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What is the Iron Triangle, and how has it changed?

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Abstract

Purpose – The Iron Triangle, also called the Triple Constraint, is a central concept to project management research and practice, representing the relationship between key performance criteria. However, there is disagreement about which criteria should be represented on the vertices of this triangle. The purpose of this paper is to explore which concepts are part of the Iron Triangle, and how these concepts have changed over time.

Design/methodology/approach – This paper explores 45 years of project management research, drawing on a database of 109,804 records from 1970 to 2015. Three corpora were constructed, representing the project management and Time, Cost, and Quality Management literature. Time and Cost are consistently identified as part of the Iron Triangle. However, the status of quality is contested. Key concepts in the project management literature were explored using scientometric research techniques, to understand the relationship between these concepts.

Findings – Significant links were found between Time, Cost, and Quality, verifying these concepts as the vertices on the Iron Triangle. These links were significantly stronger than links to alternatives, such as Scope, Performance, or Requirements. Other concepts that are core to the Iron Triangle were also identified, and how these have changed over time.

Originality/value – This research develops the understanding of a key project management concept by clarifying which concepts are part of the Iron Triangle, based on evidence of how the concept is used in research. This paper also reveals the context in which this concept is used, and how this has changed over the last 45 years.

Introduction

The concept of the Iron Triangle, also sometimes referred to as the Triple Constraint, or the Project Management Triangle, is a fundamental aspect of how we understand success in projects. The Iron Triangle is a representation of the most basic criteria by which project success is measured; namely whether the project is delivered by the due date, within budget, and to some agreed level of quality, performance or scope. The Iron Triangle has become the standard for routinely assessing project performance (Pinto, 2010, p. 35).

The concept of the Iron Triangle is an effective way of communicating the interrelationships between these central success criteria. It is typically depicted as a triangle with the criteria on the vertices. Movement of one criteria, for example in response to client demands or resource limitations, can put pressure on the other criteria. Failure in one constraint will likely lead to negative pressure on one or both of the other two (Mokoena et al, 2013, p. 814). This is sometimes expressed as “good, fast or cheap - pick two” (van Wyngaard et al, 2012, p. 1993). Misunderstanding or misinterpreting the Iron Triangle can lead to project failure despite effective management of all other aspects of a project (Mokoena et al, 2013, p. 813). Effectively managing the Iron Triangle has been found to be central to project success, however it has also been found that research into the Iron Triangle is “...one of the most overlooked fundamentals of project management” (Van Wyngaard et al, 2012, p. 1993).

Time, Cost, and Quality have been the most widely accepted project success criteria since the 1970s (Atkinson, 1999; Ika, 2009). However, research has shown that the field of project management has undergone considerable change from when it emerged as an independent field of research and professional practice (Kloppenborg & Opfer, 2002; Söderlund, 2004; Pollack & Adler, 2015). This research explores what the Iron Triangle is, whether

the Iron Triangle has remained a stable concept, or if the meaning of this central aspect of how we understand project performance has fundamentally changed over time.

Literature Review

Across industries, the Iron Triangle criteria are the most commonly cited measures of project success (Bryde, 2008). In a study of project manager's experience of projects, White and Fortune (2002) found that the majority of project managers reported using the Iron Triangle as their primary way of defining project success. According to research by Müller and Turner (2007) the Iron Triangle is valued by both experienced and inexperienced project managers. Berssaneti and Carvalho (2015) found that project management maturity is linked to the Iron Triangle. The persistent popularity of the Iron Triangle framework may be because of its simplicity. When a project is delivered to these criteria, it is relatively simple to declare its success (Judgev & Müller, 2005).

The practice of project management partially depends on the project context, with different emphases in different scales of projects (Besner & Hobbs (2006). It appears that reliance on the Iron Triangle increases when complexity and lack of certainty lead to cost and time overruns (Williams, 2005). Larger and costlier projects tend to increase the usage of practices focusing on greater time and cost control (Papke-Shields, et al, 2010). This suggests that the Iron Triangle may be used more commonly as projects become more prominent and publicised. In times of complexity, the Iron Triangle may become more attractive as it offers a simple, unambiguous, and reassuringly simple measure of performance.

As an initial step in addressing these questions, the literature was reviewed according to the date at which significant pieces of research were published. Some trends became apparent from reviewing publications that explore, or use, the Iron Triangle. Literature in the 1970s focused on the operational aspect of project management, classifying and analysing project management tools and techniques (Davis, 2014). The Iron Triangle of Time, Cost, and Quality was a primary focus during this period (Atkinson, 1999; Cooke-Davies, 1990). The literature published in this period tended to be theoretical rather than empirical (Belassi and Tukel, 1996). Research in this era tended to predominantly focus on these criteria, omitting issues of communication, customers (Judgev & Müller, 2005), and soft skills (Munns and Bjeirmi, 1996).

After the 1970s, the literature expanded from analysis of the technical aspects of project management to a growing recognition of the importance of stakeholder relationships (Pinto and Slevin, 1988), and seeking explanations of project phenomena (Padalkar & Gopinath, 2016). From the 1980s, the Iron Triangle formed the basis of common success criteria (Agarwal & Rathod, 2006; Fortune & White, 2006). Morris and Hough (1987) asserted that success is dependent upon multiple project stakeholders' perceptions, suggesting that a broader stakeholder perspective is needed. This era is characterised by divergence, and employs mainly empirical methods yielding a number of factors, methods, and practices, including the development and critique of a broader range of critical success factors. Cserháti & Szabó (2014) track developments in how the Iron Triangle is discussed in literature in terms of project success factors and project success criteria from early studies (e.g. Baker et al., 1988; Pinto & Slevin, 1988) and onwards (e.g. Judgev & Müller, 2005). In this era, de Wit (1988) identified that project phases determine which aspect of the Iron Triangle is most important. During the early phase of the project, schedule has primary position, with cost secondary and quality third. Later in the project, cost becomes the main concern, with schedule second. After the project is completed, issues with schedule and cost problems are no longer relevant and quality becomes the most important factor. From the mid- to late-1980s there is also an increasing level of commentary on the inadequacy of the Iron Triangle as a sole measurement of project success (e.g. de Wit, 1988).

Research in the 1990's continued to explore the Iron Triangle in relation success (Bryde, 2008). In this period, project managers' perceptions of the Iron Triangle were increasingly measured in the literature, examining cost (Freeman and Beale, 1992; Wateridge, 1998), time (Judgev and Müller, 2005; Wateridge, 1998) and quality (Wateridge, 1998) as factors contributing to or assessing project success. Research on the Iron Triangle from the mid-1990s onwards has tended to address issues of project complexity and uncertainty, following calls to treat projects as complex social systems and examine the lived experience of projects (van der Hoorn & Whitty, 2015). From this period, it is possible to see a significant increase in thematic diversity, with a broader mix of empirical and conceptual approaches.

