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A BRIEF HISTORY OF SCHEDULING

- BACK TO THE FUTURE -

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See also: *The Origins of Modern Project Management:*
https://mosaicprojects.com.au/PDF_Papers/P050_Origins_of_Modern_PM.pdf

The Origins of Bar Charting
https://mosaicprojects.com.au/PDF_Papers/P182_The_origins_of_bar_charting.pdf

Mosaic's complete PM History resource is available from:
https://mosaicprojects.com.au/PMKI-ZSY.php

For more scheduling papers see Mosaic's Planning and Scheduling Home page:
https://mosaicprojects.com.au/PMKI-SCH.php

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Introduction

The science of 'scheduling' as defined by Critical Path Analysis (CPA) celebrated its 50th Anniversary in 2007. In 1956/57 Kelly and Walker started developing the algorithms that became the 'Activity-on-Arrow' or ADM scheduling methodology for DuPont. The program they developed was trialled on plant shutdowns in 1957 and their first paper on critical path scheduling was published in March 1959. The PERT system was developed at around the same time but lagged CPM by 6 to 12 months (although the term 'critical path' was invented by the PERT team). Later the Precedence (PDM) methodology was developed by Dr. John Fondahl; his seminal paper was published in 1961 describing PDM as a 'non-computer' alternative to CPM. Arguably, the evolution of modern project management is a direct consequence of the need to make effective use of the data generated by the schedulers in an attempt to manage and control the critical path[1].

The evolution of CPM scheduling closely tracked the development of computers. The initial systems were complex mainframe behemoths, typically taking a new scheduler many months to learn to use. These systems migrated to the 'mini computers' of the 1970s and 80s but remained expensive, encouraging the widespread use of manual scheduling techniques, with only the larger (or more sophisticated) organisations being able to afford a central scheduling office and the supporting computer systems.

The advent of the 'micro computer' (ie, personal computer, or PC) changed scheduling for ever. The evolution of PC based scheduling move project controls from an environment where a skilled cadre of schedulers operating expensive systems made sure the scheduling was 'right' (and the organisation 'owned' the data) to a situation where anyone could learn to drive a scheduling software package, schedules became 'islands of data' sitting on peoples' desktops and the overall quality of scheduling plummeted.

Current trends back to 'Enterprise' systems supported by PMOs seem to be redressing the balance and offering the best of both worlds. From the technology perspective, information is managed centrally, but is easily available on anyone's desktop via web enabled and networked systems. From the skills perspective PMOs are re-developing career paths for schedulers and supporting the development of scheduling standards within organisations. This paper tracks the development of scheduling and looks at the way the evolving technology has changed the way projects are scheduled and managed.

The History of Scheduling Tools[a]

Pre 1956

The concept of 'scheduling' is not new; the pyramids are over 3000 years old, Sun Tzu wrote about scheduling and strategy 2500 years ago from a military perspective, transcontinental railways have been being built for some 200 years, etc. None of these activities could have been accomplished without some form of schedule; ie, the understanding of activities and sequencing. However, whilst the managers, priests and military leaders controlling the organisations responsible for accomplishing the 'works' must have an appreciation of 'scheduling' (or at least the successful ones would have) there is little evidence of formal processes until the 18th Century[b].

[a] To see the events discussed in this paper in a comprehensive historical timeline download ***Project Management - A Historical Timeline***: https://mosaicprojects.com.au/PDF_Papers/P212_Historical_Timeline.pdf

[b] The most likely planning tool used before the 18thC appear to be models. The model literally 'showed' what the finished structure (or part structure) would look like and allowed the 'project manager' to explain how his workforce should go about accomplishing the work. Models can be used to infer sequence but not necessarily timing. Filippo Brunelleschi certainly used models extensively in the design and construction

Even the concept of using diagrams in preference to words or tabulations to depict ideas was the subject of much scientific debate at the end of the 17th Century. Robert Hook published Micrographia, in 1665[c] that used diagrams to describe specimens viewed through an early microscope; he was greatly concerned about the possibility of misinterpretation and many other eminent scientist of the period were involved in the debate over the value of charts and diagrams to influence the understanding of data – over the course of the next century, the use of diagrams gradually became accepted in both the scientific and general communities, but the potential to over-emphasise, hide or blatantly misrepresent aspects of a data-set by the way information is depicted in a diagram remains to this day[d].

Graphical schedule control tools can trace their origins to 1765. The originator of the 'bar chart' appears to be Joseph Priestley (England, 1733-1804); his *'Chart of Biography'* plotted some 2000 famous lifetimes on a time scaled chart *"…a longer or a shorter space of time may be most commodiously and advantageously represented by a longer or a shorter line."*

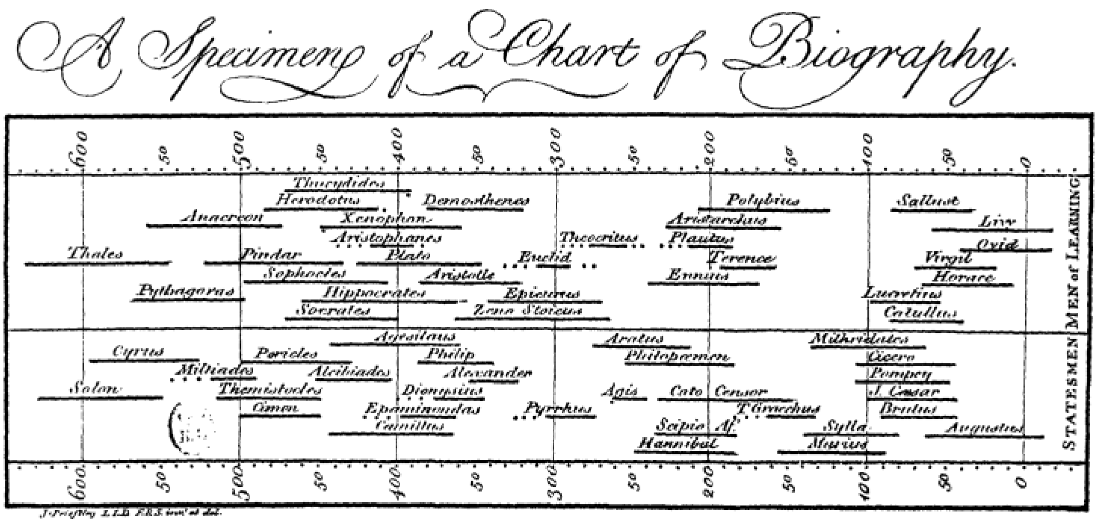


Figure 1 – Joseph Priestley: Chart of Biography

Priestley also drew *A New Chart of History* (1769) using similar concepts plotting the rule of 'empires' against geographical location and time[e]. The Chart of History lists events in 106

of the famous brick dome on top of the *Duomo di Firenze* in Florence during the 15th Century and Sir Christopher Wren's model for the reconstruction of St. Pauls Cathedral after the Great Fire of London in 1666 still survives.

[c] For more on *Micrographia*, see: http://en.wikipedia.org/wiki/Micrographia

[d] For more on the challenges of presenting schedule data graphically see ***Seeing the Road Ahead - the challenge of communicating schedule data***: https://mosaicprojects.com.au/PDF_Papers/P106_Seeing_The_Road_Ahead_PMOZ.pdf

[e] The creation of Priestley's charts and Playfair's 'Atlas' was facilitated by advances in the printing industry that enabled complex plates to be etched, printed, and then hand coloured. William Blake (1757 – 1827) used similar techniques in his illuminated books of poetry, the first of which was published in 1783. The process, called 'relief etching' involved writing the text of Blake's poems on copper plates with pens and brushes, using an acid-resistant medium. Then etching the plates in acid to dissolve the untreated copper and leave the design standing in relief (hence the name). This process meant illustrations could appear alongside words in the manner of earlier illuminated manuscripts at a fraction of the cost. Following the death of his father, Blake and former fellow apprentice James Parker opened a print shop in 1784, and began working with radical publisher Joseph Johnson. Johnson's house was a meeting-place for some leading English intellectual dissidents of the time, including theologian and scientist Joseph Priestley.

separate locations. He wrote that: *'The capital use [of the Charts was as] a most excellent mechanical help to the knowledge of history, impressing the imagination indelibly with a just image of the rise, progress, extent, duration, and contemporary state of all the considerable empires that have ever existed in the world.'* As A. Sheps in his article about the Charts explains, *'the horizontal line conveys an idea of the duration of fame, influence, power and domination. A vertical reading conveys an impression of the contemporaneity of ideas, events and people'.*[f]

Shift thinking to modern bar charts and the horizontal line conveys the duration of an activity and a vertical reading shows the number of activities in progress at any point in time.

