The origins of PERT and CPM

PERT[1] and CPM[2] played an important role in the development of project management[3] and represented a quantum shift in the practice of project scheduling[4]. This paper looks at ***'what came before the computers'***, a number of very similar techniques for scheduling developed in the USA and Europe within a few months of each other during the late 1950s, all using very similar concepts, but each development started in isolation and the developers seemed to be completely unaware of the other developments for a significant period of time. This paper seeks to identify the common roots that led to the emergence of network based scheduling from a mathematical perspective and a conceptual/terminological perspective.

Where did the terms come from?

As outlined above and in the references, the development of PERT and CPM as software systems for mainframe computers started in 1957. The developments are well documented with contemporary accounts from the key people involved readily available[5]. What is less clear is how two systems developed contemporaneously, but in isolation in the USA, as well as a number of less well documented similar systems developed in the same timeframe in the UK and Europe, all came to have so many features in common.

No area proved more challenging for the US Army Quartermaster Corps than the war in the Pacific.

The early tools developed in the USA and the UK used the 'activity-on-arrow' (AoA or ADM) notation which is a far from obvious model. Whereas later iterations of the concept of CPM in the USA and most of the European systems such as MPM used the 'precedence' notation which evolved from the way flow-charts were and are drawn.

One obvious connection between the early developments was the community of interest around Operation (or Operational) Research (OR) a concept developed by the British at the beginning of WW2 (discussed below), but while this link explains some of the cross pollination of ideas and the mathematics it does not explain terms such as 'float' and the AoA notation

Chris Fostel, an Engineering Planning Analyst with Northrop Grumman Corporation appears to offer a rational explanation[6] and is reproduced below.

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[1] For more on the ***origins of PERT*** see: http://www.mosaicprojects.com.au/PM-History.html#PERT

[2] CPM = Critical Path Method

[3] For more on the ***origins of modern project management*** see: http://www.mosaicprojects.com.au/PDF_Papers/P050_Origins_of_Modern_PM.pdf

[4] For more on the ***history of scheduling*** see: http://www.mosaicprojects.com.au/PDF_Papers/P042_History%20of%20Scheduling.pdf

[5] To access many of the original papers see: http://www.mosaicprojects.com.au/PM-History.html#CPM

[6] This oral history has been widely circulated via the Mosaic Blog and other social networking tools – to date no one has suggested the history is incorrect.

Chris' Oral History

I was told this story in 1978 by a retired quartermaster who founded his own company after the War to utilize his global contacts and planning skills. Unfortunately the individual who told me this story passed away quite a few years ago and I'm not sure any of his compatriots are still alive either. Regardless, I thought I should pass this along before I join them in the next life. I do not wish to minimize the work of Kelly and Walker. They introduced critical path scheduling to the world and formalized the algorithms. They did not develop or invent the technique.

The origin of critical path scheduling was the planning of the US Pacific Island hopping campaign during World War II. The Quartermaster Corps coordinated orders to dozens if not hundreds of warships, troop ships and supply ships for each assault on a new island. If any ships arrived early it would alert the Japanese of an imminent attack. Surprise was critical to the success of the island hopping campaign. The US did not have enough warships to fight off the much larger Japanese fleet until late in the war. Alerting the Japanese high command would allow the Japanese fleet to intercept and destroy the slow moving US troop ships before they had a chance to launch an attack.

Initially the quartermasters drew up their plans on maps of the pacific islands, including current location and travel times of each ship involved. The travel times were drawn as arrows on the map. Significant events, personnel or supplies that traveled by air were shown as dashed lines hopping over the ship's arrows. The quartermasters would then calculate shortest and longest travel times to the destination for all ships involved in the assault. The plans became very complicated. Many ships made intermediate stops at various islands to refuel or transfer cargo and personnel. The goal was to have all ships arrive at the same time. It didn't take the quartermasters long to realize that a photograph of the planning maps would be a devastating intelligence lapse. They started drawing the islands as identical bubbles with identification codes and no particular geographical order on the bubble and arrow charts. These were the first activity on arrow critical path charts; circa 1942.

