure as compared to rank 6 for the municipal officials. This indicates that the most important infrastructure that the developers will aim to provide is Employment Infrastructure. According to the developers, the presence of jobs and the potential to attract new employers are primary driver of success in a residential development. The developers are also found to value Community Infrastructure more (Rank 5) as compared to the municipal officials (Rank 9). Education (rank 3 and 1) are very high for both groups as the presence of high-rated schools are a major contributor to the success of the development by being able to attract families with children.
>
> The combined ranking of infrastructure categories, as provided in Table 3c, shows Education Infrastructure with the highest ranking, followed by Utilities at Rank 2 and Employment at rank 3. Positions 4, 5 and 6 were attained by Digital Infrastructure, Transportation Infrastructure and Waste Management, respectively. These ranks indicate the combined preference of the developers and the municipal officials regarding infrastructure provisions in a development. Since these results are based on expert opinions who know their market well, these ranks can be considered a reflection of the infrastructure needs currently prominent in a residential development. Education Infrastructure at rank 1 implies that the availability of education infrastructure attracts potential residents, and the developers give prime importance to a site located within a good school district. Second, Employment infrastructure, ranked 3, has gained popularity and this can be interpreted in several ways.

Residents prefer a house located close to or well connected with the industrial hubs and office sectors in a city. Alternatively, a mixed-use set up attracts people who prefer to have an office set-up/ workplace and residence to be in the same community. Since the people today heavily rely on internet access and cable access for working and staying connected, Digital Infrastructure (ranked 4) has become as basic a requirement as Utility Infrastructure (ranked 2), i.e., gas and electric lines.

Table 3b: Ranking of Infrastructure Categories - Municipal Officials

RANK	INFRASTRUCTURE CATEGORY
1	Employment Infrastructure
2	Digital Infrastructure
3	Education
4	Utilities
5	Community Infrastructure
6	Transportation
7(tie)	Social Infrastructure
7(tie)	Emergency Services
9	Health
10	Green Infrastructure
11	Waste Management
12	Retail
13	Renewable Energy

RANK	INFRASTRUCTURE CATEGORY
1(tie)	Education
1(tie)	Utilities
3	Waste Management
4	Transportation
5	Digital Infrastructure
6	Employment Infrastructure
7	Health
8	Retail
9(tie)	Green Infrastructure
9(tie)	Emergency Services
9(tie)	Renewable Energy
9(tie)	Community Infrastructure
13	Social Infrastructure

Table 3c: Combined Ranking of Infrastructure Categories

RANK	INFRASTRUCTURE CATEGORY
1	Education
2	Utilities
3	Employment Infrastructure
4	Digital Infrastructure
5	Transportation
6	Waste Management
7	Community Infrastructure
8	Health
9	Emergency Services
10	Social Infrastructure
11	Green Infrastructure
12	Retail
13	Renewable Energy

The last three positions 11, 12 and 13 were obtained by Green Infrastructure, Retail, and Renewable Energy respectively, meaning that this type of infrastructure comparatively holds less importance in a development. It can be inferred that the availability of green space, banks, restaurants, grocery stores and social/religious spaces is not of prime importance but can be an added advantage to a development. According to the results, Renewable Energy Infrastructure is yet to become a desirable feature in residential developments.

Ranking of Sub-categories

The ranking of the sub-categories shows a similar trend as observed from the ranking of broad infrastructure categories. Tables 4a and 4b show the results from a developer's and municipal official's perspective, respectively and Table 4c shows the combined ranking of the sub-categories.

Subcategories related to Utilities, Education and Digital Infrastructure are favored by both groups. A prominent difference in the views of the developers and the municipal officials shows the inclination of the municipal officials towards Transportation Infrastructure. Two of the top ten ranks of sub-categories in municipal officials' list in Table 4b are occupied by Local Road Network (no. 3) and Footpaths and Cycle ways (no. 9). These sub-categories are at ranks 12 and 22 in the developers' list in Table 4a. With the combined score, these two subcategories are at 7 and 13 as shown in Table 4c.

The final rankings of the sub-categories are shown in Table 4c. The sub-categories at the top 10 ranks all belong to the broad categories of Utilities, Education Infrastructure and Digital Infrastructure. Internet Access, which is a part of Digital Infrastructure, obtained Rank 2 vs Cable Access at Rank 12, which suggests that Internet Access is given more value than cable access in recent times. Some of the higher ranked amenities are Education infrastructure except colleges, Water Supply, Electricity and Gas network, Wastewater Management and Telecommunications. Local Road Network at Rank 7 indicates that the availability of well-connected roads is valued in a development. The ranks at the bottom are achieved by Community Center, Senior Citizens Facilities, Arboretum, and Renewable Energy.

Acceptable Infrastructure Distance (in miles)

The questionnaire for finding the acceptable distance consisted of only seven of the thirteen broad categories of infrastructure in which distance can be clearly measured. These categories include: Transportation, Education, Community, Social, Emergency Services, Health and Retail. The other six categories not included in this list are: Utilities, Digital Infrastructure, Waste Management, Green Infrastructure, Renewable Energy and Employment Infrastructure. The data collected through the interviews resulted in the distance for available infrastructure acceptable to the developers, the municipal officials, and a combined preferred distance. These values are shown in the Tables 5a, 5b and 5c respectively.

Table 4a: Ranking of Sub-categories - Developers

RANK	SUBCATEGORY
1(tie)	Primary Education **
1(tie)	Internet Access
3	Employment potential
4	Secondary Education **
5	Water Supply
6	Early Years Education
7	Wastewater Management
8	Cable Access
9	Electricity Network
10	Telecommunications
11	Gas Network
12	Local Road Network
13	Office space
14	Parking
15	Police Service
16	Fire & Rescue Service
17	Ambulance Service
18	Children's Day Care
19	Public Transport
20	Further Education(colleges)
21	Grocery stores
22	Footpaths & Cycle ways
23	Street lighting
24	Open Space
25	Restaurants
26	Built Sports
27	Libraries
28	Waste Collection
29	Banks
30	Pool
31	Religious spaces
32	Community Centers
33	Hospitals
34	Primary Health Care
35	Recycling
36	Arboretum/Biodiversity
37	Senior Citizens' Care
38	Solar Energy
39	Wind Energy
40	Other (Renewable energy)

Table 4b: Ranking of Sub-categories - Municipal Officials

RANK	SUBCATEGORY
1(tie)	Water Supply
1(tie)	Electricity Network
3	Local Road Network
4	Waste Collection
5	Gas Network
6	Wastewater Management
7	Internet Access
8	Telecommunications
9	Footpaths & Cycle ways
10	Primary Education **
11	Secondary Education **
12	Early Years Education
13	Recycling
14	Public Transport
15	Restaurants
16	Cable Access
17	Police Service
18	Fire & Rescue Service
19	Street lighting
20	Ambulance Service
21	Parking
22	Open Space
23	Primary Health Care
24	Employment potential
25	Grocery stores
26	Banks
27	Further Education(colleges)
28	Built Sports
29	Hospitals
30	Children's Day Care
31	Office space
32	Senior Citizens' Care
33	Libraries
34	Arboretum/Biodiversity
35	Pool
36	Religious spaces
37	Community Centers
38	Solar Energy
39	Wind Energy
40	Other (Renewable energy)

Table 4c: Combined Ranking of Infrastructure Sub-categories

RANK	SUBCATEGORY
1	Water Supply
2	Internet Access
3	Primary Education **
4	Electricity Network
5	Secondary Education **
6	Wastewater Management
7	Local Road Network
8	Early Years Education
9	Gas Network
10	Telecommunications
11	Employment potential
12	Cable Access
13	Footpaths & Cycle ways
14	Waste Collection
15	Police Service
16	Parking
17	Public Transport
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34	Religious spaces
35	Community Centers
36	Senior Citizens' Care
37	Arboretum/Biodiversity
38	Solar Energy
39	Wind Energy
40	Other (Renewable energy)

*** Note: The two education sub-categories rank in top 5 in the Developers' list and in the combined rank list. But the same are ranked 10 and 11 in the Municipal Officials' list due to low ranking by one municipal respondent.*

Table 5a: Acceptable Infrastructure Distance - Developers

INFRASTRUCTURE	ACCEPTABLE DISTANCE (miles)
Transportation hub	2
Education	2.5
Community Infrastructure	2.5
Social Infrastructure	4.5
Emergency Services	4
Health	6
Retail	5

Table 5b: Acceptable Infrastructure Distance - Municipal Officials

INFRASTRUCTURE	ACCEPTABLE DISTANCE (miles)
Transportation hub	4
Education	2
Community Infrastructure	3.4
Social Infrastructure	4.5
Emergency Services	4.75
Health	7
Retail	4

Table 5c: Acceptable Infrastructure Distance – Combined

INFRASTRUCTURE	ACCEPTABLE DISTANCE (miles)
Transportation hub	2.9
Education	2.3
Community Infrastructure	2.9
Social Infrastructure	4.5
Emergency Services	4.3
Health	7
Retail	4.5

Table 5c shows the results for the acceptable infrastructure distance (in miles) for seven categories of infrastructure. According to the results, Primary Education Infrastructure is preferred to be at the least distance of 2.3 miles. This is followed by Transportation hub and Community Infrastructure at 2.9 miles. Health Infrastructure achieved the largest acceptable distance of 7 miles and Emergency Services and Social Infrastructure received an acceptable distance value of 4.3 and 4.5 miles, respectively. It can be inferred that the residents are willing to drive up to 7 miles to a hospital but prefer 4.5 miles to a social infrastructure element, such as religious spaces. This also implies that Emergency Services are acceptable if located within a radius of under 5 miles.

Considering the results separately to account for the distinct opinions of the developers and the municipal officials, the preferred distances are not very different. Variation is seen in the preference of Transportation Hub for developers at an acceptable distance of 2 miles, in contrast to 4 miles preferred by municipal officials.

SUMMARY AND DISCUSSION

The data analysis highlights the prioritization of various infrastructure systems and subsystems for the success of a residential development. It also provides preferred distances for measurable infrastructure systems from the development.

Based on the above-discussed results, it can be inferred that the interview sample and most responses were influenced towards developments targeting young families or married couples about to start a family. These families would prefer to live in a neighborhood in close proximity to good schools. In addition to basic utilities, they would expect digital infrastructure to ensure they stay well-connected and are able to work-from-home, if needed. These rankings illustrate the relative importance of various infrastructure systems and subsystems on the success of a residential development.

The research analysis can be valuable for a wide variety of stakeholders including developers, municipal officials, financial institutions, and even private and public infrastructure providers and operators. It can serve as a decision-making tool for the developers. For example, if a development project has budget restrictions so that the developer cannot provide all the infrastructure systems, then the developer can focus on the infrastructure systems with high rankings. This analysis can also be used to make decisions when the time for delivering a project is limited. Similarly, the acceptable distance of different infrastructure can help the developer in site selection so that the site with the existing infrastructure within a suitable distance can be given higher priority. In addition, the results can guide the developers in determining a reasonable distance for providing the missing infrastructure.

Municipal officials can use these rankings to gauge the success of the new development, aligning with the best interests of the city. This can help the municipal officials in the approvals process. For instance, a proposed development with the availability of the high ranked infrastructure categories, within the acceptable distance, can be viewed to have a positive impact on the community. Consequently, the time and deliberation involved in the entire process of approving the development can be reduced. Other entities in the development process, such as public or private lenders can also use this decision-making model to choose to finance a project. The lenders can ask the developer to submit the list of planned infrastructures and check its conformance with the highly ranked infrastructure in the priority list.

There are certain limitations to this research. As the number of data samples for analysis are low, the results have scope for further refinement. Also, the numbers used for obtaining the results are only gathered from the experts primarily located in Michigan. Different locations with a considerable change in weather and price conditions may lead to variation in rankings. The analysis in this research considers the perspectives of the residential developers and the municipal officials. Occupant satisfaction is a major component in the success of the development; therefore, their input can further refine the results.