From the 2000s onwards, the literature increasingly focuses on how project managers experience and engage with the Iron Triangle. For example, Legault and Chasserio (2012) assert that when the client is given autonomy, IT project managers have little control over the constraints of the Iron Triangle. This leads to pressure to work

long hours, the only area in which they have any remaining control, despite still being held responsible for the project's success.

Limitations of the Iron Triangle

Van der Hoorn and Whitty (2015) recently critiqued the validity of the Iron Triangle in relation to how practitioners manage projects. They suggested that the Iron Triangle is one of many project management artefacts that reinforce thinking not aligned with the lived experience of projects. These authors assert that the Iron Triangle simplifies the perception of project work as experienced by project managers, as a result of practitioner anxiety about the impossibility of complete control over project outcomes. Van Wyngaard et al (2012, p. 1992) have also suggested that "...project managers often create an illusion of tangible progress by relying heavily upon traditional on-time, on-budget and on-target measures", with the implication that the Iron Triangle is an oversimplification of project practice. These papers are part of a broader stream of research that explores the limitations of the Iron Triangle as the core measure of success.

De Wit's (1988) research stands out as early work which distinguishing between task and psychosocial success criteria; the Iron Triangle being an example of traditional task-related criteria only, in contrast to psychosocial criteria such as customer and stakeholder satisfaction, and team member relationships. De Wit was also amongst the first to distinguish between project success and the success of project management processes. The contrast is that project management success might be measured by the Iron Triangle, while project success needs to consider factors including project phase, project type, the satisfaction of multiple stakeholders and the achievement of strategic goals. Since then, many other researchers have adopted, and developed upon, this important distinction, supporting de Wit's placement of the Iron Triangle contributing to project management success, rather than project success (e.g. Hermano et al, 2013; Baccarini, 1999; Cooke-Davies, 2002).

Research has increasingly started to suggest that although the Iron Triangle is important, it does not tell the whole story of project success. For example, Pinto and Pinto (1991) distinguished between short-term and long-term success criteria, categorizing the Iron Triangle as a short-term set of criteria, compared to criteria such as project benefits. Badewi (2016) argued that a strong focus on the Iron Triangle creates an overly output-focused mentality. Too much focus on the Iron Triangle can limit organisational effectiveness in realising benefits, and in the distribution between project managers and functional managers authority and responsibility (Maylor et al, 2006). In addition, Turner and Zolin (2012, p. 12) note that "...evaluations of project success by stakeholders are inherently subjective and cannot be summarized naively into the iron triangle without under or overestimating project success at critical points in the project life cycle."

In 1999, Atkinson, in the single most cited paper in either the *Project Management Journal* or the *International Journal of Project Management* (search on Scopus 21/8/17), critiqued the weight given to the Iron Triangle as the primary measure of project success. He asserted that Time and Cost are 'only guesses' and that Quality is a 'phenomenon', suggesting that new criteria are needed to evaluate the success of projects. Gardiner and Stewart (2000) extend on this, estimating that 50–70% of projects have significant budget or schedule overruns, concluding that initial estimates are inadequate for evaluating success, especially if they are used to benchmark management processes.

In the construction industry, Collins and Baccarini (2004) note that project success must go beyond meeting Time, Cost and Quality objectives. Toor and Ogunlana (2010) also identify that other performance indicators such as safety, efficient use of resources, effectiveness, stakeholder satisfaction, and conflict and dispute reduction are increasingly important in construction. Literature on project management education in this period further supports the call to extend the focus of project management beyond the Iron Triangle.

The Disputed Third Criterion

Review of the literature shows a general consensus that Time and Cost are part of the Iron Triangle, but the status of Quality is less certain. The potentially problematic nature of Quality as a success criterion is broadly reviewed by Geraldi et al (2011). One way of addressing Quality as a key criterion has been to break the criterion into sub-components. For example, Turner (2002) divides Quality into two separate criteria: Product Quality; and Process Quality. Thomson et al. (2003) recommend the implementation of a Design Quality Indicator to track progress. Winch et al. (1998) and Garvin (1984) define Quality in a construction project as Quality of Conception, Specification, Realisation and Conformance.

Some criticise the efficacy of Quality as a success criterion based on the contestable nature of its assessment. Morris and Hough (1997), Heisler (1990), Jha and Iya (2007), and Chan and Chan (2014) all categorise Time and Cost as objective and Quality as subjective. Paquin et al. (2000) develop the concept of Earned Quality, as a way of quantifying progress in achieving quality metrics during a project. However, even if measured, Quality may remain subjective, leaving it open to interpretation and dispute. Indeed, Basu (2014) suggests this overall difficulty in defining Quality means that practitioners and academics pay only lip service to Quality in project success measurement.

Other researchers suggest alternatives to Quality as part of the Iron Triangle. One popular interpretation is to replace Quality with Scope (e.g. Badewi, 2016; van Wyngaard et al, 2013). For example, Van Wyngaard et al (2012, p. 1991) state that “Although the triple constraint theme has various interpretations, the literature shows a general agreement that project scope, time and cost comprise the three key triple constraint variables...”, and these authors argue that it would be more useful to include Scope, than Quality, as one of the vertices in the Iron Triangle. Mokoena et al (2013) also take this position, defining that Scope in the Iron Triangle is made up of three aspects: Quality; Standards; and Specifications. Other suggested alternatives include Performance, and Requirements. Barnes (1988), Lock (2007), and Pinto (2010) all refer to the Time, Cost, and Performance criteria, while other writers replace Quality with meeting Requirements (Pinto & Slevin, 1988; Judgev & Müller, 2005).

Another response to authors’ concern about Quality as a third criterion has been to add extra criteria. Atkinson (1999) proposed that information systems and organisational and stakeholder benefits should be added to the Iron Triangle, transforming it into a ‘square root’. Others have adapted this idea, such as Schwalbe (2009) who suggested that the criteria should be Scope, Time, Cost and Quality. Pinto (2010) advocated for the addition of client acceptance as a fourth essential constraint in the Iron Triangle. Similarly, Williams et al (2015) identified that customer satisfaction and other client relationship issues should be additional criteria in assessing project success. Similarly, Kliem and Ludin (1992) suggest human or soft aspects as a fourth dimension to the Iron Triangle.

