UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Including Generative Mechanisms in Project Scheduling using Hybrid Simulation

by Jeffrey Scales

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under the supervision of

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Jeffrey Scales declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of the Built Environment, Faculty of Design, Architecture and Building at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Peer reviewed publications from this research

Scales, J. 2020, 'A design science research approach to closing the gap between the research and practice of project scheduling', *Systems Research and Behavioral Science*, vol. 37, no. 5, pp. 804-12.

Abstract: This paper illustrates one researcher's experience of applying Design Science Research (DSR) to the nexus between systems thinking and project scheduling. Project management has become increasingly popular in the decades since its advent but has changed little in that time. This is especially true because of its signature technique, project scheduling. Scheduling research however is vibrant and modern and even includes dynamic concepts such as learning curves in schedule construction. However, justifications for acquiring this level of systems literacy have not yet convinced the practice community. A similar gap is identified in management science, and a literature review yields two potential solutions: dissolving the subjective-objective divide by adopting Critical Realism and using DSR as a framework for producing artefacts. This paper outlines how these concepts were applied to project scheduling, resulting in a new method for schedule construction that allows an expanded range of concepts to be included.

Scales, J. 2019, 'Including Generative Mechanisms in Project scheduling using Hybrid Simulation', *63rd Annual Meeting of the International Society for the System Sciences*, Corvalis.

Abstract: Scheduling is central to the practice of project management and a topic of significant interest for the operations research and management science academic communities. However, a rigour-relevance gap has developed between the research and practice of scheduling that mirrors similar concerns current in management science. Closing this gap requires a more accommodative philosophy that can integrate both hard and soft factors in the construction of project schedules. This paper outlines one interpretation of how this can be achieved through the combination of discrete event simulation for schedule construction and System Dynamics for variable resource productivity. An implementation was built in a readily available modelling environment and its scheduling capabilities tested. They compare well with published results for commercial project scheduling packages. The use of System Dynamics in schedule

construction allows for the inclusion of generative mechanisms, models that describe the process by which some observed phenomenon is produced. They are powerful tools for answering questions about why things happen the way they do, a type of question very relevant to practice.

This paper won the 2019 Anatol Rapoport Memorial Award for the best student paper presented at the conference in a quantitative, engineering, hard science, natural science, technological, or logico-empirical systems framework (Scales 2019).

Other peer reviews of this research

In April 2018 a paper titled "Project scheduling with System Dynamics" was submitted to PMS 2018, the 16th International Conference on Project Management and Scheduling in Rome, Italy. The paper was peer reviewed and accepted but withdrawn due to insufficient funding for travel and accommodation.

Abstract: This paper outlines the concepts underlying research into bridging the gap between System Dynamics and resource constrained project scheduling. The aggregation of tasks into flows is identified as the major impediment against System Dynamics being used in scheduling contexts. A new level of aggregation is proposed compatible with task decomposition and network analysis. The implications and limitations of this approach are considered. A method for benchmarking the capabilities of such an approach is proposed. Sample output is presented from a proof of principle version of such a scheduling engine, currently being built in the AnyLogic multi-method modelling environment. Further research goals are outlined.

In June 2018 a paper titled "Including Human Factors in Project scheduling using Hybrid Simulation" was submitted, peer reviewed, accepted and presented (December) at the 2018 conference of the International Research Network on Organizing by Projects (IRNOP 2018) in Melbourne, Australia. The accepted version of this paper was also reviewed and presented at a combined UTS and Sydney University doctoral symposium in November 2018.

Abstract: Scheduling is central to the practice of project management and a topic of significant interest for the operations research and management science academic communities. However, a distinct divide has developed between the research and

practice of scheduling. As new scheduling challenges appear, we risk the deepening of this divide. One such challenge is including human factors, physiological or psychological human attributes, as planning assumptions in project scheduling. The diversity of approaches currently taken do not help in closing the existing divide. This paper outlines one interpretation of how this can be achieved through the reuse of components for scheduling methods, tools and models, specifically for the investigation of the effect of human factors in scheduling. It is based on two simple design principles; that human factors are best described as continuous rather than discrete variables, and that replicability and reproducibility require an open-source approach to the tools used.

An extended thesis abstract titled “Including Generative Mechanisms in Project Scheduling Using Hybrid Simulation” was reviewed and presented at the Asia Pacific Project Studies doctoral colloquium (online) in December 2020.

Other peer reviewed publications by the author.

Scales, J., Sankaran, J. & Cameron, R. 2015, 'Is the project management field suffering from methodological inertia?: Looking for evidence in publications in a recently established journal', *EURAM 15th Annual Conference 2015*, EURAM, Warsaw, Poland.

Abstract: Project management (PM) researchers have traditionally used quantitative methods in their research due to the origins of this practice-based discipline in defence and engineering. Although qualitative methods have started being used in PM research most of the qualitative research reported tends to use case studies. Recently there has been a call for PM researchers to use more novel methods to enlarge the variety of methods used by the researcher in the field contributing to its further development (Drouin, Muller and Sankaran 2013; Cameron, Sankaran and Scales 2015). A review of papers presented at the International Research Network on Organizing by Projects (IRNOP) conference in Berlin in 2009 showed a surprising trend that papers presented at these conferences used more qualitative methods in comparison with papers being published in key PM journals. This paper analyses papers published over the past six years in a comparatively new PM journal, since its inception, to explore whether a new journal has motivated PM researchers to overcome their methodological inertia and broaden the variety of research methods being utilised by them. A mixed methods prevalence study was undertaken on articles published in the International Journal of

Managing Projects in Business (IJMPiB) from 2008 to 2014 (n=265). The findings point to methodological inertia in the majority of research but also an unusually high proportion using mixed methods. Future research is needed to add finer granularity to the analysis.