This research is focused on the importance of infrastructure in the success of new residential developments. Currently, redevelopment projects are gaining popularity in urban areas due to the problems associated with population growth, lack of buildable land area and urban sprawl. The impact of infrastructure on residential revitalization projects in urban areas should also be studied.

This research provides a multi-criteria analysis for determining the priorities of different infrastructure categories. The authors believe that this analysis will be valuable in guiding the developers and the municipal officials in prioritizing the infrastructure for a successful residential development, especially in situations with budget limitations.

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A Culture-Based Analysis of Construction Management Students' Conflict Management Styles

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ABSTRACT

The use of collaborative project delivery systems in the construction industry requires cooperation and shared management of the construction process to achieve success. This growth in collaborative systems requires project representatives to effectively manage conflict. Project failures utilizing collaborative methods are frequently attributed to an inability of project representatives to collaboratively resolve conflict. Research suggests that minorities are prone to use a collaborative conflict management style and the inclusion of minorities in construction management (CM) roles can reduce negative conflict. The growing evidence that increasing workforce diversity in CM is beneficial to the industry indicates that there is value in determining whether minority CM students could help manage conflict better. Researchers at Central Washington University's (CWU) CM program employed the Thomas-Kilmann Conflict Instrument (TKI) to compare the differences in conflict management styles between majority and minority CM students. Two conflict management styles showed statistically significant differences including Competing and Accommodating. Differences also existed along the Cooperative axis of the TKI graph. However. there was no statistically significant difference regarding Assertiveness. Results indicate that minority CM students are stronger in some attributes required for collaboration and exhibit conflict management behaviors that complement their majority counterparts.

Keywords: Conflict Management, Integrated Project Delivery, Diversity

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INTRODUCTION

Influencers inside and outside of the construction industry are demanding more collaborative working environments. Collaborative methods such as Construction Management at Risk, Design/Build, Lean Construction, and Integrated Project Delivery (IPD) now account for the majority of construction contracts (Martin and Plugge 2015). However, the use of these increasingly collaborative project delivery systems does not ensure collaboration. For example, although Lean Construction proponents frequently employ the principles of IPD, success does not occur on every project. The reasons for failures are considerable, but one commonly cited cause is the inability of the construction managers, on these projects, to manage conflict in a cooperative manner or adjust their mindsets to operate within a collaborative framework. Although individuals with strong records of success on previous projects are often selected to manage these collaborative projects, they are often unable to collaborate well due to the noncooperative habits ingrained in them from years of previous experience (Martin and Plugge 2015). Post (2007) suggested that one of the primary factors for this uncollaborative behavior was the adoption of a 'competitive' approach to project management which considers collaborative behavior to be indicative of weakness. As these convictions revealed themselves on projects through non-cooperative behavior, expectations were diminished, and distrust ensued. Consequently, this distrust among project participants eventually led to poor communication, unproductive conflict, and reduced performance. Many members of the construction industry recognize this dilemma, which is attributed to an unwillingness on the part of the project participants to behave in a collaborative manner and are eager to discover methods to encourage increased collaboration.

BACKGROUND

Collaborative project delivery systems now account for more than 50 percent of all construction projects compared to just 10-15 percent twenty-five years ago (Martin and Plugge 2015). However, the use of these collaborative project delivery systems does not ensure long term, sustainable collaboration. Increasingly, the amount of litigation still present in Design-Build and CM-at-Risk indicates that there is an underlying difficulty in establishing true collaborations within the context of contractually organized and controlled delivery methods. Despite the integration of more collaborative contracts into projects, successful collaboration has not always been achieved. To further complicate the issue, in addition to the typical uncooperative construction managers that continue to manage the same way that they were conditioned through other methods, there is evidence that the construction industry tends to attract inherently uncooperative individuals (Martin and Plugge 2015). In the end, a successful collaborative project needs more than just a properly written contract or enhanced technology. It requires the project participants to act in a collaborative manner during conflicts, negotiations, and operational exercises. Therefore, entrants as well as veterans in the construction industry are required to be adept at managing conflict collaboratively in an IPD project. However, mindsets are not easily altered without some impetus to make the change. The introduction of individuals into the industry that are more inclined to act collaboratively could act as a catalyst for change.

PURPOSE OF THE STUDY

Diversity has been connected to increased profits across multiple industries (Herring 2009). These findings have led to the creation of the value-in-diversity perspective, which contends that a diverse workforce has a distinct benefit to business (Herring 2009). However, these benefits are not limited to increased earnings. For example, there is evidence that diversity in CM may decrease conflict and increase collaboration. Holt and DeVore (2005) suggests that cultural norms influences conflict management and suggests that those from collectivist cultures may possess more effective collaborative resolution attributes than their individualistic counterparts. Individualistic cultures were typically found to be more forcing or Competing in conflict than collectivist (Ting-Toomey et al. 2000). As Competing is considered more disruptive in the conflict resolution process than collaboration is helpful, the inclusion of collectivist cultures in CM roles may reduce non-productive conflict. People's roles in society are theoretical constructs of learned behavioral norms which are socially appropriate for a certain race within a specific culture (Jenkins 1997). The Competing behavioral norms typically displayed by individualistic cultures tend to escalate tension in situations of conflict (Ting-Toomey et al. 2000). These behaviors also often increase individual aggression during conflict (Kochman 1981). However, a collectivist presence during conflict situations can diffuse potential arguments and increase agreement between parties due to their less threatening and aggressive archetypes (Ting-Toomey et al. 2000). According to Ting-Toomey et al. (2000), European Americans tend to be individualistic, while Latino/a, Asian, and African Americans are collectivist. Therefore, this research project was undertaken with the goal of comparing the conflict management styles preferred by the majority (European American) CM students versus minority (Latino/a, Asian, and African American) CM students at CWU using the Thomas-Kilmann Conflict Mode Instrument (TKI). Determining the cooperative characteristics that minority students possess that their majority counterparts lack is a good starting point to promote more collaborative attitudes among construction participants within the construction industry.

LITERATURE REVIEW

A large amount of literature has been devoted to the topic of conflict in the construction industry. It is widely known that construction projects are prone to disputes among stakeholders, including owners, engineers, designers, and contractors (Jaffar et al. 2011, Ng et al. 2007, Safapour 2019). Research suggests that these conflicts can become very costly and time-consuming when they are not addressed in a prompt manner and have the potential to negatively affect project schedule performance and success (Jaffar et al. 2011, Safapour 2019, Wu et al. 2017, Zhang and Huo 2015). Due to the high potential costs of conflict in construction and the deleterious effects that conflict can have on project outcomes, the topic has been widely suggested as an area of future study (Gardiner & Simmons 1994, Ng et al. 2007, Zhang and Huo 2015).

Conflict management styles

The TKI is a method to determine an individual's preferred behavior in conflict situations. Conflict situations are the situations in which two individuals' concerns appear to be contradictory. In these situations, an individual's behavior can be plotted along two simple dimensions: (1) Assertiveness, defined as the magnitude to which a person endeavors to satisfy their own concerns, and (2) Cooperativeness, defined as the point to which a person attempts to gratify the other individual's concerns. These two basic dimensions of behavior can be used to determine which of the five conflict management styles an individual uses when dealing with conflict. These five conflict-handling modes are shown in Figure 1.

Figure 1: Thomas-Kilmann Conflict-Management Styles (Kilmann 2019)

All five styles are appropriate in specific situations and each represent a set of useful social skills. For example, the adage that "two heads are better than one" (Collaborating) is frequently considered to be valuable when solving complex problems. However, the opposite style, "Leave well enough alone" (Avoiding) is also often considered valuable, depending on the situation. The same could be said regarding "Kill your enemies with kindness" (Accommodating), "Split the difference" (Compromising), or "Might makes right" (Competing). All styles have their place and usefulness at specific times. The practicality of a particular conflict management style varies with the needs of the specific conflict situation.

Following is a brief description of the modes and the psychology behind each (Herck et al. 2011).

> Competing is assertive and uncooperative. An individual pursues their own concerns at the other person's expense. This is a power-oriented mode, in which one uses whatever power seems appropriate to win one's own position.
>
> Accommodating is unassertive and cooperative. This is the opposite of Competing. When Accommodating, an individual neglects their own concerns to satisfy the concerns of the other person.
>
> Avoiding is unassertive and uncooperative. The individual does not immediately pursue their own concerns or those of the other person. Avoiding might take the form of diplomatically sidestepping an issue, postponing an issue until a better time, or simply withdrawing from a threatening situation.
>
> Collaborating is both assertive and cooperative. This is the opposite of Avoiding. Collaborating involves an attempt to work with the other person to find some solution which fully satisfies the concerns of both persons.
>
> Compromising is intermediate in both Assertiveness and Cooperativeness. The objective is to find an expedient, mutually acceptable solution which partially satisfies both parties.

Each person has the ability to use all five conflict management styles and no one person can justifiably be categorized as having a single inflexible style of managing conflict. However, any individual employs some styles better than others and therefore, is inclined to rely upon those styles more habitually than others, whether because of temperament or experience in using them. The challenge for IPD participants whose predisposition is to be "Competing" or "Avoiding" is to learn how to acclimate to more cooperative styles because the situation of an IPD project requires cooperation for success (AIA 2007).

Conflict management styles across cultures

For this study, the designations of "majority" and "minority" refer to designations typically used in the United States. The majority designation applies to those of Euro and Scandinavian descent whereas, the minority designation applies to those of African, Asian, Latino/a, and Native American descent. Close to 40 years of research, in the United States, on conflict styles across cultures indicates than majority and minority groups manage conflict differently. Most of these studies have measured conflict management propensities in terms of the five styles of conflict management styles discussed above. Early studies of the topic in the 1980s suggested that African Americans tended to be more Cooperative (Jaffar et al. 2011). Similarly, several conflict management style studies across cultures in the early 2000s by Holt and Devore (2005) found that the majority was more Competing, and minorities were more Compromising, per self-reported data from the TKI. More recent studies have continued to support the theory that majorities and minorities manage conflict differently (Prause and Mujtaba 2015).

METHODOLOGY

This quantitative, descriptive study identified the conflict management styles of the CWU CM majority and minority students during their junior year at CWU and then compared the conflict management styles between them. The researchers elected to observe students, in the fall quarter, near the beginning of their junior year when they first enter the CM program. The primary reason for observing the students early in the CM program was to determine which styles the students possess before any CM program influence had taken hold. Understanding these differences aids in developing pedagogies to match the needs of the student demographic. The researchers used this analysis to detect differences in the majority and minority conflict management styles in CWU's four-year, campus based, American Council for Construction Education (ACCE) accredited CM program. The results of the TKI were evaluated through a series of statistical analyses. Over a span of six years (winter 2014 – Fall 2019), a total of 49 junior-level majority students and 28 junior-level minority students (23-Latino/a, 2-Asian, 2-African, and 1-Native American) completed the TKI questionnaire.

These TKI questionnaires were distributed to the students during regularly scheduled class periods and was considered part of the normal educational process to help students better understand their personal conflict management styles. Students were not required to complete the questionnaire, but it was strongly encouraged to complete it for their own edification. One hundred percent of the students present, participated in the survey. The TKI scores were tallied and documented in order to determine each student's conflict management style during their junior year and to determine whether the construction management majority and minority students, as distinct separate groups, preferred one conflict management style over another. To accomplish this effort, five independent samples two-tailed *t*-tests were performed for each TKI conflict management style. First, the scores for the 49 majorities were compared against the tallied scores of the 28 junior minorities for the "Competing" dimension from the TKI. Following that comparison, each of the other four dimensions were evaluated similarly.

FINDINGS

Tables 1-5 presents the comparisons between the majority and minority students in the representative conflict management percentile scores. The percentile scores are an indication that these students utilize the associated style as their dominant style more or less than the general population. For example, the majority Competing style in Table 1 (66.98) indicates that these students' use of Competing are in the 66.98th percentile as a dominant style.

The results of the paired samples *t*-test as shown in Table 1 determined that the majority Competing percentile scores ($M = 66.98$) were significantly different from the minority Competing percentile scores ($M = 50.71$), ($t[75] = 2.78$, $p < 0.01$).