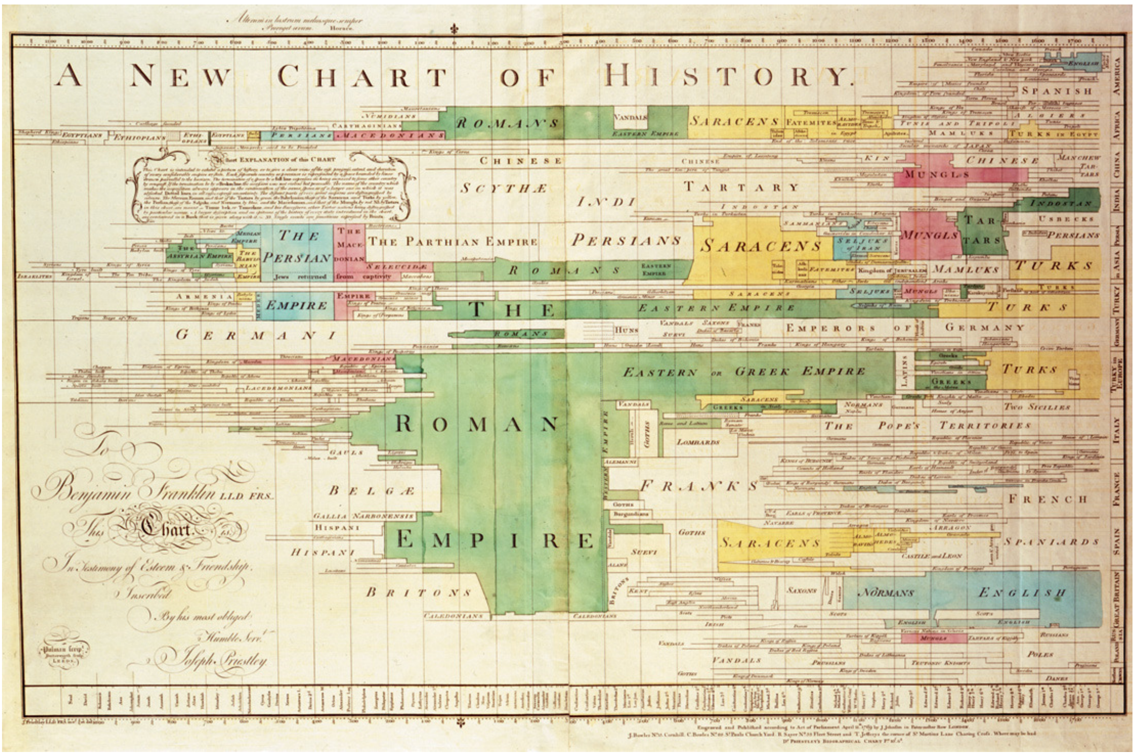


Figure 2 – Joseph Priestley: A New Chart of History

Priestley's ideas were picked up by William Playfair (1759-1823) in his *'Commercial and Political Atlas'* of 1786. Playfair is credited with developing a range of statistical charts including the line, bar (histogram), and pie charts[g]. The *Atlas* contained 43 time-series plots and one histogram[2].

f For more information on the charts developed by Joseph Priestley see: https://mosaicprojects.com.au/PMKI-ZSY-020.php#Barchart

g The ideas underpinning the work of Priestly and Playfair can be traced back to the Ancient Greeks. Bar charts are in essence a stylised graph, where data in the form of a start and end point for a line (or bar) is plotted against an 'x' and a 'y' axis with the activities defined on the 'y' axis and time on the 'x' axis. These developments are traced in ***The Origins or Bar Charting***: http://www.mosaicprojects.com.au/PDF_Papers/P182_The_origins_of_bar_charting.pdf

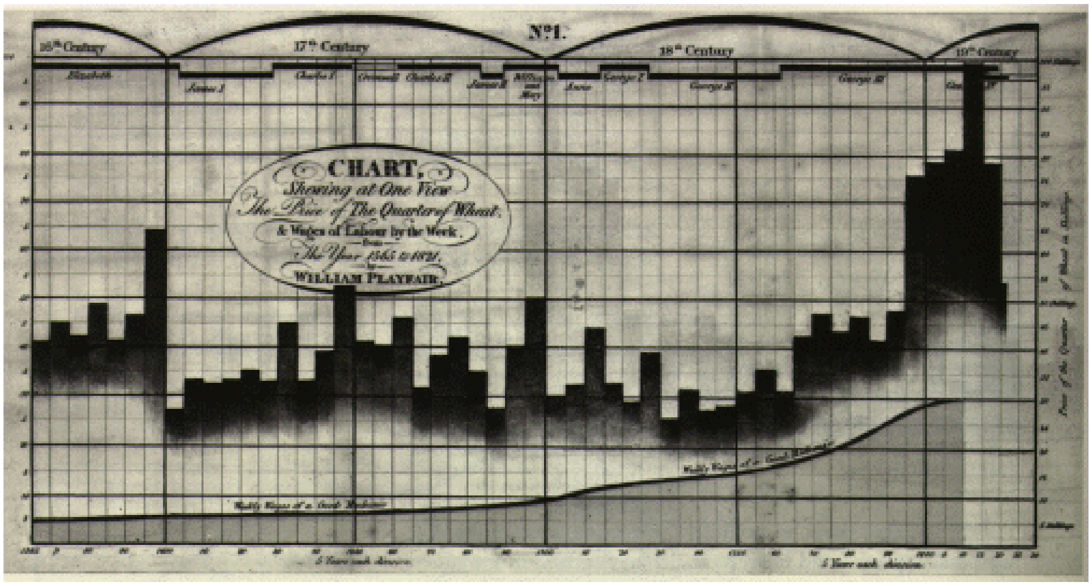
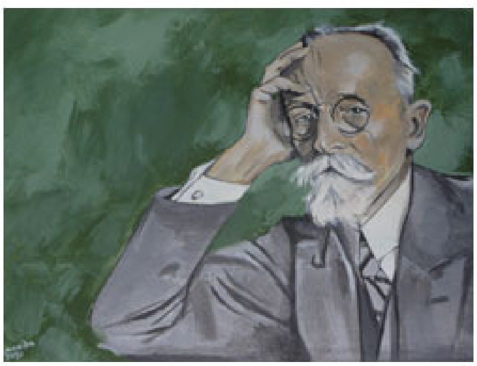


Figure 3 – One of Playfair's Charts from the 1801 edition of his Atlas



Following on from Playfair; another European, Karol Adamiecki[3] - a Polish economist, engineer and management researcher, developed a methodology for *'work harmonization'* that was based on graphical analysis. The charts used in this method have become known as *Harmonograms*, (or Harmonygraph).

Adamiecki's 1896 Harmonygraph has a date scale on the vertical axis (left hand side) and lists Activities across the top. Each activity was represented by a scaled paper strip, and the current schedule and duration of the activities were depicted by the position and length of the strips. In the header of the strips, the name and the duration of the activity and the list of preceding activities were shown. The strips representing the preceding activities were always to the left of the strip of the successor. The tabulation of each activity's predecessors and successors in the Harmonygraph ('from' and 'to') makes it a distinct predecessor to the CPM and PERT systems developed some 60 years later.

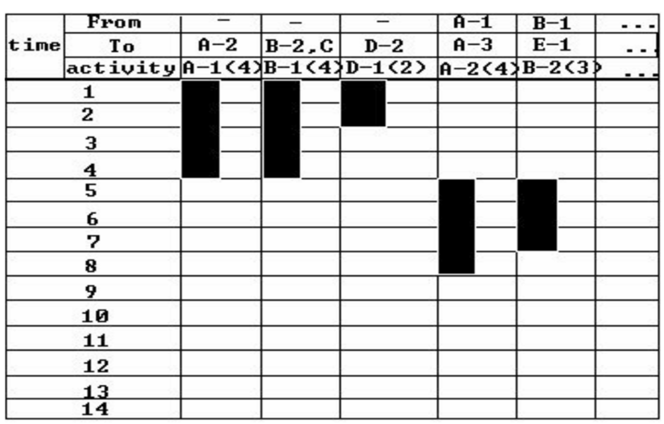


Figure 4 – Adamiecki's Harmonygraph

Karol Adamiecki emphasised the importance of creating harmonious teams, practical scheduling, and compatible, measurable means of production. It is claimed that companies implementing his method saw productivity increases of up to 400%.

By 1912, the modern barchart seems to have been fully developed and in use at least in Germany. In its pure form, the bar chart correlates activities and time in a graphical display allowing the timing of work to be determined but not interdependencies[h]. Sequencing is inferred rather than shown and as a hand drawn diagram, the early charts were a static representation of the schedule. However, the quality of the information in the 'Schürch' barchart[i] (below) and its supporting histograms are far too sophisticated to be either 'one-off' or original.