Despite the disputed position of Quality as a vertex in the Iron Triangle, frequent insistence that success criteria need to extend past the Iron Triangle, and suggestion that the Iron Triangle distorts our perception of the lived experience of project managers, the Iron Triangle remains an important and popular aspect of how we understand project management practice and the relationship between important constraints. This paper serves two functions, both of which deepen our understanding of what the Iron Triangle is, and how it has helped to shape the discipline of project management. First, this paper answers the question of whether quality, or some other criterion, is the third vertex on the Iron Triangle. Second, this paper explores project management literature to understand whether, how, and when the concept has changed over the last 45 years of research into project management.

Methodology

This research uses techniques from the field of scientometrics, a discipline which has also been called domain mapping, or knowledge domain visualisation (Hook & Börner, 2005), and has been identified as a subfield of information visualisation (Hook, 2007: 442). Scientometrics is a quantitative, and increasingly computational, approach to studying scientific communication, that has developed from the discipline of citation based domain visualisation (Chen, et al, 2011: 131). The aim of these research methods is “...the graphic rendering of bibliometric data designed to provide a global view of a particular domain, the structural details of a domain, the salient characteristics of a domain (its dynamics, most cited authors or papers, bursting concepts, etc.) or all three” (Hook & Börner, 2005: 201).

Images of science are becoming increasingly significant given the significant amount of data that is now available (Börner, 2012: 430). “Just like old sea charts, maps of science can help people to find places of interest while avoiding monsters. They complement local fact retrieval via search engines by providing global views of large amounts of knowledge” (Börner, 2007: 808-9). Scientometric techniques have been used to identify the actors that are driving scientific advancement, whether they are institutions, research communities, or individuals (Scharnhorst, 2012: xii). Visualising Project Management research as a whole provides an opportunity to develop a holistic account of publications in the field.

This research used ISI WoS and Scopus as the sources of research data. The search term ‘Project Management’ was used in the ‘topic’ category to retrieve records from the ISI WoS database. The search term ‘Project Management’ was used across all fields in the Scopus database. Records were retrieved from 1970 to 2015. The

combined results of the searches of both of these databases formed the dataset used in this research (“the database”). It is “...hard if not impossible to identify and compare the entities (records and authors) from all contributing domains” (Börner, 2007: 814). Not all publications on Project Management will have been included in the database, but it was considered that a sufficiently large number of sources had been included to justify a claim that this is a representative sample of the literature.

Börner (2010: 50) previously noted that approximately “...80 percent of a typical project’s total effort is spent on data acquisition and preprocessing...”, and this estimate was consistent for this research, with considerable attention paid to extracting and cleaning publication records. Further details of development of this database can be found in (Reference withheld for blind review).

To test whether Quality, or some other criterion, is the third vertex on the Iron Triangle, and explore how the Iron Triangle has changed during the last 45 years of research into Project Management, it was necessary to first have sufficiently large a body of literature to justify claims of the legitimacy of the research results. However, of the 109,804 records in the database, only 31 included the term ‘Iron Triangle’ in the abstract, and only 6 included the term in the title. The results for the term ‘Triple Constraint’ were 25 and 4, respectively. This was not a sufficiently broad sample to justify representative claims.

Instead, the authors decided to understand how the Iron Triangle has changed by exploring how the knowledge areas that constitute it have changed. Three separate searches were made of the database, searching for the terms ‘time’, ‘cost’, or ‘quality’ in the abstract of a publication. The results of these searches were used create three corpora, representing how Time Management, Cost Management, and Quality Management are discussed in the Project Management literature. Figure 1 depicts the number of the number of records in each corpora, and overlap between corpora, as a Venn diagram. For example, there were 19,855 records in Time corpus, 3,218 records that appeared in both the Time and Quality corpora, and 1,458 records that appeared in the Time, Cost, and Quality corpora.

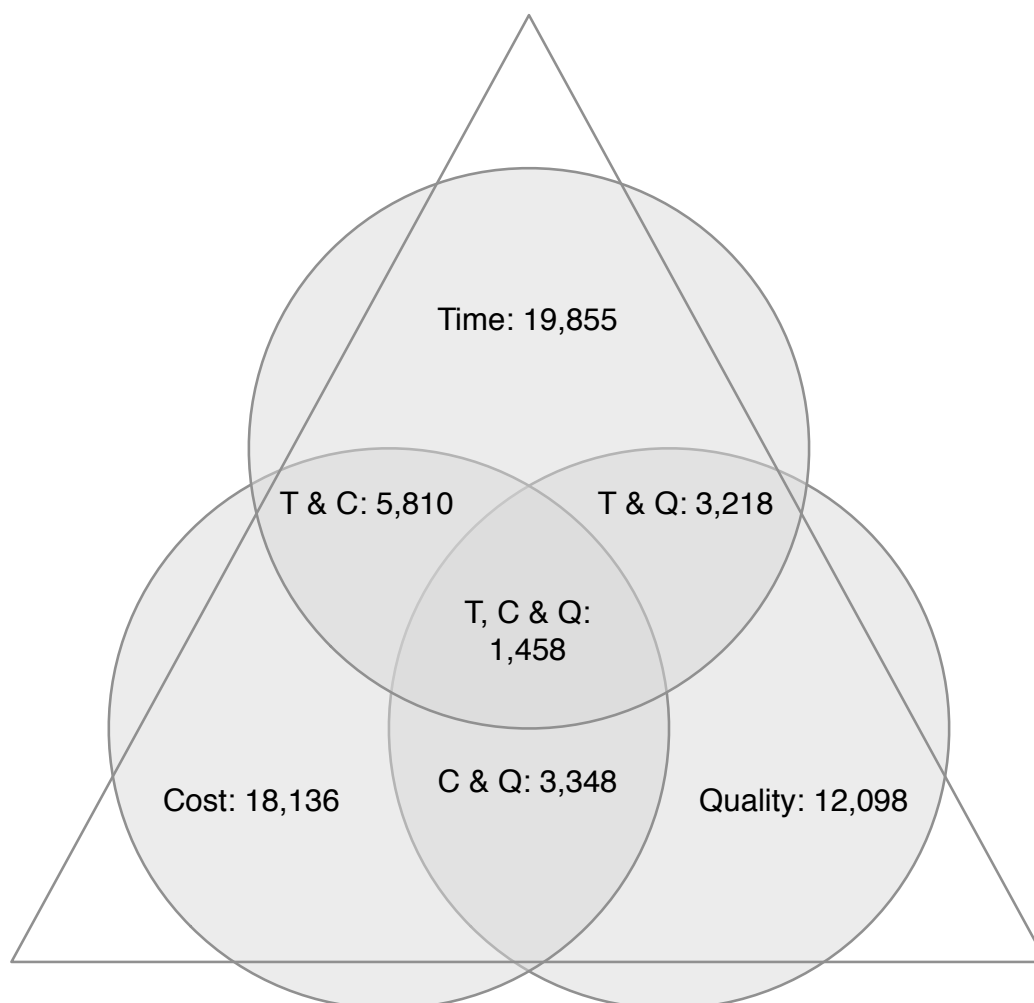


Figure 1: Number of papers in each corpus, and overlap between corpora

Other options for extracting representative texts from the database were explored, including using a variety of words that could be used to indicate an interest in the topic, such as using 'schedule' or 'Gantt' as an indication of interest in Time Management, but this approach was rejected as it introduced the opportunity for additional interpretive variation, and searches using only the single search term per corpus were returning sufficient results to support conclusions about the field as a whole. We did not include paper titles in the search fields, as the software used in this research, Leximancer, is more suited to the analysis of either longer, or shorter, blocks of text, but not both in one analysis.