Table 1: ***Paired Samples t-test Comparing "Competing" Means of Majority and Minority***.

t-Test: Two-Sample Assuming Equal Variances

Competing

	Majority	*Minority*
Mean	66.98	50.71
Variance	566.69	692.29
Observations	49	28
Pooled Variance	611.90	
Hypothesized Mean Difference	0	
df	75	
t Stat	2.78	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.01	
t Critical two-tail	1.99	

The results of the paired samples *t*-test shown in Table 2 indicated that the majority Collaborating percentile scores ($M = 37.41$) were not significantly different than the minority Collaborating percentile scores ($M = 48.79$), ($t[75] = -1.85$, $p > 0.05$). However, a statistically significant difference exists if measured at the 93% confidence level.

Table 2: ***Paired Samples t-test Comparing "Collaborating" Means of Majority and Minority***

t-Test: Two-Sample Assuming Equal Variances

Collaborating

	Majority	*Minority*
Mean	37.41	48.79
Variance	656.66	705.80
Observations	49	28
Pooled Variance	674.35	
Hypothesized Mean Difference	0	
df	75	
t Stat	-1.85	
P(T<=t) one-tail	0.03	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.07	
t Critical two-tail	1.99	

The results of the paired samples t-test shown in Table 3 indicate that the majority Compromising percentile scores (M = 44.33) were not significantly different than minority Compromising percentile scores (M = 47.54), (t[75] = -0.51, $p > 0.05$).

Table 3: ***Paired Samples t-test Comparing "Compromising" Means of Majority and Minority***.

t-Test: Two-Sample Assuming Equal Variances

Compromising

	Majority	*Minority*
Mean	44.33	47.54
Variance	602.43	883.15
Observations	49	28
Pooled Variance	703.49	
Hypothesized Mean Difference	0	
df	75	
t Stat	-0.51	
P(T<=t) one-tail	0.31	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.61	
t Critical two-tail	1.99	

The results of the paired samples t-test in Table 4 indicate the majority Avoiding percentile scores (M = 56.37) were not significantly different than minority Avoiding percentile scores (M = 49.11), (t[75] = 1.15, $p > 0.05$).

Table 4: ***Paired Samples t-test Comparing "Avoiding" Means of Majority and Minority.***
t-Test: Two-Sample Assuming Equal Variances

Avoiding

	Majority	*Minority*
Mean	56.37	49.11
Variance	644.03	840.99
Observations	49	28
Pooled Variance	714.93	
Hypothesized Mean Difference	0	
df	75	
t Stat	1.15	
P(T<=t) one-tail	0.13	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.26	
t Critical two-tail	1.99	

The results of the paired samples *t*-test in Table 5 indicate the majority Accommodating percentile scores ($M = 41.59$) were significantly different than minority Accommodating percentile scores ($M = 57.04$), ($t[75] = -2.46$, $p < 0.05$).

Table 5: ***Paired Samples t-test Comparing "Accommodating" Means of Majority and Minority.***
t-Test: Two-Sample Assuming Equal Variances

Accommodating

	Majority	*Minority*
Mean	41.59	57.04
Variance	736.29	644.92
Observations	49	28
Pooled Variance	703.40	
Hypothesized Mean Difference	0	
df	75	
t Stat	-2.46	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.02	
t Critical two-tail	1.99	

Using coordinate geometry, a graph was developed with a two-dimensional axis resembling the orientation of the TKI chart previously shown in Figure 1. The collective results of the styles were plotted against a Cartesian coordinate graph and centroids were located to determine which quadrant the collective majorities and minorities were located. Figure 2 shows the associated polygons and centroids for the majorities (red) and minorities (blue). The majority and minority centroids were analyzed using independent samples two-tailed *t*-tests to compare the x- and y-coordinate centroids of the two groups. The Compromising style is in the center of the other four styles as shown in Figure 1. Therefore, the Compromising means were proportionately distributed to the other four conflict management styles for ease of understanding on a two-dimensional format.

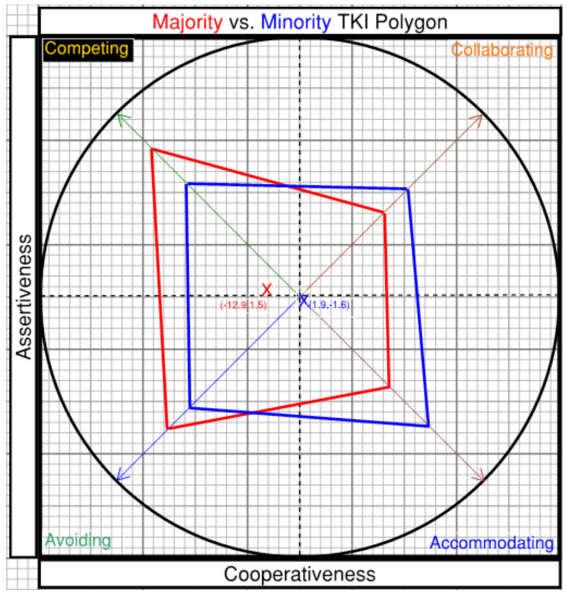

Figure 2: Cartesian Coordinate Graph for Conflict Styles Centroids

The mean values of each conflict management style for each collective majority and minority group were plotted on the Cartesian Coordinate Graph (Figure 2) using 45-degree vectors starting from the (0.0, 0.0) coordinates. In Figure 2, a 45-degree vector was plotted in Quadrant 1 (Competing) and the majority Competing mean (M = 80.82) was located on that vector. Using right triangle trigonometry ($a^2 + b^2 = c^2$), the x,y (-57.15, 57.15) coordinates were identified. Next, the minority Competing mean (M = 62.00) coordinates were identified (-43.84, 43.84). Following the Competing vector, another 45 degree vector was plotted into Quadrant 2 (Collaborating) and the majority Collaborating mean (M = 45.41) x,y coordinates were located on that vector (32.11, 32.11) followed by the minority mean (M = 61.11) which yielded (43.21, 43.21) coordinates. Quadrant 3 (Accommodating) majority mean (M = 50.47) yielded (35.69, -35.69) coordinates while the minority mean (M = 69.55) yielded (49.18, -49.18) coordinates. Finally, Quadrant 4 (Avoiding) majority mean (M = 69.98) yielded (-49.48, -49.48) coordinates while the minority mean (M = 60.52) yielded (-42.79, -42.79) coordinates. Once these coordinates were identified, each point was connected to create the polygons.

In addition, the polygons' respective centroids were determined for each majority and minority student. When all of the centroids were averaged within each majority and minority group, it was determined that the centroid's x,y coordinates for all majorities collectively was (-12.82, 1.46) and the centroid's x,y coordinates for all minorities collectively was (1.92, -1.64) as presented on Figure 2.

A paired samples *t*-test was then conducted to determine whether there was a significant difference between the majority and minority centroid means consisting of two different population sets. Therefore, a two-tailed test was appropriate. The results of the paired samples *t*-test shown in Table 6 indicate that the majority centroid x-coordinate (Cooperativeness) mean (M_x = -12.82) was significantly different than the minority centroid x-coordinate mean (M_x = 1.92), ($t[75] = -3.97$, $p < 0.01$).

Table 6: ***Paired t-test Comparing Centroid X-Coordinate Means of Majority and Minority.***

t-Test: Two-Sample Assuming Equal Variances

X-Axis Cooperativeness

	Majority	*Minority*
Mean	-12.82	1.92
Variance	281.55	180.84
Observations	49	28
Pooled Variance	245.30	
Hypothesized Mean Difference	0	
df	75	
t Stat	-3.97	
P(T<=t) one-tail	0.0001	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.0002	
t Critical two-tail	1.99	

The results of the paired samples *t*-test on Table 7 indicate that the majority centroid y-coordinate (Assertiveness) mean (M_y = 1.46) was not significantly different than the minority centroid y-coordinate mean (M_y = -1.64), ($t[75] = 0.66$, $p > 0.05$).

Table 7: ***Paired t-test Comparing Centroid Y-Coordinate Means of Males & Females.***

t-Test: Two-Sample Assuming Equal Variances

Y-Axis - Assertiveness

	Majority	*Minority*
Mean	1.46	-1.64
Variance	328.38	496.79
Observations	49	28
Pooled Variance	389.01	
Hypothesized Mean Difference	0	
df	75	
t Stat	0.66	
P(T<=t) one-tail	0.25	
t Critical one-tail	1.67	
P(T<=t) two-tail	0.51	
t Critical two-tail	1.99	

CONCLUSIONS AND RECOMMENDATIONS

Results of this study indicate that, although one group does not appear to be more collaborative than the other, important distinctions in how majority and minority students manage conflict do exist. For example, although at first glance the results of the paired samples *t*-test shown in Table 2 appear to indicate that the majority Collaborating percentile scores (M = 37.41) were not significantly different than the minority Collaborating percentile scores (M = 48.79), ($t[75]$ = -1.85, $p > 0.05$), one must take into account that the Collaborative conflict management style is associated with both a high level of Cooperativeness (x-axis) and Assertiveness (y-axis), as shown in Figure 2. Therefore, an increase in Cooperativeness or Assertiveness has the potential to increase overall collaboration. The results of the paired samples two tailed *t*-tests from the majority and minority centroid analysis indicated the conflict management styles of the CM students at CWU were significantly different regarding Cooperativeness. However, the results of the paired samples *t*-test in Table 7 indicated the majority centroid y-coordinate (Assertiveness) mean (M_y = 0.52) was not significantly different than the minority centroid y-coordinate mean (M_y = -7.97), ($t[69]$ = 1.633, $p > 0.05$). Therefore, although minority CM students may not differ significantly in their propensity to use a collaborative style overall, they do appear to offer a more Cooperative approach to conflict management than the majority students. As Assertiveness was previously defined as the magnitude to which a person endeavors to satisfy their own concerns, and Cooperativeness is the point to which a person attempts to gratify the other person's concerns, it appears that minority CM students may be better adapted to work towards solutions that meet the needs of others without sacrificing their own needs.

The study found two other significant differences between majority and minority CM student conflict management styles. The results of the paired samples *t*-test in Table 5 for Accommodating indicated that majority Accommodating percentile scores (M = 41.59) were significantly lower than minority Accommodating percentile scores (M = 57.04), meaning that the minority students were more likely to use an Accommodating style than their majority counterparts. Additionally, the results of the paired samples *t*-test as shown in Table 1 determined that the majority Competing percentile scores (M = 66.98) were significantly higher than the minority Competing percentile scores (M = 50.71), which indicates that minority students are less likely to use a Competing conflict management style than their majority counterparts. These differences complement the less Accommodating and more Competitive styles of their majority counterparts. Harnessing and pooling these complimentary styles could benefit the construction industry's need for increased collaboration.

The results of the *t*-tests from the majority and minority centroid analysis raises another potential concern. Although the minority CM students were more cooperative than their majority counterparts, their collective centroid lands very near the center of the cooperative ledger implying that the minority CM students are neutral in this regard. These results suggest that the construction industry may attract uncooperative people, regardless of their culture, as suggested in Martin and Plugge's article (2015).

The study sample was limited to undergraduate junior-level students enrolled full-time in the CM program at CWU. The research did not attempt to evaluate the entire university population, nor did it attempt to examine student populations at any other post-secondary institution. Furthermore, the research did not use any other demographic other than the culture to compare students. There was no attempt to group students based upon age, gender, class, or any other characteristic.

Recommendations for future research include evaluating additional students in other CM programs to assess a larger sample population. This would provide a more accurate assessment of conflict management trends across cultures among students in CM programs. Future research projects could also consider characteristics of the CM students other than culture, such as grade point average, or the discipline (heavy civil versus general) within the CM program in which the student is enrolled in order to determine whether these attributes have any influence on conflict management styles. Another consideration for future research is to determine the CWU CM students' conflict management style movement from their junior to senior years.