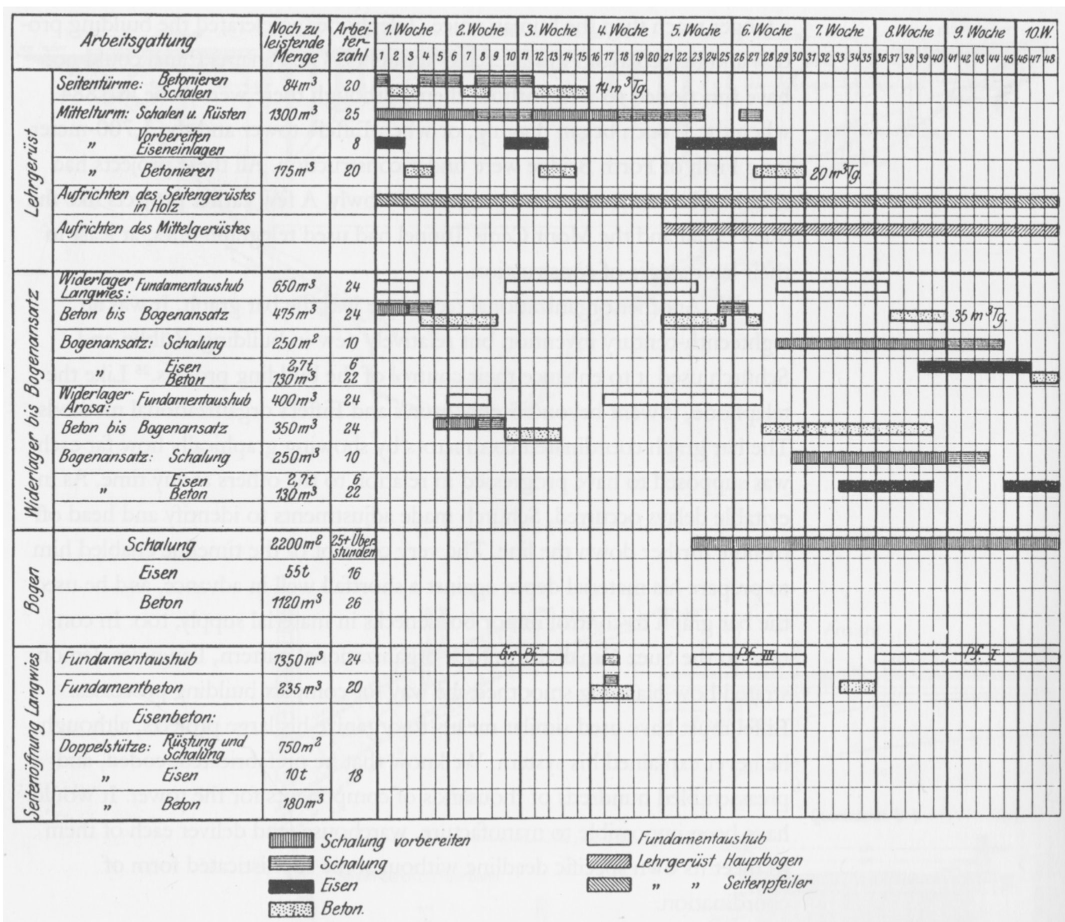


Fig. 5 A Bar Chart developed for a bridge constructed in 1912[j] (From Schürch1916: p35)

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[h] This type of chart is very different to the charts developed by Henry Gantt. For a complete discussion of Gantt's work, see: ***Henry L. Gantt, A Retrospective view of his work***: https://mosaicprojects.com.au/PMKI-ZSY-025.php

[i] For more on the origins of the ***Schürch bar chart*** and a set of supporting resource histograms see:
The original published article (German Language):
http://www.mosaicprojects.com.au/PDF_Papers/P042_Barchart_Origins.pdf
A translation of the reference to the program contained in the article:
http://www.mosaicprojects.com.au/PDF_Papers/P042_Barchart_Origins_Comment.pdf

[j] The bridge in question was one of the early uses of reinforced concrete in bridge construction (the primary focus of the article). The concept of reinforced concrete was discovered in 1849 by Joseph Monier (a Parisian gardener), patented in 1867, and first used by French engineer Francois Hennebique for constructing reinforced concrete floor slabs in 1879.

Unfortunately, the evolution of ideas mapping the development of bar charting between 1800 and 1900 has so far proved elusive, but they would seem to be commonplace.

The concepts embedded in bar charting continued to be developed through to the 1970s and 80s when sophisticated mechanical and magnetic strip 'bar charts' were available. Some tools such as Planalog included elements of CPM or PERT logic in the form of 'fences' that constrained the times a 'bar' could be moved (ie, defined its early and late dates)[k].

In parallel with development of barcharts, Flowline Planning was developed in the 1930s or earlier and Milestone charts were also in regular use by the 1950s[4]. Major contracts were subdivided into sections with target dates set for accomplishing the work required to achieve each 'milestone'. However, as with Bar Charts, all of the dates and durations shown in these charts were based on heuristics (rules of thumb) and/or experience. It was possible to identify slippage but any assessment of the impact of a delay was based on a personal view of the data rather than analysis. As a consequence, when schedule slippage became apparent on major contracts, the tendency was to flood the work with labour and 'buy time' frequently at a very high premium.

PLANALOG'S physical and visual properties promote group participation in planning, and all interrelationships of activities are easily followed on the PLANALOG.

Independent of the development of schedule control processes based on barcharts and milestones, work on linear programming had been going on for a number of years. This branch of mathematics looked at the cause and effect of actions on each other in situations such as the flow of traffic along a freeway. One of the mathematicians involved in this work was James E. Kelley[l].

[k] The patent for Planalog was filed in 1966. For more on the value of tools such as Planalog and Flowline in facilitating engagement with the planning process see ***Seeing the Road Ahead***: https://mosaicprojects.com.au/PDF_Papers/P106_Seeing_The_Road_Ahead_PMOZ.pdf

[l] The mathematical roots of CPM are discussed in ***The origins of PERT and CPM***, see: http://www.mosaicprojects.com.au/Mag_Articles/P037_The_Origins_of_CPM.pdf

CPM and Kelly and Walker[5]

The development of CPM as computerised project management tool can be traced back to mid 1956. E.I. du Pont de Numours (Du Pont) was looking for useful things to do with its 'UNIVAC1' computer (this was one of the very first computers installed in a commercial business anywhere and only the third UNIVAC machine built).

Du Pont's management felt that 'planning, estimating and scheduling' seemed like a good use of the computer! Morgan Walker was given the job of discovering if a computer could be programmed to help. Others had started studying the problem, including other researchers within Du Pont but no one had achieved a commercially viable outcome.

In the period from late 1956 through to April 1957, Walker assisted by Kelly and others had scoped a viable project. Their challenge was to solve the time-cost conundrum. They could demonstrate that in preference to flooding a project with labour to recover lost time, focusing effort on the 'right' tasks can reduce time without significantly increasing cost. The problem was identifying the 'right' tasks!

Fig. 6 – An early UNIVAC Computer

On the 7th May 1957, a meeting in Newark Delaware committed US$226,400 to a project to develop CPM; Du Pont's share was $167,700, Remington Rand Univac contributed $58,700. Univac had decided to help 'to keep IBM at bay'; competition can be useful…… but more important than the money was the people brought to the project by Univac. The Du Pont team was led by Morgan R. Walker, key players from Univac were James E. Kelley and John Mauchly[m]. Kelley was the mathematician and computer expert nominated by Mauchly to 'solve the cost optimization problem' for Walker. Kelley's solution, the original CPM model assumed that every activity has a normal duration, which is based on doing the work using normal technology, working times, resources, etc., and the so-called normal cost is associated directly

[m] John Mauchly and J. Presper Eckert of the University of Pennsylvania are credited with designing the Electronic Numerical Integrator And Computer, or ENIAC, the world's first electronic digital computer, completed in 1945. ENIAC was programmed through a physical system of adjusting switches and cables manually. Australia's CSIRAC ran its first program late in November 1949 and was the fourth computer in the world

with this duration. On the other hand, some of the activities can be accelerated by using longer shifts, faster technologies and application of more resources. The fastest activity duration is called the crash duration and the associated cost is called the crash cost. It is also assumed that the crash cost is greater than the normal cost, and the curve in between these costs is linear.