Leximancer is commercially available text analysis software that semi-automatically identifies a set of key concepts in a body of text, and graphically represents the relationship between these concepts. This software uses "...word occurrence and co-occurrence counts to extract major thematic and conceptual content..." (Angus et al, 2013: 263). The software facilitates research at the level of concepts and themes, instead of authors or publications, such as the research conducted by Biesenthal and Wilden (2014: 1292) into Project Management governance, or by Pollack (2015) into themes in the Change Management literature. Research by Cummings and Daellenbach (2005) is also comparable. They used Leximancer to analyse changes in the strategy and planning literatures. Research by Middleton et al (2011) provides another example of how the software can be used, in this case to examine managers' narratives to understand how they subjectively perceive time.

The analysis process starts by identifying seed words; words that frequently occur in the text. The user has the opportunity to modify, delete, combine, or impose seed words, based on review of how these terms are used in the text. Following this, the software iteratively develops a set of concepts based on the seed words, and based on co-occurrence between terms based on positive and negative correlation. The software learns which concepts are key, with the intention of identifying clusters of terms that when taken together as a group are relevant to the corpus. The relationship between concepts is displayed as a concept map, which in the case of this research has been represented as a minimum spanning tree. The spanning tree shows only the most likely connections between concepts, not all links between concepts. On the concept maps, the size of a concept represents the relevance of the concept within that map. Concepts are more likely to be near each other on a map the more frequently they co-occur in a piece of text. Examining the concept maps allowed for an understanding of how concepts co-occur in the corpora.

Leximancer also identifies the relevance of each concept within a corpus. Relevance is a comparative rating of the frequency with which concepts appear in the corpus. Each concept is also associated with a thesaurus, composed of the terms that are most likely to appear with it. In this research, comparing the lists of most relevant terms allowed the researchers to develop an understanding of how individual knowledge areas are being discussed, and the relationships between concepts. Further, by comparing the words that were likely to co-occur with highly relevant terms, it was possible to develop an understanding of whether the context in which some of these terms were used had also changed. The main way of answering the question of whether Quality, or some other criterion, was the third vertex of the Iron Triangle was by analysing the significance of concepts, and relevance of concepts they are linked to. If Quality was the third vertex, it was anticipated that this concept would be particularly significant in the Time and Cost corpora, and the Quality corpus would similarly emphasise Time and Cost, over and above other potential criteria.

The researchers' role in this stage of the analysis largely related to the interpretation of the meaning of concepts in context. The concept seeds for each period were examined in detail, by reading the concept seed in the context of the original text to understand its meaning. Automatic concept generation was supplemented by a round of manual concept creation, combination, concatenation, and deletion. The singular and plural instances of a concept seed were combined into a single concept seed. Noun and adjective forms of concept seeds were combined in some instances, when they were most commonly used with a comparable meaning. Other concept seeds were deleted, as not adding any explanatory insight. For example, 'project' and 'management' were deleted from all periods, while 'cost' was deleted from the concept seeds for the Cost Management graphs, as were the respective equivalent keywords. Concept seeds that primarily indicated research specific terminology were also deleted, such as 'results'.

Additional processes were used to understand how the corpora had changed. Each corpus was divided into 5-year time slices. Lists of relevant concepts were created and compared for each of these periods, looking for points at which there were clear shifts in the literature, including the appearance of new concepts, earlier concepts dropping off later lists, and significant changes in the relevance of concepts. The intention was to investigate whether there had been a significant shift in how these knowledge areas are discussed in the literature, and to separate each corpus into representative periods. The intention in this process was not to

identify an exact date when a shift in the literature occurred, as a literature changes as a non-linear process with multiple trends changing simultaneously, at different rates. A literature does not change at one specific instance. The intention was to produce graphs that represent earlier and latter periods in the development of the literature. The choice of dates at which a corpus was to be divided was an interpretive process, based on which combinations of years showed the greatest differences in the lists of relevant concepts and concept maps.

Once turning points were identified in each corpora, concept maps were then made for each period of each knowledge area. Each concept map was examined to understand how the concepts clustered, and how this changed between periods. The concepts identified as most relevant in each period were then examined. This included the terms that were most likely to occur with each of these most relevant concepts. This review helped to develop an understanding of how these knowledge areas are changing, and how the meanings of the words used to discuss these knowledge areas have varied over time.

Analysis

The literature on Time, Cost, and Quality management will each be discussed in turn, including consideration of how these knowledge areas have changed. The results of this analysis will then be used to answer the question of whether it is Quality, or some other quality, on the third vertex of the Iron Triangle.

Cost

Network diagrams were created for two periods: 1970 to 1989 and 1990 to 2015. There are considerable differences between the network diagrams, as can be seen in Figure 2.

The earlier period included concepts which are not apparent in the latter network, including Capital, Estimating, Performance, Schedule, and Activities. When these concepts are interpreted in the context of the abstracts in which they are used, they respectively, most typically referred to capital works projects, estimation techniques, performance measurement and monitoring, and the process of scheduling activities. This suggests that these concepts have become less central to the concept of Cost Management. In the earlier period, Cost Management was mainly focused on engineering, software systems development, and the construction of large projects, often using power plants as a focus for research.

New concepts and clusters of concepts have emerged in the latter period, enriching the concept of Cost Management as an activity that plays a broader role in more aspects of a project. The previous industry focus remains, but this has extended to consideration of oil and gas projects as an area of focus. Cost Management issues in the construction industry have extended to consideration of safety and site conditions. The literature on Cost Management in the energy, oil, gas, and power sector has broadened to include discussion of facilities management, supply chains, supply and capacity issues, and environmental concerns, with a focus on public sector projects and public funding. A new cluster of concepts related to product development appeared in the latter period, while the range of concepts associated with information systems and engineering systems development has broadened. These areas are strongly linked to concepts related to business value, understanding requirements, knowledge and decision making. Students also appeared as a key concept in the second period, suggesting the emergence of a new focus on education.