Conflict is a part of everyday life. The way an individual manages and resolves conflict is known as their conflict management style. Depending on the situation, scenario, and environment, certain styles may be preferred over others. The rising use of collaborative project delivery systems in the construction industry, such as IPD, is leading to increased collaboration between project partners, thus increasing the need for construction industry affiliates to adopt a more collaborative conflict management style (Wu et al. 2017). To meet these new industry demands, CM education programs across the United States are exploring methods to prepare students for the collaborative industry evolution. Many programs are focusing on implementing technological advances that have become common on IPD projects, such as Building Information Modeling, cloud-based communication methods, etc. while others are focusing on educating students in the content and nuances of IPD contracts. Both aforementioned educational efforts are appropriate for facilitating collaboration, however as Kanagy and Kraybill (1999) assert, in addition to technology and structure, culture is also an integral component of society and since each construction project functions as its own mini society, so to should cultural integration be advanced by construction management educators. As alluded to earlier, very little has been accomplished regarding the "culture" arena in IPD construction education. One potential tactic for addressing this issue is to allow students the opportunity to learn from one another. As discussed above, our results indicate that minority CM students are not only stronger than majority CM students in some attributes required for collaboration, but they also exhibit conflict management behaviors that are different, yet complementary to their majority counterparts. Therefore, increasing diversity into the classroom can allow various cultures an opportunity to learn from one another with the recognition that they each have something to teach each other regarding collaboration.

Therefore, an increase in cultural diversity in the construction industry has the potential to increase cooperativeness in times of conflict during construction projects, and this can also help fill in the gaps of collaborative behavior between cultures. This idea may prove to be especially advantageous considering the evidence suggesting the industry attracts uncooperative people, regardless of culture (Martin and Plugge 2015). Allowing students to experience and learn from diverse conflict management styles can better prepare them to work in diverse teams in support of the collaborative industry evolution before they enter the industry.

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Identifying Challenges to Project Outcomes from a Transportation Project Owner Perspective

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ABSTRACT

Transportation project owners are often concerned with the risks associated with construction, because these challenges can directly affect project outcomes and often lead to increased time and cost for projects. It is, therefore, vital to identify challenges early within the project life cycle. Transportation project delivery has evolved to strengthen the influence that the owner has upon the project, transitioning away from the exclusive use of traditional Design-Bid-Build to the more innovative and involved approaches of Design-Build and Construction Manager / General Contractor. Unfortunately, this has resulted in increased owner risk. In this research, transportation project owners were asked to identify and discuss the challenges and risks associated with three main delivery methods: Design-Bid-Build, Design-Build, and Construction Manager / General Contractor. These results identify the most challenging aspects for successful project completion for each of these project delivery types. Practices that can improve project outcomes were also explored within this research. The results of this research can assist transportation owners and construction managers alike in identifying transportation construction project related risks and selecting the most effective ways to mitigate those risks.

Keywords: transportation construction, construction risk, project delivery

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INTRODUCTION

There are few things that cause greater concern for transportation project owners than the risks associated with construction, because these challenges can directly affect project outcomes and often lead to increased time and cost for projects. Transportation project owners desire projects that are successfully completed on time, within budget, and to the quality specified. Highway projects that are over budget are unfortunately all too common (Creedy 2010). It takes great effort to efficiently and effectively identify and manage project risk. Although meeting the demands of cost, quality, time, and innovation simultaneously is the aim of the highway construction industry, doing so can accentuate and amplify the risk within an industry already impacted by significant risk factors. A focus on any of these demands can potentially result in additional risk in any of the other areas. Therefore, it is imperative that project owners and managers identify potential challenges early in the project life cycle and try to mitigate the risks that can result in poor project outcomes.

The purpose of this research was to explore various risks associated with transportation construction projects and potential practices for improving project outcomes. However, this research is unique in that it specifically targeted the perspective of transportation project owners. This paper reports the findings from 56 transportation project owners and owner representatives identifying the most prevalent challenges to successful projects, as well as the best preparation and mitigation practices for these challenges. This paper specifically explores transportation project challenges and solutions with regard to different project delivery type, including traditional Design-Bid-Build and two other alternative delivery methods (Design-Build and Construction Manager / General Contractor). This independent look at the risks associated with these different delivery methods indicates which challenges tend to be more likely encountered for each of the different delivery methods being used. These results can be used by transportation project owners that wish to identify common project challenges and the corresponding suggestion of industry professionals for how to reduce the risks in order to improve project outcomes.

LITERATURE REVIEW

Project delivery is a project management tool used to manage the scope, quality, schedule, and timing of a construction project, by defining the way that contracts and project relationships will be set up to deliver the project (Kenig, 2011). In essence, the delivery method refers to the establishment of all contractual relations, roles, and responsibilities of the entities involved in the project. The delivery method identifies the contractual relationships and responsibilities the owner has towards designers and contractors, each of their responsibilities to the owner and to each other, and the timeline these relationships are to follow (Kenig, 2011). These contracts are essential for establishing assignment of risk ownership for the risks and uncertainties associated with the project. Delivery methods include typical contracting structures; however, modification of the contracting structures under any delivery method can be made to address the needs and risks of a specific project (Ghavamifar and Touran, 2009).

The construction industry continually demands improvement. Owners demand projects at reduced cost while still delivering ever-improving quality on a compressed schedule (Keck et al., 2010). The delivery of transportation construction projects typically follow one of three project delivery methods: Design-Bid-Build (DBB), Design-Build (DB), or Construction Manager / General Contractor (CM/GC) (Minchin et al., 2014). Within the state and federal highway industry, these demands have driven a shift away from traditional DBB delivery to reducing public impact through innovative construction and delivery methods, including DB or CM/GC. This continual demand for better processes, ideas, means, and methods leads to beneficial advances within the industry but also exposes it to greater risk. Innovative processes may positively affect a schedule or reduce public impact, but they mean higher risk to the project, which in turn will likely result in a higher premium to cost (Kenig, 2011). Of particular concern is which party (owner, designer, or contractor) then accepts this higher level of risk (Farnsworth et al, 2016).Innovative project delivery methods have been shown to improve the identification of project risks at earlier stages in construction and provide mechanisms to eliminate, reduce, or share risk among project stakeholders (Gransberg et al., 2010; Sullivan et al., 2017).

Design-Bid-Build (DBB)

Of the three major project delivery methods, Design Bid Build (DBB) is the traditional method for delivering transportation construction projects. In DBB delivery, the design is completed using either the owners in-house design professionals or by contracting with a consultant to provide complete design services. Either way, design and construction are provided by separate entities and governed by separate contracts (Minchin et al., 2014). Following design completion, the owner becomes responsible for the design and warrants the quality of the construction documents to the contractor (Kenig, 2011). Typically, public DBB projects are awarded to the low bidder following advertisement (Gransberg and Shane, 2010). DBB may not be the best fit for a complex, demanding applications such as highway construction. Because of the price-competitive selection process used under DBB, the owner runs the risk that the project team may not be sufficiently qualified to realize a demanding project to the required specifications. The design, bidding and construction phases may stretch over multiple construction seasons, risking price inflations or the need for scope changes. DBB also provides little protection against risks and additional costs that can stem from an incomplete or unfeasible design, or conditions not fully understood by the engineer during design (Minchin et al., 2014).

DBB is characterized by little builder input to the design. In most cases, design has been completed before a contractor is even consulted. The owner relies on the designer alone for constructability review, and trusts that the design will not exceed the budget (Gransberg and Shane, 2010). While a competitive bid may promote competitive cost initially, the costs associated with changes and overruns require substantial owner and contractor contingencies for a DBB project to stay within a project's budget (Minchin et al., 2014). In short, there is not a contractual incentive for the builder to minimize the cost growth within this delivery system. Rather, a builder winning a bid with the lowest possible margin may look for post-award changes as a means to make a profit on a project (Scott et al., 2006). For these reasons, DBB may not be the best fit for complex highway construction projects.

Design-Build (DB)

Design-Build (DB) is an alternative method for project delivery that has rapidly grown in popularity for highway construction projects, because it offers a single point of responsibility (and a single contract) for both the design and construction of the project (Kenig, 2011). The DB entity often consists as a joint venture between qualified general contractors and design firms. The owner develops the essential project requirements and performance standards the agency will require, and solicits a Request for Qualifications or Request for Proposal. The DB entity is then typically selected by the owner based on corresponding qualifications and a firm fixed price. In turn, the DB entity becomes liable for all design and construction costs (Minchin et al., 2014). DB is often selected because of its ability to compress schedule compared to DBB (Shrestha et al., 2012).

DB project delivery mitigates some of the risks that the DBB method does not by a contractual partnership between the designer and contractor. This ultimately increases the quality of the design through constructability input. The DB entity is also committed to a price guarantee early in the delivery process, which is beneficial for the owner and any associated funding sources (Gransberg and Shane, 2010). One major appeal of DB delivery is the ability of the owner to delegate almost all project risk to the DB entity, as the design-builder literally controls the project delivery process. As a result, DB is the delivery method that has the greatest ability to compress the project delivery period and is often used to fast-track projects. However, under DB the owner runs the risk of losing control over the design. Any innovations developed by the DB entity belong to the design-builder and may not benefit the owner on future projects. Additionally, cost and schedule are not flexible to the needs of the owner that may change over the course of the project (Gransberg and Shane, 2010). The owner in essence turns over all risk to the design-builder and gives up the ability to make project decisions (Minchin et al., 2014). Further, by procuring a cost guarantee prior to design completion, it is difficult for owners to identify the costs associated with project risk.

Construction Manager / General Contractor (CM/GC)

Construction Manager / General Contractor (CM/GC) is a newer alternative method for project delivery that is slowly becoming more prevalent in transportation construction. Under the CM/GC delivery method, the design and construction are still under separate contracts, but the builder engages with the project before the design is complete. This delivery method is similar in concept to Construction Manager at Risk (CMAR or CMR) commonly used in vertical construction (CDOT, 2015). However, there are two principal differences. First, transportation construction typically includes sophisticated highly involved project owners (the agency itself), with both the need and the desire to keep control of the project (Minchin et al., 2014). Second, the awarded construction manager / general contractor will generally self-perform a majority of the work, eliminating the advantage of including competitive subcontractor bids in the guaranteed maximum price (GMP) (West et al., 2012). It is, therefore, more difficult to gauge the GMP the contractor proposes against what the project might cost if bid competitively through DBB. With CM/GC delivery for transportation construction, these two differences result in the construction manager / general contractor shouldering a great deal of the project risk (Minchin et al., 2014). In CM/GC an agency qualifies a contractor for the project this qualification can be based on previous experience or what is determined to be the best value to the agency (FHWA 2020).

Although the agency has the knowledge and experience to manage the project, the overall construction process with CM/GC delivery benefits from early involvement of the integrated project team, especially from involvement of the contractor. The contractor delivers crucial expertise and innovation, while the agency is able to maintain control over the overall design, budget, and schedule, and chooses to hold the majority of project control and contingencies (Gransberg and Shane, 2016). In CM/GC the agency or the GC can in effect function as the project manager, this would depend on the contract language used. A sophisticated owner could effectively represent the interests of the public by relying on the information provided by an involved and knowledgeable project team, yet reserving the ability to make project decisions. CM/GC is meant to reduce the overall risk associated with the construction project by promoting an integrated team approach to problem solving early within the design process, continuing throughout construction (Farnsworth et al., 2016). The selection of the engineer and contractor is based on qualification (Minchin et al., 2014). Ultimately, because the design and construction processes are directed by the owner, the owner maintains control over the design and flexibility in meeting the changing needs of the project (Warr et al., 2017). It is important to note that any of the delivery methods could implement principles of an Integrated Project Delivery (IPD) which may change the involvement and approach of the listed delivery methods. As a philosophy, IPD occurs when integrated practices are applied to more traditional delivery approaches such as CM/GC, Design-Build or Design-Bid-Build (where the owner is not party to a multi-party contract). IPD is characterized by traditional transactional CM at-Risk or Design-Build contracts, some limited risk-sharing, and fully integrated project teams (AGC 2020).