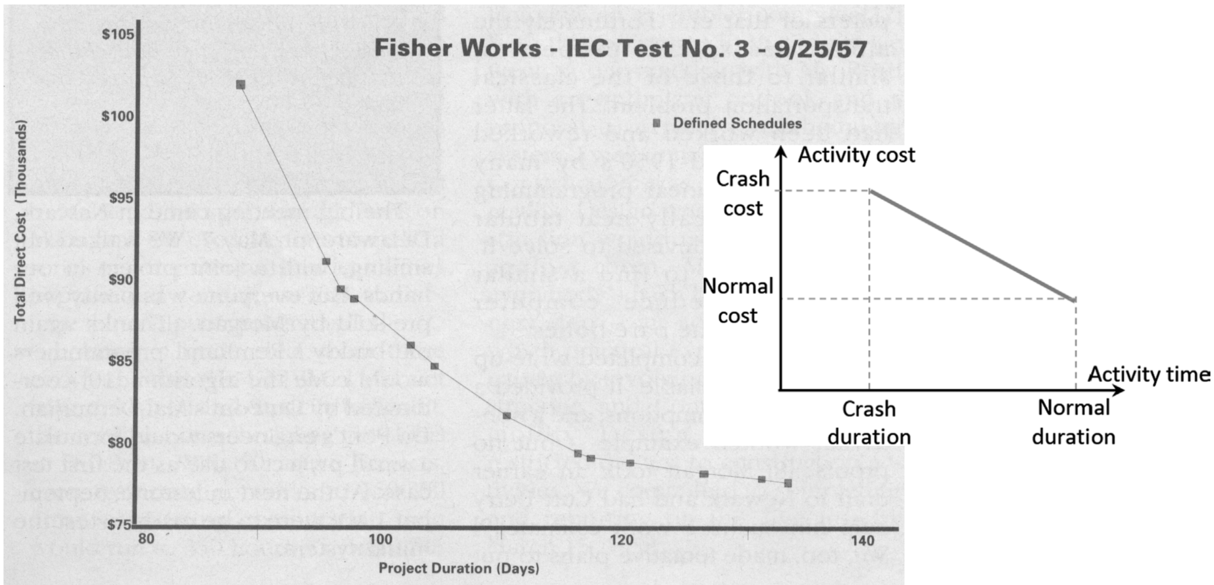

Fig. 7 – The Time / Cost Curve

The solution adopted by Kelley borrowed from 'linear programming' and used the i-j notation to describe the relationship between activities. This constrained the sequencing and made the calculations feasible (remembering the challenge was still to resolve the 'time-cost' trade off).

This solution created a couple of significant challenges. One was gathering the data needed to load the computer model. Engineers were not used to describing work in terms of activities (tasks) with resource requirements and different costs depending on the resources deployed for a 'normal' duration and a 'crashed' duration[n]. Gathering the data for the first CPM model took Walker over three months.

The other problem was that unless you were a mathematician the concept of i-j[o] was virtually meaningless! The 'Activity-on-Arrow' diagram was developed to explain the mathematics to management[p]. Despite the problems, by 24th July 1957 the first analysis of the George Fischer

[n] The term 'crashed duration' can be traced back to at least 1947: "1947: Hearings before the Subcommittee on Public Buildings and Grounds - Page 173; *"...Colonel Nicholson demanded in order to proceed on their crash schedule and by whichever route and with whatever tools they deem necessary".* The use of the term implies accelerated work more resources used than optimal.

[o] I-J notation refers to the numbering of the 'arrows' in a CPM network. The 'I' number is at the beginning of the arrow (left), the J number is at the end (right). CPM systems link all of the arrows with a common 'I' or 'J' number together at the same node (or connecting point). All of the tasks represented by arrows with a common 'J' number need to be completed before any of the succeeding tasks represented by arrows with the same common 'I' number can start. Interestingly, the idea of writing activity descriptions on the 'arrows' did not eventuate for several years; a separate table listed the I-J numbers and the descriptions.

[p] Quoting Kelley 1983: *"Kelley was there and, and he said, well, this was all mathematical, and when we put it on the computer and we got the answers we wanted, but when I had to explain to DuPont's management what this scheduling approach was, they couldn't understand the algorithm so I used the arrow diagram. I developed the arrow diagram to show them what the algorithm was saying."* Jim O'Brien interview.

Works schedule had been completed and the concept proven. The schedule included 61 activities, 8 timing restraints and 16 dummies.

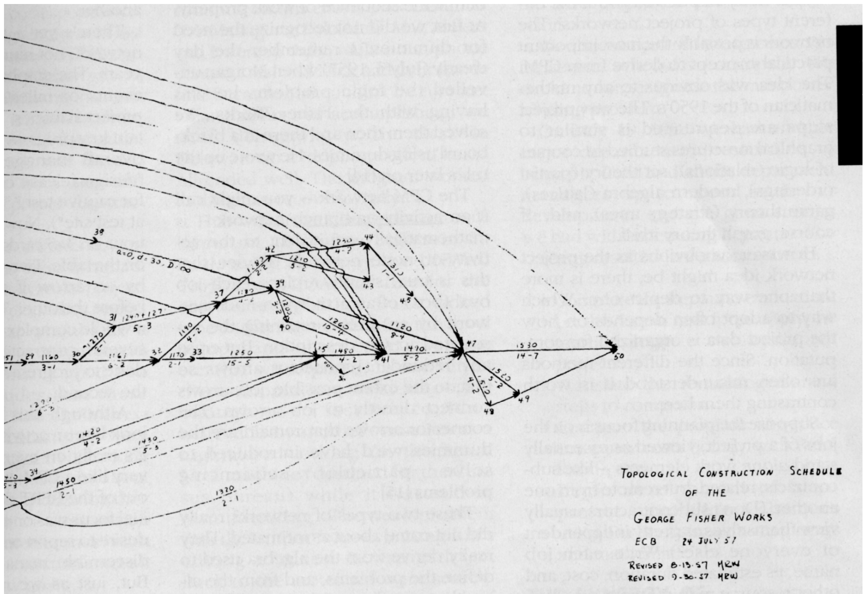

Fig. 8 - A section of the 'George Fisher Works' CPM schedule

The major challenge then became reducing the number of calculations and variables to a level that could be processed in a reasonable timeframe. The UNIVAC 1 did not have the speed and capacity to handle the construction scheduling problems at Du Pont. Based on the early runs, with 50 active projects, even restricting networks to 150-300 arrows, updating computation time would run to 350 hours a month. For each project this effort would involve generating and choosing from among 50 or so schedules of different cost and duration. Some of the challenges to overcome these issues were as basic as accessing the right computer; magnetic tapes storing the schedule data were prepared on the DuPont computers and then flown across the USA to be run on machines capable of analysing the data[q].

Development continued through 1958[r]. As with many innovations though, CPM nearly died as a concept. CPM saved DuPont 25% on their shutdowns, but they dropped the system shortly after the management team responsible for its development changed in 1959. Similarly, RemRand could see little future in the system and abandoned it!

CPM as a technique was 'saved' by Mauchly & Associates (including John Mauchly and Jim Kelley). Starting in 1959, they commercialised CPM, simplified the process to focus on schedule (rather than cost), organised training courses[s] and developed an entire new way of 'doing

[q] The same computer was used to run both the CPM and PERT programs – it is likely that some of the insights developed by Kelley and Walker influenced the development of PERT leading to a very similar network diagram but quite different calculations. Jim O'Brien's view is *"PERT pinched the game, but Kelley and Walker pinched the name…."* The Pert team develop the name 'critical path' K&W started off using the name 'Main Chain' for the same controlling sequence of activities. Additionally, one or both of the developments may have been influenced by earlier scheduling work undertaken during WWII by the USA Quartermaster Corps: http://www.mosaicprojects.com.au/Mag_Articles/P037_The_Origins_of_CPM.pdf

[r] See Attachment A for extracts from the 1959 paper by Kelley and Walker. The full paper can be downloaded from: http://www.mosaicprojects.com.au/PDF/PM-History_Critical_Path_Planning_&_Scheduling_Kelley_and_Walker_1959.pdf

[s] CPM was first mentioned publicly in March, 1959, in an article in Business Week (Astrachan, 1959); but official presentations by the developers did not take place until the final two months of 1959. Their first

business'[t]. Catalytic Construction of Philadelphia was the first large construction company to buy into the Critical Path Method in 1961, others quickly followed. CPM was popular but expensive – solving scheduling problems (eg loops) could cost the price of a small car! However, the commercial 'push' from Mauchly & Associates and others moved CPM to the forefront of scheduling systems[u] (overtaking PERT) until both of the 'Activity-on-Arrow' systems were eventually supplanted by 'Precedence' systems in the 1970s.

PERT and Associated Systems[6]

PERT[v] was developed by the US Navy Special Projects Office, Bureau of Ordnance (SPO). Apart from introducing uncertainty into schedule durations, the lasting contribution the PERT team have made to the business of scheduling was the invention of the term 'critical path[w]'. Kelly and Walker used the name 'main chain' for the longest path through their schedule.