The only validation I can offer you is that by now you should realize that activity on arrow diagrams were intuitive as was the term 'float.' Float was the amount of time a particular ship could float at anchor before getting underway for the rendezvous. Later when the US quartermasters introduced the technique to the British for planning the D-Day invasion the British changed float to "Slack", to broaden the term to include air force and army units which did not float, but could 'slack off' for the designated period of time.

You will not find a written, dated, account of this story by a quartermaster corps veteran. Critical path scheduling was a military secret until declassification in 1956. In typical fashion, the veterans of WWII did not write about their experiences during the War. No one broke the military secrecy. After 1956 they were free to pass the method on to corporate planners such as Kelly and Walker. A living WWII Quartermaster veteran, should be able to provide more than my intuitive confirmation.

This narrative makes sense from a historical perspective (military planning has involved drawing arrows on maps for at least 200 years) and a timing perspective with the development of PERT in particular kicking off in 1957 on a major US navy program[7].

[7] Any contrary of corroborative information will be gratefully received.

Operations Research (OR)

Operations Research is a branch of applied science that supports management decision making and has a critical role in the development of CPM scheduling. Operations Research (OR) is an interdisciplinary science which deploys methods such as mathematical modelling/optimisation, statistics, and algorithms to decision making in complex real-world problems concerned with the coordination and execution of the operations within an organisation. It is distinguished by its ability to look at and improve an entire system, rather than concentrating only on specific elements (though this is often done as well). The growth of OR was to a large extent the result of the increasing power and widespread availability of computers. Most (though not all) OR involves carrying out large numbers of calculations which would be a practical impossibility without computers. Some of the specific techniques used include linear programming, statistics, optimisation, stochastics, queuing theory, game theory, graph theory, and simulation[8].

Americans refer to 'operations research', British/Europeans to 'operational research'; fortunately both are shortened to just OR. Other terms used for this field (or closely allied fields) include 'management science' (MS), which can be combined to OR/MS or ORMS, 'industrial engineering' (IE) and 'decision science' (DS).

OR started in the late 1930s and has grown and expanded tremendously. In July 1938, with the prospect of war imminent, the British Air Ministry conducted a major air-defence exercise using its new radar stations. This exercise revealed a new and serious problem had arisen, the need to coordinate and correlate multiple, and often conflicting, streams of information received from various sources. A new approach was needed.

Accordingly, on the termination of the exercise, the Superintendent of Bawdsey Research Station, A.P. Rowe, proposed that a crash program of research into the operational - as opposed to the technical - aspects of the air-defence system should begin immediately. The term 'operational research' [RESEARCH into (military) OPERATIONS] was coined as a suitable description of this new branch of applied science. The first team was selected from amongst the scientists of the radar research group the same day.

Although scientists had been involved in the hardware side of warfare for decades (if not centuries) scientific analysis of the operational use of military resources had never taken place in a systematic fashion before the Second World War. What the OR people brought to their work were 'scientifically trained' minds, used to querying assumptions, logic, exploring hypotheses, devising experiments, collecting data, analysing numbers, etc. By the end of the war OR was well established in the armed services both in the UK and in the USA.

Following the end of the war OR took a different course in the UK as opposed to in the USA. In the UK many of the distinguished OR workers returned to their original peacetime disciplines. As such OR did not spread particularly well, whereas in the USA OR spread to the universities so that systematic training in OR for future workers began.