Transportation Construction Risk

Risk is an inherent feature of transportation construction, and must be identified and managed (Ashley et al., 2006). Ignoring or failing to plan for risk can lead to failed projects. However, appropriate risk taking is also an essential element of transportation construction, when attempted with a well thought out plan for appropriately managing the risk. While developed to manage scope, design, cost, and schedule, project delivery methods can also be effective in responding to risk (Tran et al., 2015). However, special consideration must be taken to fit the project delivery method chosen to the needs of the project, as well as the risk factors that must be addressed (Tran et al., 2013). For these reasons, it is important to understand the risks associated with the different project delivery methods. Further, it is important to understand how these risks affect the various parties involved in the project.

The risks associated with transportation construction vary some within the literature, but generally follow the same elements and themes. Effective risk analysis and management practices include identification, assessment, analysis, and mitigation of the associated risks occurring throughout the various phases of a construction project (Molenaar et al., 2010). Sullivan et al. (2017) explored the overall effects of project delivery type of cost, schedule, and quality, but did not focus on specific risks. Tran et al. (2014) studied the critical risk factors that affect the selection of appropriate delivery type, and determined that the categories of risks associated with construction, scope, and constructability and documentation have the greatest impact. In a follow up study, Tran and Molenaar (2015) demonstrated the relative importance of analyzing project cost, risk, and uncertainty with regard to selection of project delivery method. These studies, however, are associated with the overall risks of the project and selection of an optimal delivery type, and are not specific to the impact upon the individual parties. Other studies focus on the effects of specific risk factors with regard to different delivery types (for example, constructability of design, third party delays, unexpected utility encounters, etc.), but again do not demonstrate the impact on individual parties (Tran and Molenaar, 2012). A few recent studies have focused on the impact of delivery type to various risk factors for individual parties (Farnsworth et al., 2016; Warr et al., 2017), but have not fully addressed the issue. The purpose of this study is to expand the body of knowledge with regard to the impacts of various risks associated with project delivery type, but specifically from the perspective of transportation project owners.

One finding of the result of the research was a list of identified risks for transportation owners. A study into each of these risks reveals examples of how these risks could be detrimental to project success. A few of the most cited challenges or risks included "environmental impacts" and "public evolvement". Many examples can be found of the effects of environmental impacts on transportation projects including project delays, increased project costs, and cost or delays due to environmental impact studies. The U.S. Environmental Agency describes the impacts of highways in their 1994 report. They describe these impacts as any and all changes in the structure and function of an ecosystem (Southerland 1994). With this definition, it is easy to see how any project could be affected by the possible environmental impact, especially if the second listed risk of public involvement becomes an issue. Public involvement often leads to the highlighting of impacts related to eco systems, cultures, as well as social costs (Tolga et al. 2017). For both environment and public impacts, the literature suggests the earliest possible identification of impacts on the environment, and identification and involvement of the possible public entities that may affect project outcomes.

RESEARCH OBJECTIVES AND METHODS

Data for this research was collected by sending a survey to national transportation project owners, state transportation owners (departments of transportation), to identify high-risk elements associated with different project delivery types, and various practices that were used to mitigate these risks. These risk mitigation practices were tied to actual project outcomes, as well as the owner's perception of project outcomes, in other words, project success. Factors leading to project successes and failures to meet desired objectives were identified by the project owners. All projects included in this study were horizontal projects dealing with highway transportation. Projects used in the study fell mostly into three categories: Design-Bid-Build (DBB), Construction Manager / General Contractor (CM/GC), and Design-Build (DB). Design-Bid-Build was the dominant project delivery method, with 30 of the projects in the study using this delivery method. Design-Build was used on 18 projects in the study, followed by 8 CM/GC projects. As some of the respondent did not answer all of the questions; the number of respondents for each group is noted after each figure or table. The 56 survey participants reported on individual projects on which they had a management or ownership role. The projects ranged in cost from one million to over 900 million US dollars. They represent a total capital project value of almost six billion US dollars. DBB projects had the lowest average cost at just over 19 million US dollars. CM/GC projects had an average cost of over 22 million US dollars, and DB projects had the highest average cost at just over 51 million US dollars. DB projects also showed the largest range of project costs. As total project cost can be a source of added risk, this information can be used by project owners as a comparison to their projects.

This study follows a strategy for data analysis using statistical models (Ramsey, F., & Schafer, D. 2012). In the preliminary study a set of questions and interests is established and used to form the design of the study. Next preliminary data was explored to look for initial answers and to identify potential models. For this study the exploration aspect came in the form of a survey created for a group of researchers and industry practitioners involved in the research. This research group was able to use information from data exploration to then formulate an inferential model about the data. The model is then checked for appropriate fit and outliers are examined. Researchers can then move into a broader scale as was done with this national study of transportation projects. Survey questions were improved to reflect the models identified in the data in the first round. After multiple iterations of data collection and model formulation, the data is then used to infer answers to the study questions and objectives. Finally, the results are communicated to the intended audience. This study strategy has been well documented as effective to combine findings from narrative or multiple case study analysis (Vogt 2015).

FINDINGS

Researchers compiled the data from the project owners and their respective projects and analyzed the results. The findings compiled from this analysis are detailed in this section. The results of the survey data provided information on the specific challenges to project completion and the management practices that could improve project outcomes. The most challenging aspects to successful project completion for all delivery methods considered together, was found to be environmental impacts. "Environmental impacts," "public involvement," and "project schedule" were the greatest challenges for successfully completing a project for all delivery methods as a whole. Other challenges can be seen in Table 1 in order of frequency of response.

When considering the individual delivery methods considered in the study, Table 1 breaks down the most challenging aspects for project completion by the three delivery methods in order of frequency selected. "Environmental impacts" was the most frequently chosen as the most challenging aspect for successfully completing a DBB project. "Environmental impacts" also showed up as a concern for CMAR and DB projects, albeit with less frequency. "Public involvement" and "construction site access" were the most frequent selections for CMAR and DB projects, respectively. It is fitting that delivery methods with overlap of the design and construction phases would have additional risks from the conditions of the site, as many decisions about design may have to be made without full information about the existing site conditions or access to the site. The limited number of projects within each delivery method is however a limitation of this study and more projects would need to be analyzed to make significant observations about challenges as they relate to individual delivery methods. It can be observed however through the aggregate of all delivery methods that environmental impacts pose a great threat to successful project completion. This factor is identified within all delivery methods as a high-risk topic. Practices that can improve project outcomes or mitigate risks like those caused by environmental impacts were identified in this research effort.

Table 1. Most Challenging Aspects for Successful Project Completion

	ALL Projects	DBB	DB	CM/GC
Challenge	**No. (N = 56)**	**No. (N = 30)**	**No. (N = 18)**	**No. (N = 8)**
Environmental Impacts	9	6	2	1
Public Involvement	7	5	1	2
Project Schedule	6	3	2	1
Differing Site Conditions	4	2	2	-
Constructability Procedure	3	2	1	-
Construction Site Access	3	-	3	-
Decision Complexity	3	1	1	1
Exiting Conditions	3	3	-	-
Schedule Acceleration	3	2	1	-
Cumulative Impact of Change Orders	2	-	1	1
Owner Changes / Approvals	2	1	-	1
Right of Way	2	1	1	-
Equipment Complications / Availability	1	-	1	-
Long Lead Items / Procurement	1	1	-	-
Owner-Mandated Subcontract	1	-	1	-
Project Delivery Method	1	1	-	-
Project Funding	1	-	-	1
Safety Hazards	1	1	-	-
Team Member Coordination	1	-	1	-
Unclear Project Purpose	1	1	-	-
New or Unfamiliar Technology	-	-	-	-
Project Cost Controls	-	-	-	-

Projects owners should seek to find the practices most likely to meet desired outcomes. This paper provides the management practices identified by industry leaders that could have improved project outcomes. One question on the survey asked respondents to select "which one management practice could have improved project outcomes the most." In other words, project owners were being asked to look back on a specific project and identify in hindsight the practice that would have had the most effect in mitigating the risks encountered on that project. The management practice options were analyzed by looking at the frequency of responses. The options and their frequencies were recorded and examined by all delivery methods together, as well as each delivery method individually. "Front end planning" was most frequently listed as the one management practice that could have improved the outcome of the project. The pie chart in Figure 1 shows the management practices that could have improved the project outcomes based on the frequency selected. One can see that 20 percent of the projects could have improved their outcomes by implementing better front end planning. "Project risk assessment" was also a management practice that was frequently selected, with 12 percent of respondents stating that this could have improved the outcomes. "Alignment of project participants" was the next most frequent selection, with 10 percent of respondents claiming this could have improved outcomes.

The management practice options were also broken down and analyzed by delivery method. It can be seen in Table 2 that the top selection of "front end planning" from above was also frequently selected for each delivery method, with a large portion of respondents in the DBB grouping selecting this as the management practice that would best improve project outcomes.

Table 2. Management Practices for Improved Project Outcomes

	ALL Projects	DBB	DB	CM/GC
Challenge	**No. (N = 56)**	**No. (N = 30)**	**No. (N = 18)**	**No. (N = 8)**
Front End Planning	12	8	2	2
Project Risk Assessment	6	4	2	-
Alignment of Project Participants	5	3	-	2
Dispute Prevention and Resolution	5	3	2	-
Constructability	4	1	2	1
Partnering	4	1	2	1
Team Building	4	2	2	-
Change Management Process	3	1	2	-
Materials Management	3	2	1	-
Use of Lessons Learned System	2	2	1	-
Planning for Startup	2	-	-	2
Quality Management	2	-	2	-
Benchmarking of Other Projects	1	1	-	-
Life Cycle Costing	1	1	-	-
Other	1	1	-	-
Value Engineering	1	1	-	-

Project owners identified the top practices that should be used to mitigate challenges that may face a transportation project. Most of these practices have been identified in project management research, and some have reached a level of recognition considered to be a "best practice" in the industry. It is critical to project success that these practices be studied and implicated to be able to best prepare for the inevitable risks of any project.

Risk Mitigation Practices

Understanding the practices that should be used to mitigate risk or project challenges is important for all involved in the construction process. Through this research, 21 individual risk mitigation suggestions were identified. The list of risk mitigation practices was compiled from interviews with transportation project owners. For a more detailed description on how these suggestions were obtained and vetted please refer Bingham (2014). Reported below is brief explanation of each suggestion. Additionally, the best practices to meet the objectives were identified. Owners and

Managers should identify the tools or practices in this list that pertain to their project and learn more about how to implement these practices within a project. Figure 1 shows a list of services recommended by transportation project owners and the recognized best practices to identify and reduce risk therefore reducing challenges to project outcomes. For example, project owners were asked to rank each best practice according to the effect they might have to reduce inherent risk involved in the services a transportation owner may require. If a transportation project owner wants to know how their fellow project owners would best reduce risks dealing with "schedule development", Figure 1 would point them to the use of a "Front End Planning" process first (weight of 25 in Figure 1) then to a "Plan for Startup" process (21), then a "use of lessons learned system" (14) and so on. Each service is therefore tied to the processes that will lead to the best outcome for that service or procedure. The number shown for each pairing relates to the number of times a transportation project owner gave a number one ranking to that best practice. For example if an owner wants to improve "agency coordination and estimating" then "alignment of project participants" should be the practice they should pursue as it was ranked number one 24 times.