The Navy 'Special Projects Office' (SPO) for the Fleet Ballistic Missile program (Polaris) was created on Nov. 17th 1955[7]. During 1956, the 'Plans and Programs Division' of the SPO surveyed the systems used by other organisations to manage large scale projects and a small development team comprising members of the SPO and consulting firm Booz, Allen and Hamilton was established in December 1956 to progress the work.

In January 1957, Admiral Raborn, head of the Polaris program, outlined his thoughts on the features of a control system and development work formally began on 27th January 1957, on a program called PERT, which was an acronym for 'Programme Evaluation Research Task'. By July of the same year the name had changed to 'Programme Evaluation Review Technique'. The team lead by Mr Wil Fazar quickly described the features of the system including 'a precise knowledge of the sequencing of activities' and 'a careful time estimate for each activity, ideally with a probability estimate of the times the activity might require'.

public presentations of CPM were in a 5-day workshop in Philadelphia on 16-20 November, and a paper to the 1959 Eastern Joint Computer Conference in Boston, on 1-3 December.

[t] The term 'Forward Pass' and 'Back Pass' originated from these early computers where the project data was held on punch cards. The sorted cards were read into the computer and the forward pass dates calculated in the first processing. This data was the punched onto the cards to complete the process. Based on the forward pass date information, the cards were then sorted into date order using a card sorter, and the reordered cards were then read back into the computer to calculate the back pass dates.

Using punched cards to hold complex data dates back to 1801 and the Jacquard loom, a mechanical loom that simplifies the process of manufacturing textiles with complex patterns. The loom was controlled by a replaceable 'chain of cards', a number of punched cards laced together into a continuous sequence. Multiple rows of holes were punched on each card, with one complete card corresponding to one row of the design. Charles Babbage knew of Jacquard looms and planned to use cards to store programs in his Analytical engine (1837). Herman Hollerith took the idea of using punched cards to store information a step further in 1890 when he created a punched card tabulating machine, the predecessor of the 'tabulators' used in 1959.

[u] Initially called the "Kelly-Walker Method" this procedure was rebranded as the 'Critical Path Method' or CPM and sold to the world by Jim O'Brien's book *CPM in Construction Management* (published 1964 by McGraw-Hill). Contractors rushed to implement this new idea without demands of owners – this was scheduling of, by and for the contractor. CPM in Construction Management became (and remains) the single best seller of the professional series of McGraw-Hill.

[v] PERT = Program Evaluation and Review Technique.

[w] Whilst the term 'critical path' has been universally adopted, it lacked a precise definition. For more on ***defining the 'critical path'*** see: http://www.mosaicprojects.com.au/WhitePapers/WP1043_Critical_Path.pdf

By July 1957 the first PERT procedures had been published, and by October PERT was being run on computers and the system was applied to parts of the Fleet Ballistic Missile programme[x]. Interestingly PERT was not widely used within the Polaris program but was widely publicised and used by Raborn to 'manage his external environment'[y]. This publicity was very successful; first Polaris missile was launched in 1960, PERT was credited with 'saving 2 years' and by 1964 the PERT bibliography included more than 1000 books and articles[z]!

By 1961, a multitude of PERT like systems had been developed including PERT/Cost[aa], PERT-RAMPS (Resource Allocation & Multi-Project Scheduling), MAPS, SCANS, TOPS, PEP, TRACE, LESS and PAR. These systems were all network based and had distinguishing features of their own. PEP is particularly interesting as it was essentially 'a connected barchart; ie, a set of bars with links connecting the ends of related bars'[8]. A concept that has re-surfaced in a range of computerised scheduling tools in recent years.

The Hughes-PERT system (Hughes aircraft corporation) had developed to include a 'multi-project network condensation and integration routine which included resources and cost' by 1962[9].

PERT and CPM were remarkably similar, both used the arrow diagramming technique (with arrows representing activities). The basic difference was that Du Pont's business was fundamentally known (construction and maintenance of chemical plants) and activity durations could be estimated with some degree of accurately based on known quantities and production rates. Consequently, CPM was focused on optimising costs by balancing resources. The Navy's work on Polaris was largely R&D with cost a secondary issue; durations could only be assessed and PERT was focused on determining the probability of an event happening by some future date. However, by the late 1960s both CPM and PERT had merged into 'network based management systems' and became the default standard for project scheduling[bb].

UK and European Developments

The development of scheduling systems was not exclusively based in the USA. Europeans developed a number of systems although none survived as a dominant tool. By 1968 PERT and CPM had emerged as the standard nomenclatures and dominant systems.

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[x] The original PERT paper was published in 1959, a copy can be downloaded from: http://www.mosaicprojects.com.au/PDF/PM-History_PERT-Original_Paper.pdf

[y] In 1959 Russ Archibald was in charge of PERT at Aerojet-General for the solid rocket component of the POLARIS missile system. He believes PERT got a lot of undeserved credit for the "ahead of schedule" success of the project. He believes that the real reason for the success of POLARIS was Admiral "Red" Raborn, who as an inspired Project Manager got the many POLARIS contractors working together as an effective team. He was constantly visiting the many plants around the country, showing the flag, pressing the flesh, exhorting top managers and workers on the shop floor to make things happen on schedule and to spec. The Navy never did integrate the Aerojet-General PERT network plans with Lockheed's PERT network plans, although Lockheed was the overall systems integrator for the missile system. (Letter dated 14/4/2008)

[z] For a detailed review of PERT see WP1087 ***Understanding PERT***: http://www.mosaicprojects.com.au/WhitePapers/WP1087_PERT.pdf

[aa] The DOD & NASA Guide PERT/COST Systems Design, was published in 1962.

[bb] The advent of CPM was quickly adopted by lawyers (in the USA at least) to define delays. As early as 1963–1964, consultants to the litigants on both sides of a case involving the Atomic Energy Commission used CPM to prepare their positions, and by 1967 reported cases were citing CPM as the basis for decisions. By 1972 courts were demanding a CPM be the basis for allegations of delays to allow separation of competing claims. This trend continues today.

The UK - ICI and CEGB[10]

The British chemical company ICI may have developed a CPM type tool as early as 1955 at its Billingham works. ICI's 'controlled sequence duration' for plant maintenance scheduling used Work Study data to estimate durations and a 'network sequencing', unfortunately, very little information has been found concerning this system.

The Operational Research Section (ORS) of the Central Electricity Generating Board (CEGB) in the UK in the period 1955 to 1958 were involved in developing their version of CPM working on the development of a basic method for planning work to power-plant shutdown. ORS-CEGB first came up with the term 'longest irreducible sequence of events' (a bit of a mouthful) which by 1960 that had become the 'major sequence' was soon renamed 'the critical path'. By continuing to develop its CPM method and applying it to the shutdown and maintenance of Keadby Power Station in Leicestershire in 1957 the CEGB was able to reduce the shutdown time to 42% of the previous overall average time, and by 1960 to achieve a further 32% reduction. Unfortunately, these developments were not widely publicised and seemed to fade into oblivion.

Interest in the USA developments appear to have superseded the home-grown scheduling systems. In April 1963, the UK Ministry of Public Building and works published Technical Report No. 1030 *Planning and Control of Engineering and Building Construction Work by use of the Critical Path Network and the Program Evaluation and Review Technique – "P.E.R.T."*. And, in 1966 the Road Research Laboratory (Ministry of Transport) published a similar report on the use of CPN for Road construction.

Based on the author's personal knowledge of ICL's PERT mainframe scheduling system and the PC based Micro Planner, a significant part of the ORS-CEGB work appears to have rolled into (or at least influenced) the forebears of the UK computing company ICL (now owned by Fujitsu) in the development of what became its 'ICL PERT' mainframe scheduling software[cc], as well as its later spin-offs into UK developed PC systems such as Micro Planner and PlanTrac[dd].

European Tools and Systems

The USSR (Russia) developed its own PERT like system called *Setevoe planirovanie i upravlenie*. Whilst never significant in the 'West' Russian schedulers have developed other interesting tools, one of the latest being SPIDER Project[ee] which dynamically links time, resources and cost (the original Kelley and Walker objective) within a managed risk profile.