Changes in the meanings associated with these concepts can also be understood when concepts that appear in both periods are compared. Table 1 lists the most relevant concepts in each time period. For example, although Construction is a relevant concept in both periods, in the former it is more commonly associated with planning and power stations. By the latter period, the emphasis has shifted to greater consideration of industry wide issues of safety and management control. The concept of Design in Cost Management lost some emphasis on the design process as a way of ensuring construction quality, and gained an emphasis on requirements definition, product development, and how this could be taught to students. Reviewing the lists of top concepts, it is also possible to see changes in the field of Cost Management as a whole. While Control, Engineering, Planning, and Scheduling were top concepts by frequency in the earlier period, they were not top concepts in the latter period, being replaced by a greater focus on data, technology and decision support.

The change in emphasis in the Cost Management literature can also be understood in terms of the changing relevance of concepts. Although Control and Process were both identified as significant concepts in both networks, they are much less significant in the latter period. In contrast, Models and Modelling become much more significant in the more recent period, particularly in terms of the development of predictive algorithms for use in decision support software.

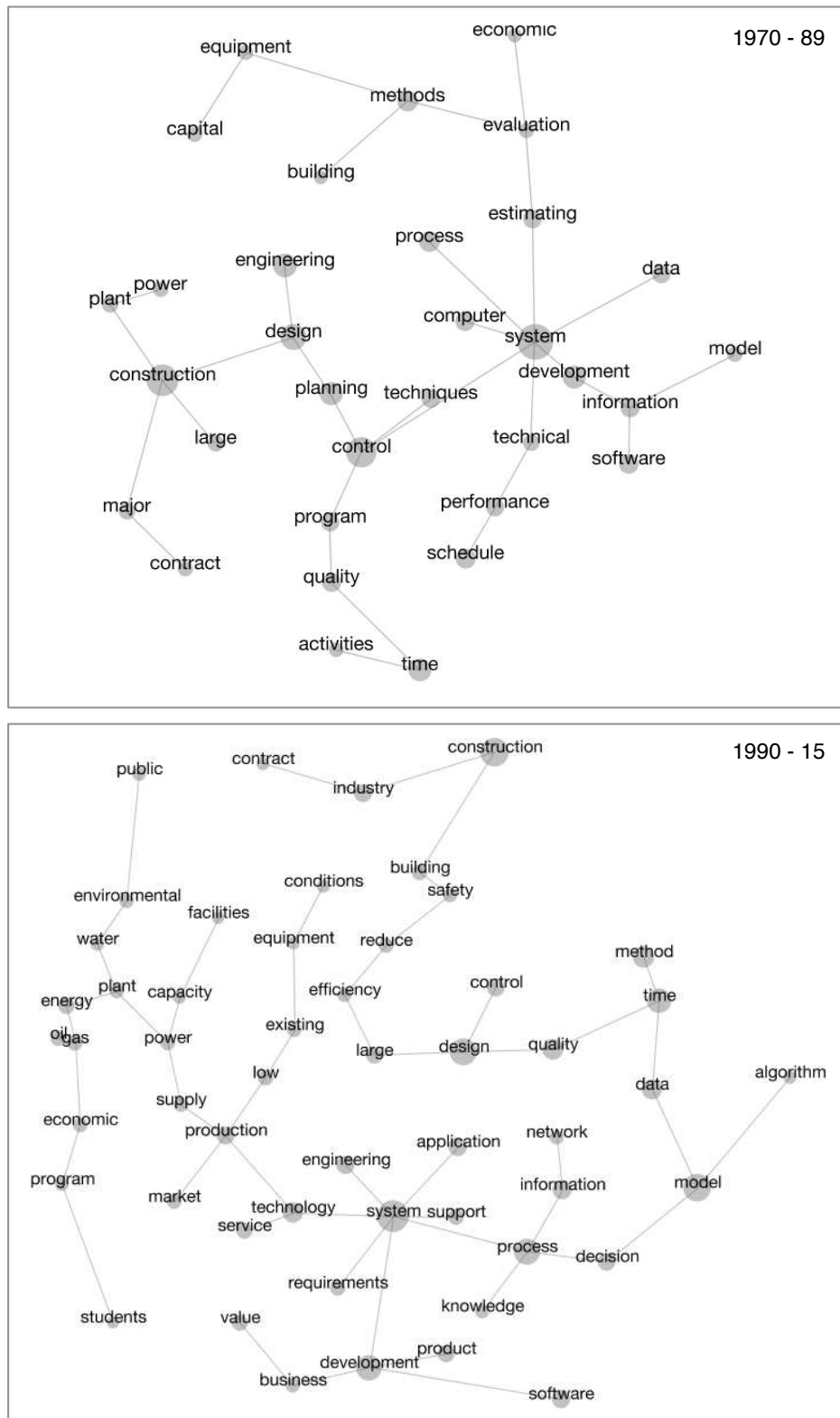


Figure 2: Network diagrams for two periods of the cost management literature

These changes suggest a field that has been developed within a limited range of industries, but over time has been applied in a broader range of application areas, including an increased emphasis beyond the strict confines of the project to the integration of the project within a broader business environment, and a deeper understanding of the implications of site conditions, production, market and supply constraints on a project's financial performance.

Top Concepts	Most Likely Associated Concepts
Cost: 1970 - 1989	
System	Computer, information, software, control, estimating, data
Construction	Contract, design, building, plan, power, engineering
Control	Contract, planning, scheduling, system, quality
Time	Activities, quality, model, techniques, performance
Design	Building, engineering, construction, process, quality
Engineering	Design, power, plant, technical, estimating, construction, control
Development	Software, technical, model, economic, process, system
Planning	Control, activities, program, contract, schedule, design, major
Schedule	Performance, control, techniques, activities, contract, quality
Quality	Performance, contract, program, control, design, schedule, time
Cost: 1995 - 2015	
Construction	Industry, building, contract, safety, design, control, engineering
System	Control, power, information, support, network, existing, water
Model	Algorithm, network, data, decision, software, time, support
Design	Students, engineering, product, facilities, requirements, building
Time	Algorithm, quality, network, reduce, product, model, market, safety
Development	Product, software, technology, market, requirements, oil
Data	Information, network, model, software, support, application, control
Quality	Product, safety, time, service, control, software, efficiency, water
Technology	Information, power, application, oil, gas, energy, network
Decision	Support, information, value, business, knowledge, economic, capacity

Table 1: Top concepts in each Cost Management period

Time

Investigation of five-year time slices of the data showed a shift in disciplinary focus for the Time Management literature at approximately the year 2000. Network graphs for the periods 1970 to 1999 and 2000 to 2015 are provided in Figure 3.