Pre-construction Service / Best Practice	Identification of project objectives	Risk identification and assessment	Risk mitigation	Design management	Agency coordination and estimating	Constructability/bidability analysis	Value analysis/engineering	Bid packaging	Schedule development	Site logistics planning	Disruption avoidance planning	Small, women, and minority business participation	Construction phase sequencing	Subcontractor prequalification	Multiple bid package planning	Real-time cost feedback	Building information modeling	Total cost of ownership analysis	Cost estimating	Budget management	Stakeholder management	AVERAGE
Alignment of project participants	18	6	9	18	24	3	0	8	4	0	4	14	0	5	6	5	13	4	4	4	28	8.43
Benchmarking of other projects	9	3	0	3	3	3	0	0	11	0	4	5	4	10	0	0	0	4	4	4	0	3.19
Change management process	3	3	6	3	3	0	0	0	7	0	28	0	0	0	0	0	0	0	4	17	3	3.67
Constructability	3	10	3	9	0	53	7	8	7	12	8	5	42	0	12	0	7	0	15	0	0	9.57
Disputes prevention and resolution	3	3	6	6	3	7	0	0	0	4	24	0	4	5	0	10	0	0	0	4	0	3.76
Front end planning	33	6	6	15	14	10	4	24	25	32	8	0	12	0	12	5	13	8	11	4	14	12.19
Use of lessons learned system	3	6	12	6	0	3	4	8	14	16	4	0	4	14	18	5	7	0	7	8	3	6.76
Materials management	0	0	0	0	0	0	0	4	0	0	0	0	8	0	0	5	0	0	0	0	0	0.81
Partnering	9	3	6	6	17	3	4	0	0	4	4	24	4	14	6	5	0	0	0	0	24	6.33
Planning for startup	0	0	0	0	7	3	7	16	21	16	8	10	4	10	24	5	20	8	4	4	0	7.95
Project risk assessment	3	55	38	0	0	3	4	8	0	8	4	0	0	5	0	5	0	0	0	0	0	6.33
Quality management techniques	6	0	0	9	7	3	0	8	7	0	0	5	4	5	12	20	13	0	15	17	7	6.57
Team building	3	3	3	9	7	0	0	8	0	0	0	24	0	14	0	5	0	0	4	4	17	4.81
Zero accidents techniques	0	0	0	0	0	0	0	0	0	4	4	0	0	5	0	0	0	0	0	0	0	0.62
Sustainable design and construction	6	0	3	3	3	0	11	0	4	4	0	0	12	0	0	5	0	13	4	13	0	3.86
Value engineering	0	0	3	9	7	3	59	4	0	0	0	0	0	0	0	10	0	8	11	4	0	5.62
Life cycle costing	0	0	0	3	3	0	0	0	0	0	0	0	4	0	0	5	20	54	15	13	0	5.57
Other	0	0	3	0	0	3	0	4	0	0	0	14	0	14	12	10	7	0	4	4	3	3.71

Scale from least to most beneficial

Figure 1. Recommended Services and the Best Practice to Reduce Risk

There were 21 individual services identified that are common for transportation projects. In this section the authors provide insight into the findings for each of these services. While Figure 1 is a graphical representation of these findings, the commentary here represents a summary of the best approach for risk management and the ideal goals for each service. These are the direct suggestions of the 56 transportation project owners abridged for immediate contribution to current transportation project owners.

Identification of project objectives: Documentation of the project goals and objectives in clear, articulated, and agreed upon manner. Documentation of the requirements for the project, understanding of goals and aspirations, identification of key attributes, critical constraints, expected durations, budget, technologies, tools, and techniques to be used, quality requirements, and benefits to be achieved. Identification of project objectives is best accomplished through a formal front end planning process. Tools like the Project Definition Rating Index for Infrastructure Projects (CII 2020) can help formalized the process. Resources that deal with the alignment of project participants can also be helpful. Lastly, a benchmarking process can help in identifying objective from similar projects.

Risk identification and assessment: Determining the risk events that are likely to affect the project and classifying them according to their cause and source. Review, examination, and judgment to see whether identified risks are acceptable according to proposed actions. Transportation project owners cited the use of a formal project risk assessment procedure that includes a study of feasibility and examines alignment of project concept, scope, design, procurement, construction, commissioning and closeout. One key component for project owners was a thorough constructability review.

Risk mitigation: Risk response strategy that decreases risk by lowering the probability of a risk event occurrence or reducing the effect of the risk should it occur. This is different from risk identification and assessment because it assumes we will have certain risks, and those risk should therefore be managed wisely. Project owners once again cited a formal risk assessment procedure as the best practice to identify and mitigate risks, together with a use of a lessons learned system. In a lessons-learned system, project stakeholders can identify risks encountered in similar projects and communicate how those risk could have been mitigated.

Design management: Formal, documented, comprehensive and systematic examination of a design to evaluate its ability to meet specified requirements, identify problems, and propose solutions. There were several practices cited by project owners that could be used to avoid the risks related to design. Among those suggestions where the use of a front end planning process, alignment of project participants or team alignment practice, a constructability review, value engineering component, and team building exercises to improve communication within the design team.

Agency coordination and estimating: Management of functions and activities of representatives of agencies; facilitating decisions regarding the sharing of limited resources and the financial obligations of parties. Project owners felt that having a team alignment procedure in place was the best way to achieve good agency coordination. Partnering was also cited as an important aspect.

Constructability/bidability analysis: Review of design documents to ensure the documents are clear, the construction details efficient, and the architectural, structural, mechanical and electrical drawings are coordinated. The best way to assess constructability and bidabiltiy is to have a formal constructability review. This could be a part of a general front end planning review or separate.

Value analysis/engineering: Activity concerned with optimizing cost performance. Systematic use of techniques to identify the required function of an item, establish values for those functions at the lowest overall cost without loss of performance. Examines each element of a product or system to determine if there is a more effective way to achieve the same function. Tools that were identified to achieve a successful process of value engineering was to in short, have a component of value engineering in the project. This means advertisement and incentives for such a program. In the newer delivery methods, this process is improved because of the structure of the design, bid and build process.

Bid packaging: Ensuring that all the documents necessary for response and participation in a bidding process are complete. The concept of "planning for startup" was cited by a good number of project owners to help with bid packaging. Because startup is a transitional phase, a formalized plan for startup can help capture activities that bridge between phases. The majority of project owners cited the formal front end planning practice as the most important step to improve bid packing.

Schedule development: Analysis of activity sequences, activity durations, and resource requirements used to develop the project schedule. Involves assigning start and end dates to the project activities. These dates can be determined initially by applying the activity duration estimates to the activities in the project network diagram. Three highly cited best practice to help with schedule development were one again; a front end planning procedure, a plan for startup procedure, and the use of a lessons learned system. The best indicator of schedule durations and risks is past performance. Meaning learning from the lessons of the past, and making a plan to improve, is seen by project owners as a critical step in developing the project schedule.

Site logistics planning: Producing a site specific plan to establish efficient and safe working conditions for all parties adjacent to and within the construction zone. The plan is inclusive of major equipment placement, pedestrian and vehicular travel paths, staging of facilities and required temporary functions, lay down areas as well as means of emergency operation routes. Successful practices include front end planning, use of a lessons learned system, and planning for startup.

Disruption avoidance planning: Identification of potential disruptions to the project with specific planning for circumvention and prevention. Project owners advised to have a formalized change management process together with a plan for dispute prevention and resolution. A dispute prevention resolution plan could use a separate review board to avoid conflicts that may affect work progress. A change management process should touch all phases of a project from concept and feasibility through closeout.

Small, women, and minority owned business enterprise participation: Planning and coordination to meet goals for participation with a diverse group of business enterprises. Capturing the economic and social benefits of diverse business relationships. It may not be the goal of every project to include these types of incentive programs. But they do offer benefits to project that take advantage of partnering programs. Project owners site the need for team building programs to improve communication and cohesiveness. Alignment of project participants was also cited as a best practice.

Construction phase sequencing: Systematic structuring of related project activities resulting in major deliverables. The top cited practice to improve construction phase sequencing was completion of a constructability review.

Subcontractor prequalification: Determination of sub-contractor's responsibility prior to issuing a solicitation, request for proposal or tender.

Multiple bid package planning: Creation of multiple bid packages based on design documents. Administration of contracts with the owner.

Real-time cost feedback: A system or mode of software operation in which cost computation is performed during the actual time that the external process occurs.

Building information modeling: (BIM) is a process that involves creating and using an intelligent 3D model to inform and communicate project decisions. Design, visualization, simulation, and collaboration, provides greater clarity for all stakeholders across the project lifecycle.

Total cost of ownership analysis: Systematic process of examining the cost of owning, deploying and using a product, including the purchase price as well as support and maintenance of the life cycle of the product. Designed to guide in product selection and life cycle management.

Cost estimating: Process of estimating the cost of the resources needed to complete project activities. May include an economic evaluation an assessment of project investment cost, and a forecast of future trends and costs.

Budget management: Administration and oversight of resource requirements.

Stakeholder management: Action taken by the project team to curtail stakeholder activities that would adversely affect the project.

The construction services described above introduce into the project added risks, or can be used to mitigate risks. Project owners should be aware of these tasks, as well as the best practices to implement to be able to maximize the benefits and minimize possible risks.

CONCLUSIONS

Transportation project owners should be continually trying to identify and mitigate risk. This paper is helpful for project owners and managers alike to learn from the experience of other project owners as they identify the most prevalent sources of challenges to project outcomes, and ways these risk and challenges can be mitigated. As the use of different delivery methods influence the amount of involvement, and therefore risk that a project owner takes on, owners can use these results as a guide to mitigate risk within the main delivery methods used for these projects. Three delivery methods were discussed in this paper: Design Bid Build, Design Build and Construction Manger as Risk. The paper identifies environmental impacts, public involvement, and the project schedule as top risks for transportation projects in general. For DBB projects, existing conditions becomes a concern, and for DB projects construction site access was cited as a top concern. Practices that could improve project outcomes are also identified in the research. Front End Planning is the top practice suggested by owners, followed by performing a project risk assessment and adequate alignment of project participants. This paper contributes to the body of knowledge by providing a valuable tool for project owners and managers to identify possible sources of risk, and the most effective ways to mitigate those risks. Limitations of the research include the small sample size within the individual delivery methods. Future research will focus on identifying risks for a larger population of commercial construction and comparisons will be made between groups.

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Change Management in Construction: Necessity, Obstacles, and Suggested Solutions

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ABSTRACT

The construction industry is one of the major harbingers of the economy of any industrialized nation. Its contribution to the Gross Domestic Product is undeniable. The major economic downturn that lasted from 2008 to 2011 resulted in a lot of change in the industry personnel at both the administration and labor force levels. This resulted in expediting the retirement of a generation of seasoned professionals, and creating a gap in the ranks of construction firms that is still to be completely filled. Similar impacts followed the uncertainty resulting recently from Covid-19 and the economic instability and uncertainty it caused. One of the positive aspects of this downturn, and the following growth resulting from the economic recovery is the emergence of a new generation of industry leaders, and a relatively younger, more technologically perceptive workforce. Change was a necessity to cope with the generational change, and some companies managed to implement this change more successfully than others did. This paper aims at shedding some light on change management in general, with a focus on its obstacles in the construction industry, and some suggested solutions to facilitate and consolidate this change.

Keywords: Construction Industry, Change Management, Leadership

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Background

The construction industry is a major contributor to the US economy. In 2016, the industry employed 10.328 million people in the United States alone, with a payroll of approximately $792.5 Billion. AGC estimates that an extra $1 billion in nonresidential construction spending adds about $3.4 billion to Gross Domestic Product (GDP) (AGC 2018). With increasing factors affecting the international trade and national economies, the construction industry is one of the first industries to suffer from economic downturns, and one of the last to fully recover from such downturns (FMI 2017). This cyclical alternation between times of boom and bust are becoming the norm in the industry resulting in bankruptcies, mergers and consolidation, and other major restructuring efforts affecting the face of the industry and its practices. Upon recovering from each downturn, the industry faces new challenges necessitating changes in its mode of operation and many of its established practices. This most recent recovery after the start of Covid-19 pandemic is no exception. Construction companies are competing for acquiring business from more sophisticated and money-savvy clients.

Problem Statement

Developments in project delivery and technologies assisting this delivery are becoming the standard rather than the exception. Changes in the leadership of construction businesses create another set of challenges as a younger generation comes with a new perspective on the construction industry. This new perspective includes a new vision and modern concepts and tools such as sustainability, project visualization and virtual construction, big data and analytics, machine learning and artificial intelligence. This new leadership will also have to deal with more dynamic domestic and international markets. This happens while the departing leadership sometimes fails in transferring their cumulative knowledge to the new leadership, resulting in a loss of the institutional memory and some of the lessons learned from both past successful and failing implementations. Instituting change has its obstacles and should follow a structured approach leading to the safe and efficient transition among generations.