OR appears to be the catalyst that triggered the start of CPM scheduling. The Operational Research Section of the UK Central Electricity Generating Board were significant early adopters of CPM[9] and the purchase of a book on 'Operation Research' in 1958 triggered the ground breaking work by H.B. Zachry Company (Texas) that led to IBM developing its 'Project Control System' software[10]. Critically, OR was also an area of interest to Jim Kelley. Kelley was scheduled to give a paper to the Case Institute operations research conference in January 1957 when he was seconded to the du Pont team being assembled by Morgan Walker

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[8] See http://en.wikipedia.org/wiki/Operations_research

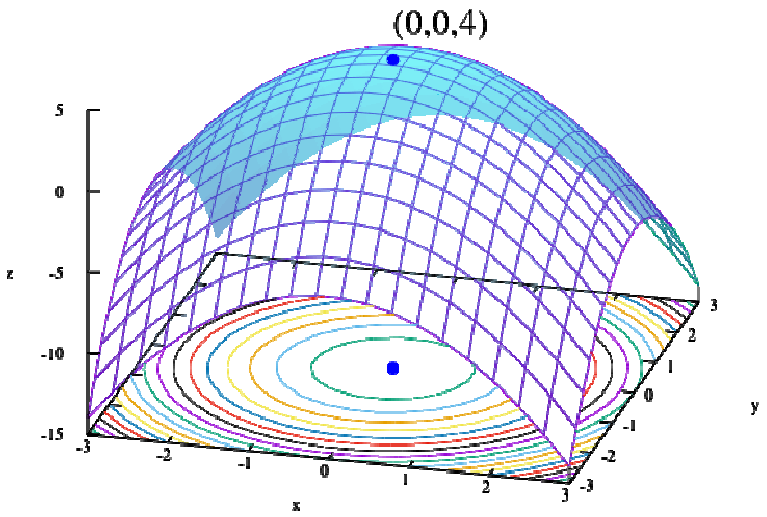
[9] Discussed in more detail in ***'A brief History of Scheduling'*** http://www.mosaicprojects.com.au/Resources_Papers_042.html

[10] Discussed in more detail in ***'A brief History of Scheduling'*** http://www.mosaicprojects.com.au/Resources_Papers_042.html

that lead to the development of CPM. Kelley's paper to the OR conference went ahead with the inclusion of a 'simple linear program formulation' of the construction scheduling problem'[11]. There would also appear to be a strong link between the work at the Case Institute[12] and the development of CPM at the H.B. Zachry Co. Later the development of Hammocks, Ladders and other advanced techniques by ICL in the UK was supported and encouraged by a carder of UK, OR Society members[13].

The relatively coordinated developments of various CPM systems in the USA, UK and Europe and the documented links between OR and several of these developments strongly suggest that OR concepts and processes such as linear programming spawned the concepts of CPM and the inter-society communications led to the early cross pollination of ideas between the pioneers prior to the emergence of 'project management' organisations such as INTERNET and PMI.

Mathematical Optimisation



In mathematics, computer science and (importantly) operations research, mathematical optimisation (alternatively named mathematical programming or simply optimisation), is the selection of a best element (with regard to some criterion) from some set of available alternatives.

Fermat (1607 – 1665) and Lagrange (1736 – 1813) developed calculus-based formulas for identifying optima, while Newton and Gauss proposed iterative methods for moving towards an optimum in the 18th and 19th centuries. These concepts gave rise to a range of mathematical approaches including dynamic programming and linear programming. Both are used in numerous fields of study, including Operations Research.

The term dynamic programming (DP) was originally used in the 1940s by Richard Bellman to describe the process of solving problems where one needs to sequentially find the best decision based on the consequences of previous decisions in the series. By 1953, he had refined this to the modern meaning, referring specifically to nesting smaller decision problems inside larger decisions while working as an applied mathematician at Rand Corporation. DP is based on a principle called Bellman's Principle of Optimality. DP can be applied to a variety of difficult optimization problems, but the use of DP is an art rather than science.

The DP approach looks like sequential (dynamic) decision making that involves development of a model based on a recursive relationships such as: "Completion time of a task in a project is the task duration plus the maximum of completion times of its predecessors". Using the DP approach (with a similar recursive

[11] Kelley J.E. Jr and Walker M.R. The Origins of CPM, A Personal History. pmNetwork Vol III, No. 2, Feb 1989. PMI, USA. http://www.pmi.org/learning/library/origins-cpm-personal-history-3762

[12] The Case Institute of Technology was a university that merged with Western Reserve University to form Case Western Reserve University, Ohio, USA.