The earlier period included concepts which are not apparent in the latter network, including Planning, Programming, Decision, Risk, Requirements, and Change. When these concepts are interpreted in the context of the abstracts in which they are used, Planning and Programming most typically referred to issues of activity scheduling and resource control during implementation. The Decision concept typically referred to issues of decision makers, and support for decision making. Risk analysis was also a significant concept in the former period, particularly in terms of risk analysis techniques and its impact upon decision making. The concept of Requirements was mainly discussed in terms of resource management, and requirements definition, particularly for software and product development projects. Change was also identified as a significant, with respect to the change control process, implementation of changes and variations, and risks associated with changes. The presence of these concepts in the earlier network, but not the latter, suggests these concepts have become less central to the concept of Time Management.

New concepts and clusters of concepts have emerged in the latter period, enriching the concept of Time Management as an activity that plays a broader role in more aspects of a project. These new concepts have been loosely grouped into three clusters. The previous industry focus on construction, engineering, and software projects remains. However, in the latter period the focus of the field has expanded to include oil, gas, water, power, and public sector projects. The concepts representing these new industries in Figure 3 are closely associated with other concepts that did not appear in the earlier network diagram. These include consideration of safety, conditions, and cost management.

The second cluster is dominated by the concept of Systems, which did not appear in the earlier network, but is the most frequently occurring concept in the second network. Associated with this are concepts related to applied methods and simulation, real-time monitoring of performance, and support systems, particularly decision support. It is not surprising that these concepts have only gained prominence in more recent times, due to their reliance of greater computing capacity.

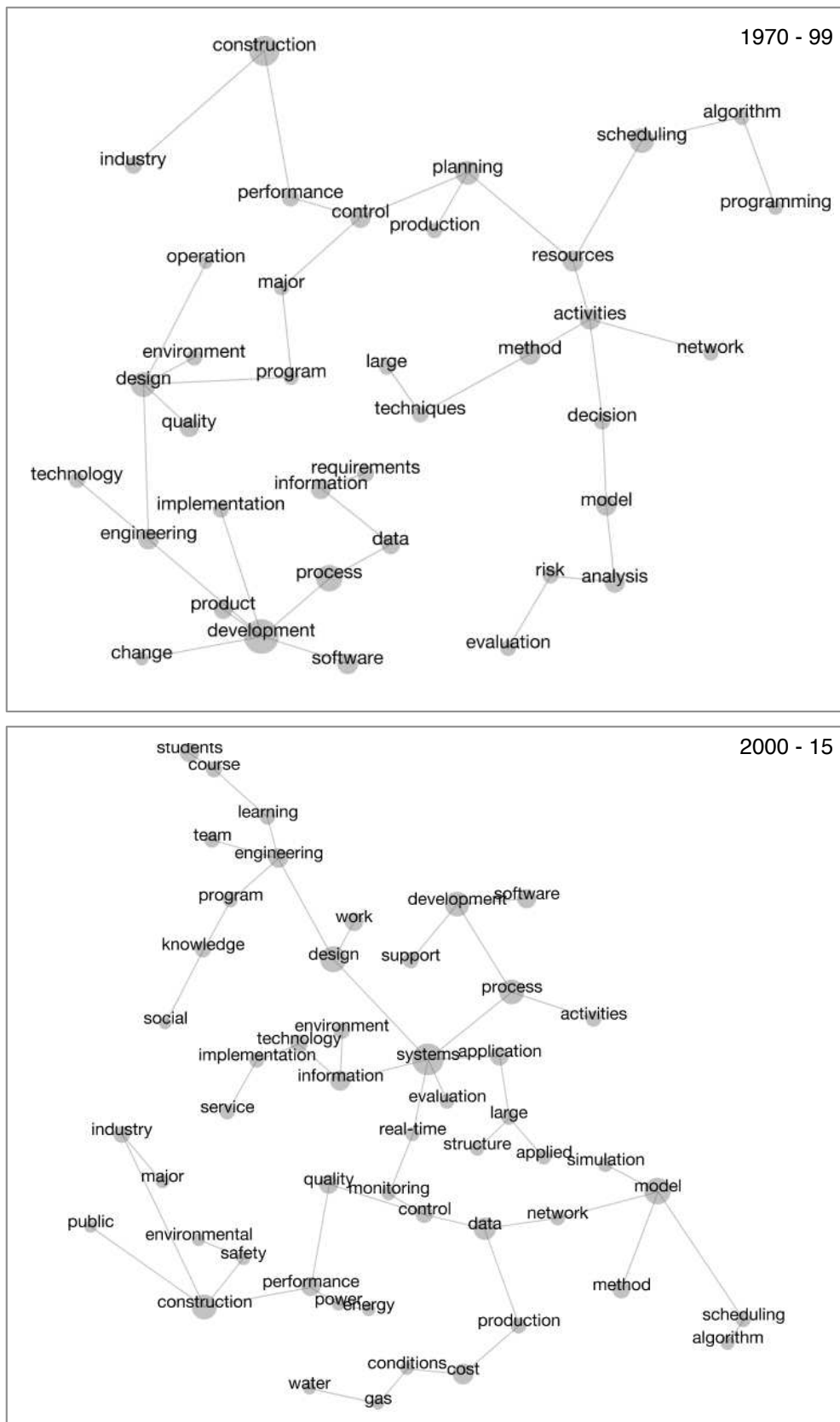


Figure 3: Network diagrams for two periods of the Time Management literature

The third cluster that appeared in the latter period is centred around the concept of Engineering. While Engineering was present in the earlier graph, it was previously associated with issues of Technology, Implementation, Quality, and Product development. In the latter graph, Engineering is most strongly associated with educational issues such as Learning, Knowledge, Students, and Courses, and interpersonal considerations

indicated by the concepts Teams and Social. This represents a major shift in how engineering related issues are being discussed in the Time Management literature.

Review of the most likely co-occurring terms (Table 2) also reveals other changes in the field. The concept of Construction has shifted from an emphasis on the design of major projects, and operational performance, to safety, public projects, and managing cost and quality. The concept of Process has changed from a focus on software and change control, to simulation, production, and quality processes. Although Design has continued to include an emphasis on engineering, its focus has also changed. In the earlier period the concept of Design in the Time Management literature emphasised major projects and product design quality. The latter period has more strongly focused on course design, to structure student and team learning. In terms of frequency, Scheduling, Planning, Engineering, Control and Resources were all highly frequently co-occurring concepts in the earlier period. These concepts were replaced by Systems, Model, Data, Cost, Performance and Software in the later period.