A survey was sent to the construction industry professionals through the mailing list of the Associated Schools of Construction to gauge their practices on change management. The survey included demographic questions about the average age and tenure of the current leadership. Other questions inquired about the segment each respondent represents in the industry, and whether the different organizations followed a structured approach for succession planning and leadership transition. Following questions included the identification of the change management approach the organization followed, if any. Responses were received from 120 organizations representing different roles in the industry including General Contractors (38%), Construction Managers (26%), Specialty Subcontractors (19%), Architects and Designers (8%), Insurance and Sureties (3%), and Academics (4%). Overall, 63% of the respondents indicated that their top leadership has been in a leadership position for over 15 years. Only 8% indicated that they have a structured process for leadership succession and change management. A vast majority of the respondents (78%) indicated that they would welcome a structured approach to facilitate that transition and implementing change in their organizations

Models for Change Management

As it has been consistently repeated, the only constant in a project is change. Failing to proactively address change results in undesirable project outcomes manifested as project delays, cost overruns, disputes, and souring relationships among different project stakeholders. The old adage of starting the project with a solid plan has been practically replaced by the new motto: start the project with a fluid plan; one that can incorporate changes and adapt to these changes before, during, and after they materialize.

Change management has been integrated in project management as one of its essential skills (PMI, 2017). Many change management models have been developed over the years, with different levels of popularity and success. The most notable of these models will be listed in this paragraph, and then elaborated on in the following paragraphs in the paper, together with their implementation in the construction industry.

Kotter first introduced his 8-step model in 1995 in his famous article "Leading Change: Why Transformation Efforts Fail" published in the Harvard Business Review (Kotter, 1995) which was based on the analysis of over one hundred change initiatives in organizations that planned to implement large scale changes.

Leavitt considered that the factors affecting organizational change could be condensed into four factors represented by his Diamond (2005).

Another model was the ADKAR model developed by Jeff Hiatt in his book "ADKAR: A model for Change in Business, Government, and our Community" (2006). Creasey and Hiatt further refined the model in the ProSci model (2014).

Burke and Litwin (1992) focused on developing their model on two major elements; organizational functioning and organizational change.

Merrell developed his Big Six model (2012) to address effective change management, and Mckinsey Consultants developed their 7S model for organizational change (2015).

Kotter's 8 step model to effecting the change

Kotter's model for organizational change consists of eight sequential steps leading the change champion within the organization to follow a clearly marked roadmap resulting in the sought change. This roadmap starts with:

1- Establishing a sense of urgency within the organization that change is impending or has to happen. Smart leaders in the construction industry will recognize the triggers for this change manifested by:

   a) An aging leadership (Mostly baby boomers), as it was estimated that boomers comprise 40% of the construction workforce, with an even higher percentage (54%) of construction managers (Jobsite, 2016)

   b) A change in the construction environment due to new technologies, tools and techniques

   c) The need to empower a new generation of young professionals who grew up in the digital age and are academically equipped to, with some guidance, address the new challenges facing the industry.

   As Kotter suggested, examining market and competitive realities will enable the organization to establish benchmarks to meet and identify its strengths and weaknesses while contemplate the opportunities and threats that it is facing.

2- The second step on that roadmap is to create a guiding coalition. This can be achieved from within the organization, or through local or national trade organizations and professional associations. Local AGC chapters, as well as national research organizations such as the

Construction Industry Institute (CII) or the Construction Users Round Table (CURT) can serve as a repository for lessons learned and best practices assisting the organization to achieve the change. Internally, the organization must empower change champions to form a team overseeing the development steps needed to obtain the buy-in from different stakeholders.

3- The third step is developing both a vision and a strategy for change: A vision may include expanding to new markets, tackling more complex or innovative projects, automation and modernization of assets and fleets, and most importantly grooming a new generation of construction leaders to allow the organization to remain competitive in an ever-changing market. The strategy will translate this vision into long-term steps to be taken to achieve the vision.

4- The fourth step is communicating the vision through internal communication within the organization. This communication can use both the push and pull modes: push to close and influential stakeholders and pull to the general public and other less crucial stakeholders by posting the vision for change on the organization's website. Transparency, timeliness, and openness are key features leading to the success of this communication, explaining the expected obstacles and steps to overcome them.

5- The fifth step deals with empowering others to act on the vision by reducing or removing any obstacles that could derail the change process. New behaviors will have to be learned, new processes will have to be developed, and teams will be encouraged to take risks and adopt non-traditional ideas, activities, and actions. Key employees affected by the change will have to be shown "what's in it for me", and "what's in it for the organization". Addressing the concerns of the affected employees will help reduce the resistance and pave the way for the change to settle-in.

6- The sixth step will help confirming that the change is going in the right direction by planning for and creating short-term wins. Visible and measurable performance improvements should be documented, while rewarding the employees and the change team members involved in these improvements. The low hanging fruit should be targeted and success results such as timely completion of projects, successful deployment of new systems, or acquisition of new business entities should be shared with all stakeholders. These early wins will encourage employees to follow the change roadmap hoping to achieve the full benefits of the vision and the strategy.

7- Gains from the sixth step will facilitate the seventh step, which calls for consolidating improvements and producing more change. The short-term wins result in increased credibility of the change initiative and helps beget more successes as skeptics will start seeing the results of the change. By this time, change has developed its own momentum that needs to be maintained by further education, coaching, and development of the staff to increase the number of active change agents.

8- Finally, the eighth step culminates the change process by institutionalizing the new approaches and reinforcing them so that they become the new organizational culture. Activities that can help this reinforcement include articulating the connections between the new and modified behaviors and the corporate success. Promoting the change agents to leadership positions and entrusting them with the decision-making power for the organization will accomplish the transition from one generation to the other.

Applying this model has its obstacles that can derail its successful implementation, and these include:

1- Allowing too much complacency, which would be the opposite of the urgent need for change
2- Failure to create a sufficiently powerful leading team which would be contrary to the guiding coalition
3- Underestimating the power of vision, by not properly and clearly articulating that vision
4- Failure to clearly and timely communicating the vision
5- Permitting the first obstacles to block the new vision, thus preventing the quick successes
6- Failure to create the short-term wins, thus losing momentum and weakening morale
7- Declaring victory too soon before the change has been reinforced and institutionalized
8- Neglecting to anchor the changes firmly in the organizational culture and the corporate best practices.

Understanding these obstacles before the start of the change initiative will enable devising mechanisms and metrics for their avoidance.

The Burke-Litwin Model for Change

In this model, Burke and Litwin focus on the elements that shape the organization's business climate and culture, and how impacting these elements facilitates the change process. They define Climate as the explicit external and internal parameters and constraints under which the organization operates, whereas culture is defined as the background factors leading the organization to behave a certain way. For example, the availability of competition, the market environment and whether it is a period of boom or bust in the construction industry, and the prevailing laws and regulatory environment (bidding laws, free trade and tariffs, buy-American, Davis-Bacon act, Union or open shop, etc.) are examples of factors determining the organization's working climate. Whereas culture comes from within, therefore the move from the founding generation of a construction organization to an employee-led generation, the power distance elements within the organization (including the organization's structure and hierarchy) are examples of cultural elements affecting the change.

Applying the model shown in Figure 1 takes into consideration both climate and culture conditions. Change will focus on three major elements or "Levers":

- The core values of the organization: including its mission, goals and strategies, its leadership (personnel and leadership style), and its culture
- The Alignment Levers: Which include the structure of the organization, its systems, processes and policies, and its management practices and local workplace climate.
- The Individual Levers: Dealing primarily with personnel and including their skills and competencies, their needs and values, and their motivation factors and their fulfillment

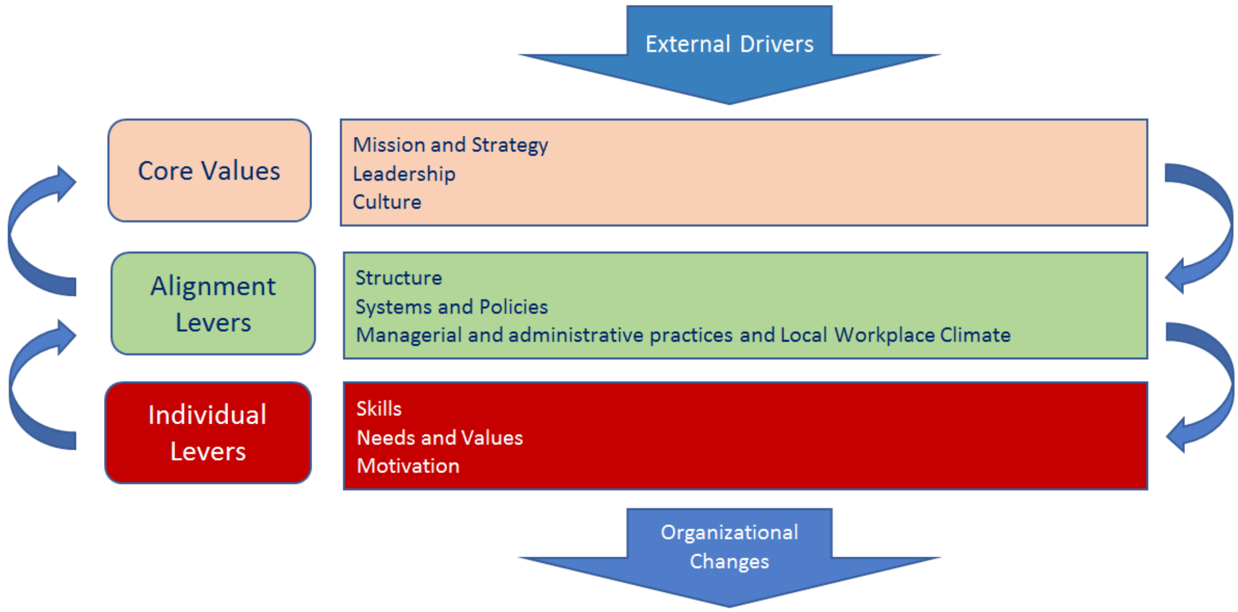

Figure 1: Burke-Litwin Model for Organizational Change

Burke later simplified and grouped the model into four major chronological phases including:

1- Prelaunch phase

2- Launch phase

3- Post-launch phase

4- Sustaining phase.

The Leavitt's Diamond

Leavitt considered that, in addition to the external environment affecting organizational performance, four internal elements affect how it operates, and any change has to occur internally along these four elements: Structure, Technology, Tasks, and People. The structure of the organization determines largely how it operates and determines the influence of project managers in managing their projects. A functional organization with distinct departments (Estimating, Scheduling, Operations, Human Resources, Legal, Financial, etc.) has a limited role for the project manager in the project evaluation and pre-construction phases. A matrix organization allows for more communication lines among the functions through the project managers and gives a larger role to the project manager from the early phases of the project. More companies today operate in a projectized environment, where the project acts as a satellite branch of the organization allowing the highest level of autonomy for the project manager. The older model of centralized functional organizations is gradually disappearing while the more agile and flexible projectized organizations are on the rise. The former model suits the founding generation, whereas the latter favors a more mobile and generally younger workforce.

Tasks represent the mission of the organization and the deliverables it produces, in this case different forms of construction projects. The Type of projects the organization pursues, their size and complexity, and the forms of contracts it works under (collaborative, competitive, firm price, cost plus, etc.) can be included under this element. With market changes moving gradually from competitive to collaborative, and from firm prices to negotiated prices and GMP, the type of competition the organization faces, and therefore its contractual relationships with its stakeholders and collaborators (subcontractors, suppliers, clients, etc.) need to be revisited.

Technology represents the software and hardware, including the information systems that the organization utilizes to operate, and which should be periodically reviewed and revisited to reflect changes in the market and organizational practices. An older generation is more versed in conventional and analog systems that are based on foundational knowledge and standard practices, whereas a newer generation grew up with the digital interconnected environment and feels more at ease with visualization and digital tools. Growing trends in cloud computing and collaborative participation allow for higher levels of communication and timely information exchange among project team members. Emerging trends including machine learning and artificial intelligence, virtual construction and project visualization, autonomous vehicles and satellite-guided equipment among other technologies are gradually changing the face of the industry in favor of the newer generation.