Cameron, R., Sankaran, S. & Scales, J. 2015, 'Mixed methods use in project management research', *Project Management Journal*, vol. 46, no. 2, pp. 90-104.

Abstract: Mixed methods research is increasingly being used in business and management disciplines, in spite of positivist traditions. The aim of the study is twofold: (1) to examine the types of mixed methods approaches being used, and (2) to determine the quality of the reporting of mixed methods studies published in the field of project management. A retrospective content analysis of articles from three ranked project management journals was undertaken for a sample period of 2004 to 2010. Our findings suggest the field of project management is in need of capacity building in relation to the good reporting of mixed methods studies.

Sankaran, S., Cameron, R. & Scales, J. 2012, 'The utility and quality of mixed methods in project management research', *EURAM 12th Annual Conference 2012*, EURAM.

Abstract: Mixed methods research is being touted as the third methodological movement. characterised by a growing body of theoretical and methodological frameworks and a body of cross-disciplinary literature. Prominent mixed methodologists have championed the movement, which has strong footholds in the fields of education, healthcare, and the social and behavioural sciences. Mixed methods research is being used within business and management fields, despite the positivist traditions common in these disciplines. This paper has used a retrospective content analysis of articles from three ranked journals in the field of project management: International Journal of Project Management, the Project Management Journal and the IEEE Transactions on Engineering Management. The aim of the study is to determine the prevalence rates of mixed methods in project management and to investigate the quality of mixed methods research within this field. Implications for further research are discussed, along with some guidelines to justify and describe how mixed methods have been used in project management research papers.

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Abbreviations

ACO	Acos Plus 1
AON	Activity On Node
APM	Association of Project Management
ATP	AdeptTracker Professional
CH	Switzerland
CIMO	Context, Intervention, Mechanism, Outcome
CPLB	Critical Path Lower Bound
CPM	Critical Path Method
CSP	CS Project Professional
DES	Discrete Event Simulation
DPM	Dynamic Planning and control Methodology
DSR	Design Science Research
MSP	Microsoft Office Project 2007
NP-Hard	Non-deterministic Polynomial-time Hard
PERT	Program Evaluation and Review Technique
PMAJ	Project Management Association of Japan
PMBoK	Project Management Body of Knowledge
PMI	Project Management Institute
PP6	Primavera P6
PS8	Sciforma PS8
PSPLib	Project Scheduling Problem Library
RCPSP	Resource Constrained Project Scheduling Problem
SDESA	Simplified Discrete-Event Simulation Approach
SGS	Schedule Generation Scheme
SYDPIM	System Dynamics Project Management Integrated Model
TPP	Turbo Project Professional
UK	United Kingdom
USA	United States of America

Abstract

This research seeks to expand the range of concepts used in project scheduling and aligns with the broader research effort to rethink project management. It begins with the observation that current project scheduling practice is based on ideas from the 1960's, whilst research has developed considerably since that time. It adopts the approach of identifying and challenging assumptions underlying both the research and practice of project scheduling, to develop an understanding of why practice seems to ignore research. It develops the view that the issue is fundamentally philosophical in nature.

The solution proposed involves relaxing the constraints, both ontological and epistemological, that a preponderance of positivistic thinking imposes on project scheduling. Relaxing ontological constraints involves expanding the range of things acknowledged to be real. Adopting the philosophy of Critical Realism is proposed as one way to achieve this. Linked to this are epistemological concerns regarding the clarity of the explanations we construct, using our knowledge of real things, for the events we observe. The adoption of mechanistic explanation, using Critical Realism's generative mechanisms, is also proposed for its causal clarity.

Operationalisation of ontological expansion and causal clarity is pursued through a sequence of decisions that narrow down these theoretical concerns to ideas that can be implemented, with existing technology, for the purposes of resource constrained project scheduling. Design Science Research is adopted as the framework to guide this process. The novel idea of using the concepts of work-effort and resource-periods is proposed, as the basis for a new mathematical treatment of resource productivity that allows variation during schedule construction. Variable resource productivity is identified as a gateway technology supporting an expanded range of scheduling concepts that can be linked through non-linear relationships, feedback and time delays.

Operationalisation of these ideas proceeds through designing, building and testing a scheduling engine, as a proof of principle. Its scheduling capabilities are benchmarked against research algorithms and commercial software. Eight scheduling heuristics were tested, using 1,560 computer-generated project networks of 30, 60 or 120 tasks, comprising 12,480 resource constrained schedule duration calculations. The best heuristic, prioritising tasks with the earliest Critical Path Method parameter of 'Late

Finish', compared favourably to the benchmark data. The development of the scheduling engine is presented as an example of how a design approach can be useful in management science research and its use is illustrated by modelling the impact of overtime induced fatigue on project schedule duration.