[13] For more on the origins of ***Hammocks and Ladders*** see http://www.mosaicprojects.com.au/Mag_Articles/P016_The_Origins_of_Hammocks_and_Ladders.pdf

relation), Edsger Dijkstra developed an algorithm in 1956 to find the shortest path between any two nodes in a directed network[14]. Using Dijkstra's algorithm with a very small change in the underlying recursive relation, we can easily find the longest path in the precedence network of a project. This is exactly how CPM networks using a precedence notation (PDM or AoN) find the longest path and would appear to be one of the influences in the development of CPM in 1957[15].

Linear programming[16] (LP) is a special form of mathematical optimisation specifically mentioned by Kelley in a number of contexts around the development of CPM. LP (also called linear optimization) is a method to achieve the best outcome in a mathematical model whose requirements are represented by linear relationships – the concept of i-j nodes in the 'activity-on-arrow' (AoA) network diagram developed by Kelley and Walker is a direct lift from LP.

The term 'linear programming' was coined by George B. Dantzig, although much of the theory had been introduced by Leonid Kantorovich in 1939. It is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. It was developed during World War II to plan expenditures and returns in order to reduce costs to the army and increase losses to the enemy. LP was kept secret until 1947[17] when Dantzig published the Simplex algorithm, and John von Neumann developed the theory of duality in the same year.

In the decade between 1947 and 1957 there were numerous OR conferences discussing these mathematical consequences and seeking to improve the outcomes from industry – the transition from DP into 'precedence diagramming' and LP into Arrow diagramming would seem to be proven.

Summary

The mathematical underpinning of critical path scheduling and the reason so many similar systems emerged in a very short timeframe during the late 1950s seem to be directly linked to the advances in mathematical modelling and optimisation, supported by the forum for the exchange of ideas provided by numerous OR conferences and the professional OR organisations; some of which still exist today.

The difference in approach to the drawing of the network diagram between the 'activity on node' (AoN) approach used by PDM (John Fondahl), and MPM, RPS and HMN in Europe[18]; and the 'activity on arrow' (AoA) approach used by CPM and PERT would appear to be the influence of the US military's logistic planning processes outlined above. Fondahl deliberately chose to remain with the more normal 'flow chart' approach of AoN after seeing the US Navy's PERT system, and the European's were probably unaware of these classified systems. Kelley was directly involved in using LP mathematics for the US military before moving into civilian life and PERT was a US Navy development – for people working on these projects the

[14] This class of algorithm was originally developed by Czech mathematician Vojtěch Jarník[in 1930 and later rediscovered and republished by computer scientists Robert C. Prim in 1957, and then Edsger W. Dijkstra in 1959. It is also sometimes called the DJP algorithm, Jarník's algorithm, the Prim–Jarník algorithm, or the Prim–Dijkstra algorithm. The widespread use of the concept makes it highly probably that the developers of the various scheduling algorithms used in the early tools were familiar with the concept.

[15] For further discussion on the link between DP and CPM, see Prasad Velaga, PhD: https://www.linkedin.com/pulse/some-similarity-between-critical-path-method-dynamic-prasad-velaga.

[16] Programming in this context does not refer to computer programming, but from the use of program by the United States military to refer to proposed training and logistics schedules, which were the problems Dantzig studied at that time.

[17] Note: Kelley was a mathematician employed by the US military before joining Remington Rand Univac and working on the development of CPM

[18] For a brief discussion on MPM, RPS and HMN see the 'European Developments' section of in ***'A brief History of Scheduling'*** http://www.mosaicprojects.com.au/Resources_Papers_042.html

AoA approach would appear normal. For everyone else the more normal notation of a flow chart would have seemed more sensible.