The Metra Potential Method (MPM) developed in 1958 by Mr B. Roy, with METRA Consultants of France[11], may have been influenced by developments in the USA but appears to have been invented independent of the work by Dr. John Fondahl on the Precedence system (Fondahl did not publish his paper until 1961 and was unaware of Roy's work until several years later). MPM employed a graphical system of 'knots' (dots and circles) joined by 'strips'. The 'strips' (lines between the knots) may, or may not have flow direction but did specify the period of time an activity was specified to lag after the start of its preceding activity[ff]. The German scheduling tool 'ACOS Plus 1[gg]' uses MPM as its underlaying scheduling philosophy although from a user's

[cc] For more on the ICL PERT programs see: https://mosaicprojects.com.au/PDF_Papers/P207_EVM_Early_Computers.pdf

[dd] A discussion on the origins of Hammock activities highlights this connection see: http://www.mosaicprojects.com.au/Mag_Articles/P016_The_Origins_of_Hammocks_and_Ladders.pdf

[ee] For more on SPIDER Project see: http://www.spiderproject.ru

[ff] The original version of MPM used SS with minimal lag and SS with maximal lag only, which suggests MPM was the first system to use 'lags' in its scheduling algorithms; the use of 'lags' in PDM coming later.

[gg] For more on ACOS see: http://www.acos.com

perspective ACOS is similar to most precedence based scheduling tools, however, ACOS does offer a number of additional link types.

Another 'precedence' system developed by Walter and Rainer Schleip, in Munich, in 1960 was called RPS (Regeltechnischen Planning und Steuerung). RPS used a system of blocks, connections and knots (branching or collecting points) to calculate the critical path(s). Other methodologies included the HMN (Hamburger Method of Networking)[hh].

The Precedence Diagramming Method

In 1961 Dr. John Fondahl[ii] published a report entitled 'A Non-computer Approach to Critical Path Methods for the Construction Industry'[12]. This paper described the PDM system of scheduling and was offered as effective manual process to bypass the expensive computer based CPM system.

Dr. Fondahl[13 & 14], as part of a Stanford University team, was commissioned by the US Navy's Bureau of 'Yards & Docks' in 1958 to investigate ways of improving productivity. One key deliverable from this work was his seminal report: 'A Non-computer Approach to Critical Path Scheduling' published in 1961[jj]. This report sold over 20,000 copies.

The approach developed by Dr. Fondahl used a 'circle and connecting line' diagram derived from process flow diagrams or flow-charts[kk] (both CPM and PERT used the Activity-on-Arrow notation). Some of the key focuses of the 'approach' were:

- The time/cost trade off (the same problem Kelley and Walker were focused on)
- Answering the question 'can a contractors own personnel do CPM without computers'
- The perceived simplicity of the 'flow chart' approach

Notwithstanding the 'non-computer' emphasis in Dr Fondahl's research, his 'friends' in the Texan firm, H.B. Zachry Co. of San Antonio started work in 1962 to implement the system as an IBM Mainframe computer tool (see below) and at least one of Dr Fondahl's students Dick Bryan (Stanford in 1955) worked for, and later became a VP at Zachry[15].

Work at Stanford continued independent of the Zachery project and included the development of a manual updating process. This report (Technical Report No. 47) was due for publication in 1964 and caused a re-assessment of the name given to the methodology. The then current names for the methodology included 'circle-and-connecting-line', 'operation and interrelation line' (used by one of Fondahl's students for an early computerised version of the methodology), and 'Activity-on-Node' proposed by Moder and Phillips in the first edition of their book 'Project Management with CPM and PERT' published in 1964. However, in early 1964 IBM announced the launch of their 'Project Control System' for the 1440 computer. PCS used the name 'precedence diagramming'

[hh] Unfortunately, none of the European developments are well documented (at least in English).

[ii] John Walker Fondahl, PMI Fellow, Professor Emeritus in the Department of Civil and Environmental Engineering at Stanford University, passed away September 3, 2008.

[jj] Download the second edition of ***Non-computer Approach to Critical Path Scheduling,*** published in 1962 from: http://www.mosaicprojects.com.au/PDF/John_W_Fondahl.pdf

[kk] The original 'circle-and-connecting line' diagram would seem to have treated the connecting lines as links that in today's understanding would be called Finish-to-Start. The concepts of 'Leads to accelerate succeeding activities, 'Lags' to delay succeeding activities, and the other types of link (SS, FF, SF) being later developments.

and the Stanford team decided to adopt the same name as its *usage by IBM would probably prevail*.

IBM & H.B. Zachry Company[16]
The transition of Dr. John Fondahl's 'Non-computer Approach to Critical Path Scheduling' to a computer based system appears to have been engineered by the Texan construction company, H.B. Zachry Co. of San Antonio. In 1958 Mr. Zachry obtained a new book, Operation Research, and gave it to W.D. Tiner, Jr. (the firm's research director) telling him what he wanted to accomplish in the area of research and methods and asking him to familiarize and train himself in that area so as to utilize those methods in the H.B. Zachry Company. After a through study into methods and prospective costs of the necessary computer equipment, Tiner told Zachry that he did not think the company could afford to spend "that kind of money" on the machines. Zachry's answer was: "Doug, you are wrong, we cannot afford not to spend the money on those machines."

H.B. Zachry Company began experimentation with the critical path method (CPM) of scheduling construction projects in 1959. Some of the early projects to benefit from this initiative included the construction of an Atlas missile base at Abilene, Texas in 1960 using rented time on an IBM 650 and the construction of a facility for Nike Zeus on Kwajalein Island (in the Marshall Islands) in 1961 using an IBM 1620 computer installed in the H.B. Zachry Co offices[17].

Recognizing the advantages as well as the short-comings of CPM after actual use of the technique, the Research Division directed its efforts toward exploration of new methods and applications of network scheduling. In 1962, this research culminated in the development of a new CPM, based on the work of Dr. Fondahl[ll], called the 'precedence' or 'sequence' method. Shortly thereafter in March 1963, Zachry Company and IBM entered a joint venture agreement to develop and implement this system for project scheduling. The result of the joint venture was the IBM software program entitled "Project Control System (PCS)". PCS was the first computerised scheduling system to introduce lags to simplify the overlapping of activities (lags had been included in earlier manual systems but to deal with time/cost issues); interestingly Dr. Fondahl still believes lags should be used carefully and sparingly.

One of the early projects to benefit from these developments was the Devils River Bridge project near Del Rio, Texas (a 5,641ft [1,665 meters] long bridge rising to 223ft [68 meters] maximum height), completed ahead of schedule by H.B. Zachry Co in 1964[mm].

The IBM PCS system and later developments, leveraging off IBM's domination of the mainframe market, eventually made 'precedence diagramming' the dominant mainframe scheduling methodology which in turn flowed through to the 'Mini', 'Micro' and PC applications developed through the 1980s; to the point where by 2004 'precedence' was virtually the only commercially available system in general use for scheduling.

The irony being PDM is now used by every computer based scheduling system, PERT has died out completely and ADM is rarely seen[nn] and is generally only found in academic papers where the calculations are performed manually![oo]

[ll] Dick Bryan was a student of John Fondahl at Stanford in 1955 and later became a VP at Zachry

[mm] Reported in Roads and Streets: August 1964

[nn] The Micro Planner range of software is one of the very few tools still offering Activity-on-Arrow scheduling: http://www.microplanning.com.au/ .

[oo] For more on the development of scheduling see: Seeing the Road Ahead: https://mosaicprojects.com.au/PDF_Papers/P106_Seeing_The_Road_Ahead_PMOZ.pdf

ICL PERT.
In 1961, the ICT team took the RCA 301 PERT package that they had been jointly working on and upgraded and renamed it the ICT 1500 Series PERT; 1500 PERT included resource scheduling and costing. The team were also supporting the ICT 1301 PERT software and working on APPRAISE for the ATLAS computer and OPUS for the ORION computer and a small simple CPM software package for Pegasus and Mercury range of computers. The 1900 PERT software released to the public in November 1965 followed by VME PERT in the 1970s. ICL mainframe systems (both 1900 and VME PERT) continued in use through to the 1990s.

PROJECT/2 Project Software & Development, Inc.
By the late 1960s many more mainframe systems were being developed and released. In 1968 one of the better known tools, PROJECT/2 was released by Project Software & Development, Inc. PSDI was founded by former MIT student Bob Daniels, the new software, PROJECT/2, being an extension of a graduate project. PROJECT/2 ran on IBM System/360 and System/370 series mainframes, and was later ported to VAX.

The Impact of the Tools on Professional Schedulers

Mainframe days……

Through to the early 1980s, to create a project schedule you either

- used a mini or mainframe computer system, or
- drew and calculated schedules manually, or
- did both; manual calculations first (to sort out problems) then upload the corrected and checked schedule to the computer; the run-time on the computer cost too much for errors!

The spread of scheduling can be closely tied to the need to sell the concept of using a very expensive computer to analyse project schedules using the sales organizations preferred technique (PERT or CPM) and its computer. Mainframe software was often provided free of additional charge as part of a sale – everyone did accounting, etc, project scheduling software was often seen as creating a competitive advantage. There was also competition between the various consultants and developers in the market, training courses introduced people to the concept and advantages of developing schedules using dynamic networks. Finally major organizations needed to train staff; for example some of the early PERT courses for the USAF were run at USAF Bollington, Washington D.C.