Top Concepts	Most Likely Associated Concepts
Time: 1970 - 1999	
Construction	Industry, major, design, operation, performance
Development	Product, technology, software, process
Scheduling	Algorithms, resources, programming, activities, networks
Process	Software, software, change, development, design
Planning	Production, programming, control, resources, implementation
Design	Operation, product, engineering, major, quality, program
Analysis	Risk, techniques, network, data, decision, model
Engineering	Product, software, design, program, techniques, data
Control	Network, planning, quality, large, production, major
Resources	Activities, scheduling, requirements, algorithm, decision
Time: 2000 - 2015	
Systems	Real-time, monitoring, control, information, support
Model	Simulation, algorithm, scheduling, network
Construction	Industry, safety, cost, monitoring, public, quality
Design	Course, engineering, students, structure, team, learning
Process	Development, design, simulation, production, software, quality
Development	Software, process, technology, social, engineering, environment
Data	Real-time, monitoring, information, network, systems, water, control
Cost	Quality, construction, scheduling, control, performance, algorithm
Performance	Evaluation, safety, cost, quality, simulation, team, monitoring, control
Software	Development, engineering, quality, real-time, application, team, process

Table 2: Top concepts in each Time Management period

The change in emphasis in the Time Management literature can also be understood in terms of the changing relevance of concepts. Although Model and Performance were significant concepts in both periods, the relevance of these concepts increased over time, suggesting that issues of simulation modelling, models of schedules, network models, evaluating performance, and safety, cost and quality performance have all increased in significance. By contrast, the concepts of Construction and Scheduling both experienced a significant drop in significance. Both concepts remained central to the network, and their drop in significance can be interpreted as a result of there being many more concepts identified as significant in the latter network graph.

This analysis of the literature on Time Management suggests a changing discipline. While the field included an emphasis on planning, programming, decision making, risk management, requirements definition, and change control before the year 2000, this emphasis appears to be declining. More recently, the literature has discussed Time Management in terms of a growing range of industries, and has developed a focus on advanced real-time simulation techniques, and educational issues, particularly in engineering.

Quality

Review of the Quality Management time slices showed two shifts in disciplinary focus, at approximately the years 1990 and 2002. Unlike Time and Cost, this resulted in three graphs. Network graphs for the periods 1970 to 1990, 1991 to 2002, and 2003 to 2015 are provided in Figure 4.

Time were highly relevant concepts in all time periods, the consistent core to how Quality Management has been discussed. Although the way some of these concepts are used in the text has remained quite similar across the three periods, the meaning of some of these concepts appears to have changed. The concept of Design in Quality Management has lost some emphasis on construction, planning and control, and gained an emphasis on education, product, structure and materials. The Software concept lost an emphasis on development, large systems, and methods for increasing productivity, and gained greater emphasis on processes, models, and requirements management. Overall, from a review of concept frequency, while Quality Management used to emphasise process, planning and development, the latter period lost this focus, to instead more recently emphasise data, product and performance.

Top Concepts	Most Frequently Associated Concepts
Quality: 1970 - 1990	
System	Information, software, data, water, requirements, control
Cost	Time, objectives, construction, performance, production, factors
Design	Engineering, construction, planning, control, process, plant
Development	Software, large, productivity, data, product, process, information
Construction	Industry, plant, design, cost, engineering, time, performance
Process	Product, model, development, design, production, software
Software	Development, productivity, data, large, system, methods, production
Time	Cost, factors, objectives, techniques, construction, organization, requirements
Planning	Control, environmental, data, large, production, design, information, team
Assurance	Control, team, program, technical, methods, requirements
Quality: 1991 - 02	
Process	Software, development, product, activities, planning, control, major
System	Information, support, control, operation, requirements, application
Development	Software, product, technology, process, environment
Design	Students, operation, course, engineering, construction, product, control
Construction	Industry, design, operation, cost, public, large, plant, control
Software	Development, process, model, requirements, support, environment
Engineering	Students, course, design, technical, program, software, production
Cost	Time, performance, control, product, methods, construction, support, plant
Planning	Control, plant, environmental, implementation, activities, requirements
Time	Cost, product, large, activities, team, major, conditions, service, construction
Quality: 2003 - 15	
System	Information, power, monitoring, control, energy, technology, network
Construction	Industry, building, materials, cost, control, monitoring, design
Model	Algorithm, network, decisions, evaluation, structure, test, software
Software	Engineering, product, requirements, process, model, activities
Design	Engineering, students, building, structure, materials, product, power
Data	Monitoring, test, information, network, assessment, large, conditions
Product	Production, software, process, design, requirements, business, life
Performance	Factors, evaluation, monitoring, team, cost, assessment, business
Cost	Time, construction, control, life, algorithm, factors, building, product, decision
Time	Cost, life, construction, monitoring, product, control, conditions, environment

Table 3: Top concepts in each Quality Management period

Finally, we can review the Quality Management literature in terms of the changing relevance of key concepts that appear in all three time periods. Four concepts stand out as making a significant change in their relevance. The relevance of models to Quality Management has increased dramatically, particularly in terms of evaluation and testing of software, algorithms, networks, and decision making. The concept Data also shows a large increase in significance. By contrast, although Cost and Control remain key concepts in Quality Management, they have sharply declined in significance.

The Third Vertex

Some researchers have suggested that the third vertex of the Iron Triangle should be something other than Quality, such as: Scope (e.g. Bedewi, 2016; van Wyngaard et al, 2012; Schwalbe, 2009); Performance (e.g.

Barnes, 1988; Lock, 2007; Pinto, 2010); or Requirements (e.g. Pinto & Slevin, 1988; Judgev & Müller, 2005). This question will be answered through reference to concept significance and the levels of cross-referencing between these corpora.

When the graphs for Time, Cost, and Quality are compared, it is possible to see how tightly coupled these three concepts are. All of the graphs typically included concepts representing the other two, as highly-ranked concepts. Both Cost Management graphs included the concepts of Time and Quality, and all three Quality graphs included Cost and Time. The one exception to this were the Time graphs, that included Quality in both graphs, but only included Cost in the latter graph.

This level of cross-referencing becomes more interesting when other potential candidates for the third vertex are considered. Performance occurred in the first Cost period, and as low-ranked concepts in the Time corpus in both periods. Requirements occurred as a low-ranked concept only in the second Cost period, and the first Time period. Performance and Requirements occurred in all Quality time periods, suggesting these concepts are more closely coupled to Quality, than they are to either Time or Cost. It is also worth noting that of all the other knowledge areas in the PMBOK Guide (PMI, 2013), only Risk was directly identified as a concept, and even then, it only occurred in the earlier of the two Time Management graphs. Scope does not appear as a significant concept in any of the graphs.

This analysis has demonstrated that Time, Cost and Quality are highly integrated concepts in the project management literature. It is little surprise that the concept of the 'Iron Triangle', or 'Triple Constraint', emerged as a distinct and dominant concept in the field of Project Management. The level of interconnection between these concepts is significantly greater than the interconnection between Time, Cost, and any of the other concepts that have been suggested as the third vertex of the Iron Triangle.