Finally, and most importantly, people are the fourth focus of the change initiative. Training and continuous retooling of the individuals' skill sets to cope with the changes in the previous three elements becomes necessary. This starts with up-to-date construction education curricula, continuous training and upgrading of the workforce, and allowing for a career path rewarding the achievements in learning new concepts and adapting to a changing environment. Trusting the younger generation with more responsibility and delegating more authority to this generation allows them to gain confidence and approach the change with an open mind and a clear vision.

Figure 2 reflects the interaction among the four elements of the Leavitt's diamond

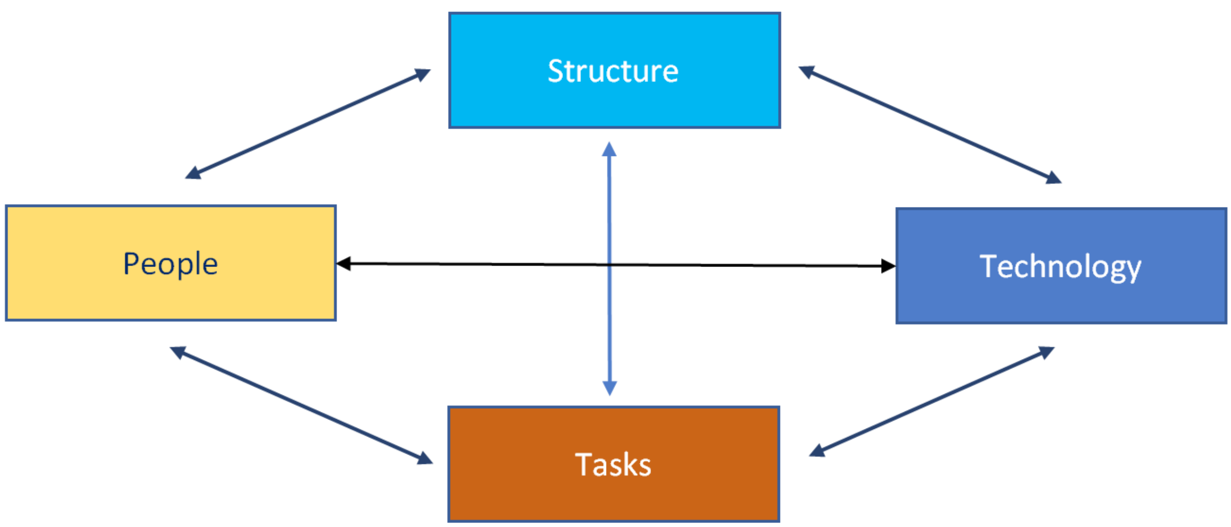

Figure 2: Leavitt's Diamond

The ADKAR Model

The ADKAR model primarily focuses on the stakeholders and how to motivate them to support the change and supplying them with the necessary skills and tools needed to facilitate the change and sustain it when it is complete. One of the main differences between ADKAR model and Kotter's model is that the former stresses the follow-up once the change is accomplished to make sure it grows roots and is reinforced within the culture of the organization.

One of the advantages of using this model is that it provides a structured approach and a roadmap for change. Like Kotter's model, it starts with the awareness of the need of change, which can be conducted in a strategy retreat mapping the organization's future in the medium to long-term. Obtaining the buy-in from the participants, including both existing and future leadership is key to the success of the process. In many cases, a facilitator is brought in to illustrate to the stakeholders the advantages of the proposed change, as well as the risks of conducting business in the same old fashion. The facilitator can assist the stakeholders in charting a path for change, including different deliverables and metrics to measure the taken steps towards the goals and results the organization aspires to achieve. Both groups (existing and proposed leadership) work on a gradual handing over approach coupled with a timeline for implementation and stage gates to gauge the progress. Similar to Kotter's model, focus should be given to fast wins to boost the morale of the change team and highlight the achieved positive results from the change initiative. Once the change is complete, a periodic review is conducted to confirm and reinforce the changes and allow for fine-tuning the methods used to institutionalize the change and make it part of the organization's culture. Figure 3 illustrates the steps forming the acronym ADKAR and consisting of the five structured steps of the process.

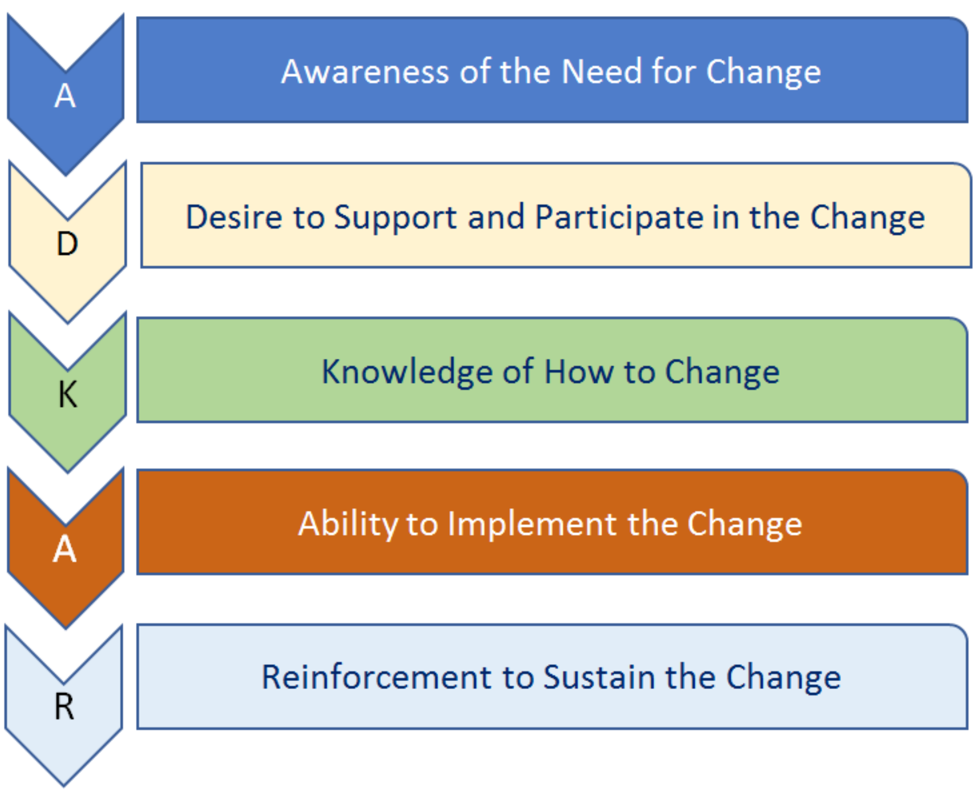

Figure 3: ADKAR Model

Some of the obstacles to the ADKAR model include:

1- Comfort with the status quo and underestimating the challenges and the risks of not adopting change

2- Lack of credibility of the change leader and allowing too much debate about the value of change

3- Fear of the unknown and seeking safety in the known comfort zone

4- Insufficient knowledge, time, or resources dedicated to the change

5- Lack of support due to limitations of individuals and psychological blocks

6- Not clearly identifying the rewards and allowing the team to revert to the old practices.

Recognizing these obstacles allows for developing counter-measures leading to a successful implementation.

The McKinsey 7S Model

As reported by Ravanfar (2015), this model was developed by McKinsey Consultants in the 1980s, and addresses seven different elements within the organization that have an influence on organizational performance. They coined the model the seven S as they listed these elements, which are Strategy, Structure, Systems, Shared Values, Style, Skills, and Staff. The key point of the model is that the seven areas are closely interconnected, as it appears in Figure 3, and that any deficiency in one of these areas will negatively affect the other areas. They divided these 7 S into two categories: the Soft S and the Hard S. The soft S, which are the main focus of the model are:

1- Structure: including the Power Distance within the organization, or the level of formality and hierarchy within that structure. If there are multiple layers separating the performers (front line on the projects) from the upper administration, whether these layers are due to age, experience, title, or position, the end result is limited communication and reduction in the ability to transfer the lessons learned from one group to another. Function organizations with minimum interface among the different departments will also create barriers to smooth communication and impede the organizational development.

2- Shared Values: These appear at the core of the model, and the emphasis is regardless of the position within the hierarchy, all members of the organization should share these values and promulgate them. Many construction organizations today try to condense these shared values into some catchy slogans like ”we Lead with Safety”, or “everybody Counts” to highlight the focus of the organization on safety or collaborative and consultative decision making.

3- Skills: Reflects the ability of the employees to perform their job to the highest possible standards. Coaching and mentoring of the young workforce by more senior leaders, in addition to regular training and education leads to an increase in the level of performance of the staff, which correlates to a better performance of the organization. Formalizing the documentation and dissemination of lessons learned from previous projects allows for a shorter learning curve and a high level of consistency in the performance of the organization.

4- Staff: Reflects the processes of recruitment, retention, promotion, and appointments for the different staff. Gradually entrusting younger staff with more responsibilities, under the supervision of senior leadership, will expedite their maturity and the ability to perform successfully on their own.

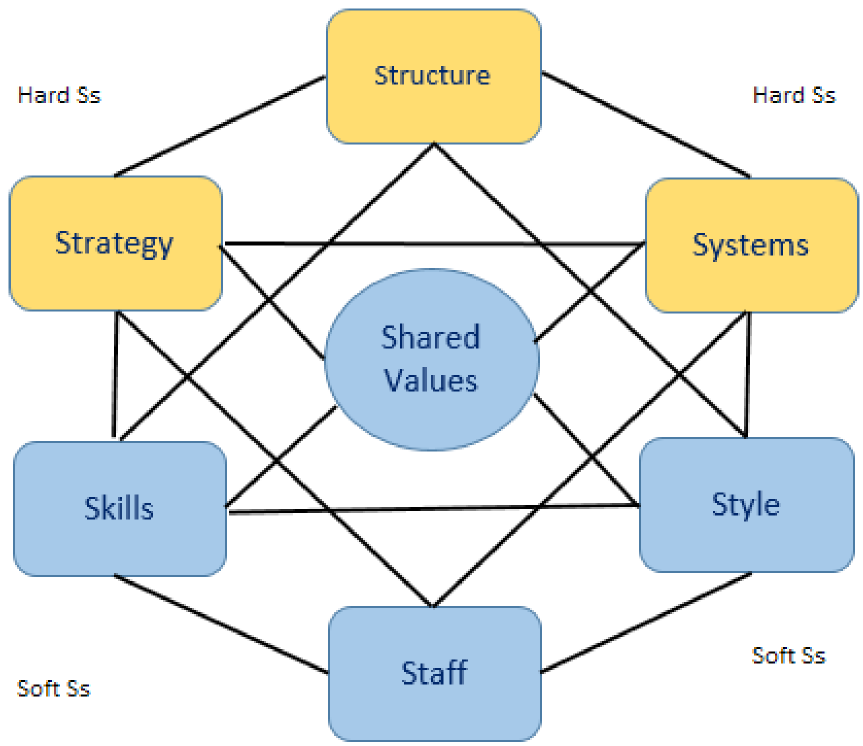

Figure 4: McKinsey 7S Model

Applying the model requires the alignment of all seven S, through a structured approach to provide proper identification of the areas that need more work, determining the optimal organizational structure, deciding where the changes should be made, making the necessary changes, and finally continuously reviewing the Seven S to make sure that the implemented changes were effective and become institutionalized.

Conclusion

Construction organizational change is imperative to allow for successful and smooth transition between generations of construction professionals, and allow for resilient response to disruptive events as currently witnessed by the Covid-19 pandemic and the uncertainty it caused in all aspects of life. Different models can provide a roadmap for the change and allow for its achievement in a structured way, leading to its institutionalization so that it becomes an integral part of the organizational culture. Each model has a specific focus, whether it is the process, its elements, or its stakeholders. All the models start from the same point and end with the same result: the start is the recognition of the need for change, and the end result is the completion of the change initiative. Change can be summarized in three consecutive steps: Unfreeze the current practice, conduct the change, refreeze and monitor the new practices while periodically reviewing and fine-tuning. The speed of change in the industry will make the adoption of such models indispensable as new opportunities and challenges emerge, necessitating a quick response and adaptation to the changing environment. Other models can be used such as the McKensie 7 step model or the Merrell Big Six model.

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