In addition to the courses, schedulers were trained through a process of apprenticeships and mentoring; it cost too much and took too long to fix problems caused by inexperience! The consequence was the evolution of a group of project schedulers skilled in both the art and science of scheduling. However, as Kelley noted from the very earliest CPM training courses, there was a significant variability in the outcome for scheduling exercises caused by differing skill levels and perceptions on the trainees.

Within organisations, the existence of scheduling departments meant the scheduling processes were standardised and the schedule data was largely ‘owned’ by the organisation. Additionally, the desire of professional schedulers to exchange information and develop their skills would appear to have been the foundation for the evolution of ‘modern project management’[pp].

[pp] See ***‘The Origins of Modern Project Management’***: https://mosaicprojects.com.au/PMKI-ZSY-005.php#Overview

PC systems

Micro Planner[e]
Micro computers emerged in the late 1970s, machines like the Commodore and Atari were initially aimed at the enthusiast. However, by the end of the 1970s micro computers were starting to make their presence felt in the business world. One of the leaders in the business market at this time was Apple Computer with its first 'commercial PC', the Apple II being launched in 1979. The first commercial scheduling software for this class of computer was developed by Micro Planning Services in the UK. Running on the Apple II Micro Planner v1.0 was released in 1980 after 14 months development; Micro Planner was based on the ICL PERT mainframe system.

The first IBM PC was launched in 1981; although the definitive IBM XT was not launched until 1983. In 1982, 'The Planner' was released for the 256K IBM PC and the Sirius/Victor.

'Windows' type operating systems became available in 1984 with the launch of the Apple Macintosh, with Microsoft's 'Windows v1.0' being launched in November '85. Micro Planner maintained their association with the Apple system launching graphical scheduling systems for the Apple Macintosh in 1986 and Windows in 1988; followed by the first true GUI[qq] scheduling tool Micro Planner X-Pert in 1989[rr].

Primavera[ss]
Primavera was founded in May 1983 by: Dick Faris, Joel Koppelman and Les Seskin (who owned a batch entry mainframe scheduling system). Today Primavera is arguably the dominant 'high end' project scheduling tool world wide. But where did the name come from[tt]?

Focusing on the then 'mainstream' DOS operating system, Primavera shot to prominence with the release of a 10,000 activity capable system in the late 1980s and has maintained its position as 'market leader' with a steady flow of innovative developments.

The Changing Industry

During the 1970s, the arrival of powerful project scheduling systems running on 'Mini Computers' caused the first major change. The lower operating cost of systems such as MAPPS on Wang and Artemis on HP and DEC hardware caused the rapid demise of mainframe scheduling systems. Apart from a few legacy systems the era of the mainframe was over by the mid 1980s. The 'mini systems' retained many of the characteristics of the mainframes though and required skilled schedulers to make efficient use of them. From the perspective of the people working as schedulers all that changed was the hardware and maybe the software vendor.

The rapid spread of relatively cheap, easy-to-use' PCs in the latter half of the 1980s spawned dozens (if not hundreds) of PC based scheduling systems including TimeLine and CA Superproject at the 'low end', and Open Plan and Primavera at the 'high end' of PC capability[uu].

The 'low end' tools spread the availability of scheduling systems to a very wide audience and allowed everyone access to cheap computer based scheduling. This had two impacts, by the early

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[qq] GUI = Graphical User Interface

[rr] For a more complete history of the development of Micro Planner see: https://mosaicprojects.com.au/Company_People_MPI.php#History

[ss] For more on Primavera see: http://www.primavera.com

[tt] Primavera= spring in Italian and Portuguese; "it seemed like a good name" according to Dick Faris!

[uu] A few of the other tools developed in this era included: Hornet, Plantrack, InstaPlan, Microsoft Project, the original Pertmaster, and literally dozens of others.

1990s no one was doing manual scheduling (apart maybe from a few 'old timers') and the number of people creating schedules on a part time, untrained basis exploded. At the same time, the increasing capability of the 'high end' systems annihilated the significantly more expensive mini systems. Scheduling had become a desk top PC based process and professional schedulers virtually disappeared from the payroll of organisations (the remaining 'professional schedulers' were predominantly 'consultants' of one form or another, particularly 'claims consultants').

The last of the significant changes in the industry started in latter part of the 1980s and has continued through to the present time. Despite the ever increasing number of people using PC based scheduling tools; the competition in the market has driven prices down and caused a major consolidation of the industry. For many years, Microsoft Project could be bought for less than $100 per set. This decimated the 'low end' market. Similarly the cost of developing GUI interfaces and staying competitive in the features arms race at the 'high end' caused most of the system developers to move to greener pastures or simply close up shop.

It is only since the start of the 21st century has this trend begun to change. The increase in the sophistication of Microsoft Project and the rise in its base cost to around $1000 has opened up the market to a number of low cost entry level tools based primarily on barcharts. There has also been an increase in the number of generally available niche systems offering enhanced; risk analysis (eg Pertmaster), time/location and line of balance capabilities (eg DynaProject™ and LinearPlus) and other functionality, that can operate stand alone or use data from and interact with the dominant systems such as Microsoft Project and Primavera.

More significantly, the emergence of 'enterprise' versions of the high end scheduling tools and their supporting 'project management offices' (PMOs) combined with an increased focus on effective corporate governance has re-focused attention on the role of the professional scheduler[vv].

Current Trends - Back to the Future

The Loss of Skills and Control

Prior to the 1980s Scheduling was a serious business; it used very expensive assets, required significant training and skill and was largely centralised and 'visible'. Where manual scheduling was used, the saving in system costs was offset by the tedium of lengthy manual calculations. It simply did not pay to make mistakes! Schedulers were trained professionals.

The arrival of 'easy to use' scheduling tools with a graphical interface radically changed the industry. Scheduling migrated to the desktop and the myth that 'anyone' can schedule (provided they knew how to switch on a PC) emerged. Many people learned 'scheduling' from using tools like Microsoft Project. There was no training or oversight and as a consequence, the average schedule is littered with 'fixes' allowed or encouraged by the tool. The trend has been towards a focus on computer processes and getting a schedule 'looking right' rather than analysing a project to determine the appropriate duration based on appropriate resource availabilities and designing the schedule to be an effective management tool in the context of each specific project[ww].

As a direct consequence of this loss of skills, the importance of scheduling has dropped in most organisations and most projects run late! But the tide is turning…..

[vv] For more on ***corporate governance*** see: https://mosaicprojects.com.au/PMKI-ORG.php

[ww] Despite the capabilities of the tools, far too many schedules are simply bar charts masquerading as CPM schedules. The value of ***dynamic scheduling*** is discussed in https://mosaicprojects.com.au/PDF-Gen/dynamic_scheduling.pdf

Back to the Future

The current requirement for effective 'corporate governance' is focusing management's attention on project controls. The requirement for visibility, predictability and accountability of project performance can only be achieved by the introduction of effective corporate tools supported by skilled project schedulers[18].

This drive for visibility has been met by the arrival of powerful 'Enterprise' tools such as Primavera Enterprise and the suite of programs from Deltek including Open Plan and WelcomeHome. These integrated tools with effective data management and security 'built in' are capable of delivering the visibility and control needed for effective corporate governance provided the tools are adequately supported. Additionally, the integrated nature of the tools makes project data visible and this visibility encourages enhanced quality.

Fig. 9 – The Deltek suite of integrated tools

However, this drive for quality is creating a world-wide demand for skilled schedulers whilst the training gap of the 1980s and 1990s caused by the PC myth that 'anyone can schedule' has created a shortage of trained schedulers. This skills shortage is being helped by the spread of PMOs[xx] and a renewed interest in scheduling training[19] but it will take several years to develop enough trained schedulers with the right mix of skills and personal attributes[yy]. Fortunately, many PMOs are starting to recognise the need for, and develop skills in the 'art' of effective scheduling, as well as providing a home and career path for schedulers.

The trend back towards a corporate view of schedule information and the requirement for skilled schedulers to operate the 'enterprise' tools and provide effective assistance to project managers is being supported by the development of new standards. PMI launched its 'Scheduling Practice Standard' in 2006, to augment the information in the PMBOK Guide. A longer term initiative is the work being undertaken by PMI's College of Scheduling to develop and publish its 'Scheduling Excellence Initiative'[20]. SEI is planned to develop and publish a comprehensive set of industry accepted best practices and guidelines for every aspect of project management 'that touches a schedule, or that a schedule touches'.

The consequence of these trends is that schedulers are once again in great demand around the world. The role of the scheduler is back!