The Common Core of the Iron Triangle

Ten concepts are common to all graphs across all time periods (Table 4). These concepts do not directly define the Iron Triangle, but they do contribute to our understanding of it, by describing the context in which the Iron Triangle is most commonly discussed. They are the context in which Time, Cost and Quality Management are most commonly discussed in the project management literature. Time, Cost, and Quality Management are most commonly discussed in the construction, and engineering industries, with some emphasis on IS / IT. There was a particular focus on large projects, as opposed to the other disciplines where project management is practiced. Issues of data processing, use of data in monitoring progress, and engineering design are also commonly associated with the Iron Triangle. There is also a significant association between the Iron Triangle and the use of models for simulation and optimisation, including activity and resource programming, and persistent interest in ways of controlling project deviation and progress.

There are also clear trends in how these three knowledge areas have developed over time. In all three of these areas, the concept Planning has reduced in significance over the period studied. Planning is now a less significant aspect of how Time, Cost, and Quality are discussed in the project management literature, compared to when the literature was initially developing. With respect to literature on Cost and Quality, the concepts of Control and Process have also reduced in significance, showing less influence in the latter period. However, Control remained a significant concept throughout the period of study in the Time Management literature.

There were many more commonalities between how the three knowledge areas have grown over time. All three knowledge areas have shown a marked increase in attention to education related issues, typified by concepts such as Students and Knowledge. The three knowledge areas also showed a consistent broadening in the range of industries addressed, with all three including the concepts related to power plants, the energy sector, information system, and public sector projects. All three knowledge areas also increased interest in information systems related concepts, including models, data, and technology, which is consistent with the increased capabilities that information system support provides in the management of projects. Decision making and decision support systems became more significant in all three knowledge areas, as did consideration of the environment, and the conditions in which a project was set.

There were considerable similarities in how the literature associated with the three knowledge areas has developed. Given that there was only a small overlap between the references referring to these three areas (Figure 1) this similarity speaks to broad consistencies in how the literature related to aspects the Iron Triangle is developing. However, it is unclear from this research whether this is an isolated area of internal consistency, or whether this is typical of the ways that the literature on project management is broadly developing.

<i>Common Concepts</i>	<i>Most Frequently Associated Concepts</i>
Construction	Industry, Materials, Cost, Monitoring, Equipment, Factors, Conditions, Design
Engineering	Education, Programming, Systems, Students, Networks, Processing, Control
Software	Development, Programming, Engineering, Tools, Products, Systems, Models
Information	Technology, Communication, Flow, Processing, System, Decisions, Monitoring
Data	Processing, Monitoring, Test, Information, Distribution, Network, Application
Design	Engineering, Students, Product, Materials, Equipment, Education, Structure
Model(s)	Optimization, Simulation, Algorithm, Programming, Network, Decision, Evaluation
Control	Networks, Programming, Processing, Planning, Systems, Monitoring, Engineering
Program	Activity, Resources, System, Gas, Cost, Network, Structure, Risk, Information
Large	Quality, Environment, System, Development, Flow, Risk, Factors, Monitoring

Table 4: Concepts common across all graphs

Limitations and Implications

This research has some limitations, which should be considered when interpreting the results. The research has focused on peer-reviewed conference papers and journal articles available through the Scopus and Web of Science databases. These sources, although comprehensive, do not represent the sum of all published material on project management, particularly excluding books and trade publications. The consequence of this is that the research will have a bias towards an academic interpretation of the Iron Triangle, and not necessarily be representative of a practitioner perspective. In addition, the research has drawn conclusions about how the Iron Triangle is represented, based on the abstracts of publications. Although abstracts are typically written as a summary of a work, they are necessarily brief, and this research may have missed some of the nuance inherent in the full-text of some articles. However, as many older publications were not available in a full-text searchable format, this kind of analysis was not possible.

Conclusion

The Iron Triangle, also referred to as the Triple Constraint, has been an indisputably central aspect of project management since early research into this field in the 1970s. Despite a significant body of research asserting that the Iron Triangle does not tell the whole story of project success measurement, the criteria of on time, under budget, and to a defined quality still maintain a preeminent place in our understanding of whether a project has been delivered as planned.

The network diagrams for all three concepts showed the following concepts are key across all time periods, suggesting that these concepts represent the core context in which the Iron Triangle is typically discussed in the literature: Construction; Engineering; Software; Information; Data; Design; Model(s); Control; Program; and Large. However, the literature associated with these knowledge areas has shown a significant change from how they were represented in early project management research. Planning has become less significant to all three knowledge areas, while Control has become a less significant concept in how Cost and Quality are discussed. The literature on all three knowledge areas has significantly broadened, extending from an original focus on engineering and construction to encompass information systems projects, the power and utilities sector, and public sector projects. The emphasis on decision making and decision support has also significantly increased, showing a developing emphasis on how project managers understand progress towards objectives during project execution.

Some researchers have made strong arguments that Scope, Performance, or Requirements, should be part of this triumvirate, instead of Quality. There are two different interpretations of the Iron Triangle, which lead to different responses to this question. From the perspective of viewing the Iron Triangle as a representation of the status of the most important project success criteria, this paper would argue that the relevance of Time, Cost, Quality, or any other criteria are entirely contingent on the context. The only persistent criteria by which the success of all projects can be assessed are client and contractor satisfaction with the outcomes and impacts of a project.

When, instead, viewing the Iron Triangle as a didactic device, intended to communicate the relationship between Time, Cost, and other potential criteria, the authors note that variations in project duration or budget could potentially affect variations to scope, the achievability of requirements, and the standard to which deliverables are produced. As a didactic device, it seems that Scope, Performance, Requirements, and Quality could all be

interchangeable as the third vertex on the Iron Triangle, and are just of varying relevance depending on the kind of project being assessed.

However, the purpose of this paper is not to advocate for what the Iron Triangle *should* be. Instead of making a prescriptive claim, this paper makes a declarative statement, based on our analysis of how researchers discuss these concepts in published research into project management. Based on this analysis, the Iron Triangle *is* Time, Cost, and Quality.

Upon reviewing the network diagrams that were created for Time, Cost, and Quality, it is clear that these three concepts are highly interconnected. In comparison, Scope does not occur as in any of these networks. Requirements and Performance do appear in these networks, but their presence is inconsistent, and of a lower significance than Quality. Both of these concepts appear more linked to Quality, than either Time or Cost. Time, Cost, and Quality are so consistently interconnected in the literature that it is not surprising that the Iron Triangle has emerged as a distinct and significant concept in the project management literature.

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