[xx] PMO = Project, Program or Portfolio Management Office.
See: https://mosaicprojects.com.au/PMKI-ORG-045.php#Overview for the different type of PMO.

[yy] For a discussion on the skills and attributes needed by a scheduler see:
https://mosaicprojects.com.au/PMKI-SCH-010.php#Process1

Scheduling Certifications

The latest trend is the development of scheduling certifications. AACE, PMI, The Guild of Project Controls (Planning Planet) and the CIOB have had planning and scheduling certifications available for many years[zz]. These developments should support the creation of career paths for schedulers within organisations.

Conclusions

The evolution of scheduling has been a fascinating journey:

- Kelley and Walker set out to solve the time-cost conundrum and invented CPM. For most organisations the resolution of time-cost issues is still in the 'too hard' basket (although SPIDER offers an interesting solution)!
- The PERT project invented the name 'Critical Path', and everyone else borrowed it.
- Dr. John Fondahl invented a non-computer methodology for scheduling that is now used by every computer package world wide!
- Whilst Kelley and Walkers CPM system that was developed for computers is now primarily seen as a manual technique.

The changing role of the scheduler has been almost as interesting:

- The mainframe era saw scheduling as:
    - A skilled profession
    - Central to the success of projects
- Then came the PCs…… everyone and no-one was a 'scheduler' in the 1980s and 90s
- However, in the 21st century, the new 'enterprise' era sees scheduling as:
    - A skilled profession
    - Central to the success of projects

We have gone back to the future! The challenge now is to find and train enough 'good schedulers'. Some personal thoughts on the attributes of a 'good scheduler' can be found at: www.mosaicprojects.com.au/PDF-Gen/Attributes_of_a_Scheduler.pdf and on what make a 'good schedule' at: www.mosaicprojects.com.au/PDF-Gen/Good_Scheduling_Practice.pdf.

[For more scheduling information and links visit: http://www.mosaicprojects.com.au/Planning.html]

Acknowledgements:

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Russell Archibald, USA   Martin Barnes, UK   Brian Doyle, Australia

[zz] For more on scheduling certifications see:
- For the AACE – PSP certification (8 years experience required): http://www.aacei.org/certification/certExplained.shtml
- For the PMI-SP certification (5 years experience required): https://mosaicprojects.com.au/training.php

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Attachment A – Extracts from Kelley & Walker, 1959[21]

The following extracts from the paper presented to the Eastern Joint Computer Conference in March 1959, by Kelley and Walker, entitled 'Critical Path Planning and Scheduling'; have been provided by Earl Glenwright:

Introduction & Summary:

A characteristic of contemporary project scheduling is the over-simplification which stems from the inability of unaided human beings to cope with sheer complexity. Even though we know that a detailed plan is necessary, we also know that management need only act when deviations from the plan occur. To resolve this situation we undertook to develop a technique that would be very simple but yet rigorous in application. One of the difficulties in the traditional approach is that planning and scheduling are carried on simultaneously.

Our first step was to separate the functions of planning from scheduling. The basic elements of a project are activities and resource expenditures and execution times are associated with each activity in the project. These factors, combined with technological relations, produce schedules proposing varying completion dates. Management comes into possession of a spectrum of possible schedules, each having an engineered sequence, a known elapsed time span, a known expenditure function, and a calendar fit. (In R&D projects, one obtains 'most probable' schedules).

Analysis of a Project

For the scheduling aspects of project work, it is necessary to consider the environment of each activity, i.e. working space, safety hazard, etc. A project activity diagram is built up by sections and the individual sections were then connected to form the complete project network diagram.

Diagramming project work has given planners several benefits:

- discipline
- a clear picture of the scope
- a vehicle for evaluating alternative strategies
- tends to prevent the omission of activities that belong to the project
- it pinpoints responsibilities
- can be an aid to refining the design of a project
- an excellent vehicle for training project personnel

The duration of each activity is a variable taken from an approximately known distribution. This information is important not only for putting a schedule on the calendar, but also for establishing rigorous limits to guide field personnel.

We may compute the latest time at which each event [node] in the project may occur relative to a fixed completion time. If the maximum time available for an activity equals its duration the activity is called critical. If the maximum time available for an activity exceeds its duration the activity is called a floater. Some floaters if displaced will start a chain reaction of displacements downstream in the project.

To proceed further we must introduce the notion of 'risk' in defining the criticalness of an activity. The elapsed time duration of an activity may change as the number of men put on it changes, as the type of equipment or method used changes, as the workweek changes from 5 to 6 or 7 days, etc. Exogenous conditions may require that an activity be expedited. This may be done in a variety of ways. But in any case there is a limit as to how fast an activity may be performed. This lower bound is called the crash duration. We must assume that the approximate expenditure functions are a piecewise linear, as in practice insufficient data is available to make more than a linear approximation. We can now force a reduction in the project completion time by expediting certain of the critical activities – those activities that control project completion time.

Manpower Leveling.

Considerations of available manpower and equipment would be conspicuous by their absence. The equipment and manpower requirements, for a particular schedule may exceed those available or may fluctuate violently with time. A means of handling these difficulties must therefore be sought -–a method which 'levels' these requirements. One should not use the maximum number of men available at one instant in time and very few the next instant of time. The difficult part of treating the manpower-leveling problem is the lack of any explicit criteria with which the 'best' use of manpower can be obtained.

Incorporating Manpower Sequences; it is possible to incorporate manpower availability in the project diagram. However, this approach can cause considerable difficulty and may lead to erroneous results therefore it is recommended that this approach be dropped from consideration. For example, three activities, A, B, & C, can occur concurrently and each activity requires the same crew. We can avoid the possibility that they occur simultaneously by requiring that A be diagrammed to be followed by B, followed by C. It is also possible to state 5 other combinations.

However, by incorporating manpower sequences, we would never really know the true scheduling possibilities. One criteria would be to displace the activities with the least float first and sub-totals kept by craft to ensure that, even though total force may be all right, craft restrictions also are met.

1st Test:
The whole project was divided into WBS work packages. The scope of work in each was analyzed and broken down into individual work blocks or activities. The updating which took place required only about 10% of the effort it took to set up the original plan and schedule. With only 30% design information, the total manpower force curve was predicted with high correlation.

For only 1% increase in the variable direct cost of the project an additional two months improvement could be gained. If the project manager were asked for improvement in the project duration and he had no knowledge of the project expense curve, he would first vigorously protest that he could not do it.

2nd Test Case:
Planning will be done much earlier in the project life to incorporate more of the functions of engineering-design and procurement.

Applications to Maintenance Work

In the meantime, it was felt desirable to describe a project of much shorter duration. An ideal application for this purpose is in the shutdown and overhaul operation on an industrial plant. For purposes of testing the Critical-Path method, a plant shutdown and overhaul was selected.

The basic difficulties encountered were in defining the plan of the shutdown. Because one never knows precisely what will have to be done to a reactor until it is actually opened up, it would be almost impossible to plan the work in advance. But the truth of the matter is that the majority of activities that can occur on a shutdown must be done every time a shutdown occurs. Another category that occurs with 100% assurance for each particular shutdown – scheduled design and improvement work.

The problem was how to handle the unanticipated work on a shutdown. This was accomplished in the following way: it was possible to absorb unanticipated work in the slack provided by the floaters.

Using the Critical-Path Method has cut the average shutdown time an average of 25%, mainly from the better analysis provided. This application has paid for the whole development of the Plan and Schedule effort five times over.

Current Plans.

The next project will include all design, procurement, and construction, starting with authorization, the point at which funds are authorized to proceed with sufficient design.

Computational Experience.

Generally computer usage represents only a small portion of the time it takes to carry through an application. Experience thus far shows that it may take six weeks to carry a project analysis through from start to finish. Fruitful use of parts of the Critical-Path Method do not require extensive computing facilities.

[Note: the full paper is 25 pages long]

Conclusion

The Critical-Path Method should be used by the contractor in making the original contract schedule. In this way many of the unrealities of government project work would be sifted out at the start.

Extensions of the Critical-Path Method

The basic assumption is that adequate resources are available (this is an unrealistic assumption). Two extremes that need to be considered are: one project, many projects.

This may be called intra-project scheduling. In the second case, we run into difficulties in trying to share men and equipment among several projects which are running concurrently. We must now do inter-project scheduling.

The fundamental problem involved here is to find some way to define the many independent and combinatorial restraints involved into account: priorities, leveling manpower by crafts, shop capacity, material and equipment deliveries, etc. Study has indicated that this is a very difficult area of analysis and as such an extension may be purely academic.

Other Applications

Consider the underlying characteristics of a project – many series and parallel efforts directed toward a common goal. The Critical-Path Method was designed to answer pertinent questions about just this kind of activity. It can be used by the government to report and analyze subcontractor performance.

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