
GREENING PROCUREMENT OF INFRASTRUCTURE CONSTRUCTION: OPTIMISING MASS-HAUL OPERATIONS TO REDUCE GREENHOUSE GAS EMISSIONS

Russell Kenley, PhD / Professor of Management, rkenley@swin.edu.au

Swinburne University of Technology (SUT), Melbourne, Australia

Unitec Institute of Technology (Unitec), Auckland, New Zealand

Toby Harfield, PhD / Research Fellow, tharfield@swin.edu.au

Swinburne University of Technology (SUT), Melbourne, Australia

ABSTRACT

The construction industry has made significant progress towards construction processes for sustainable buildings through programs and guidelines such as ISO 14000 and LEED. However, the lack of research into greenhouse gas production resulting from processes *during* construction constitutes a significant gap in our knowledge.

Linear infrastructure construction processes were examined to find a major contributor of greenhouse gas emissions. One *micro-process*, earthworks materials handling (commonly known as mass-haul), has been identified. The challenge is to define and develop sustainability measures, methodologies and tools for mass-haul that takes place *during* linear infrastructure construction. ICT tools and construction management programs such as DynaRoad do provide continuing updates of construction progress.

These data can be utilised in mathematical optimisation techniques focusing on scheduling activities, objects or locations of mass haul. The expected outcome of the research is proof of concept for the utilisation of optimisation and modelling techniques to devise measurement tools and methodologies for greenhouse gas emissions of mass-haul *during* infrastructure construction. Verification of the concept is expected to be through the application of e-government procurement protocols based on total mass-haul activities for tendered projects. These can then be assessed against environmental factors linked to greenhouse gas emission rates in other domains, thus extending sustainability practices *during* infrastructure construction.

Keywords: Procurement, Optimizing mass-haul, Sustainable construction methodologies.

1. INTRODUCTION

In 2010 the Australian Government announced \$37billion funding for development of transportation infrastructure to include roads, railways and ports. These projects will be expected to comply with the sustainability objectives of government procurement. While both government departments and contractors are taking seriously the commitment to sustainability, the methodologies, and measures related to CO₂ and other greenhouse gas emissions (GHGE) for construction processes are yet to be developed.

One suggested path forward is to focus on a micro-process in an attempt to explore the problems and issues that arise that could be applied to macro-processes of infrastructure construction (Bon and Hutchinson 2000). In addition, because both clients and providers have responsibility for sustainability, it is important to take into account both perspectives. Thus, procurement is a logical starting point.

State road and transport authorities require the necessary tools to compare sustainability claims relating to production of GHGE. Thus, a project has been conceived that firstly requires an

experiment in scoping and defining a micro-process of infrastructure construction that could provide optimising data for proof of concept. The balance of the paper sections 2-5 outline issues related to various facets of the problem. Section six outlines a proposed study as a solution.

2. GREEN HOUSE GAS EMISSIONS

The construction industry has made significant progress towards construction processes for sustainable buildings through programs and guidelines such as ISO 14000 and LEED. The development of these guidelines (and others) over the last 20 years has dealt with problems of definition, scoping and data collection as required in identifying elements of a complex system. The early focus has been on building materials rather than building processes as these are an easier part of the puzzle to isolate and calculate (Ding 2008).

The study of sustainability concerning linear infrastructure construction (roads, rail and bridges) is mostly concerned with discussions of applying the Life-Cycle perspective (Scacchi and Mi 1997). This includes phases of planning, building, maintaining and destroying the infrastructure asset. Lifecycle methodologies are based creation of an index of definable categories of environmental impact. Calculations of the factors for measurement includes weighting and comparison of characteristics or levels (Hill and Bowen 1997). This long-term *macro-view* of transportation infrastructure projects takes into account consumption of resources, embedded energy, or types of waste. However, the lack of research into greenhouse gas production resulting from *processes* of construction constitutes a significant gap in our knowledge (Huang and Lo 2011).

Australia is a signatory of the Kyoto Agreement and produces a National Greenhouse Gas Inventory Quarterly Account from self-reported registered companies. The account provides estimates of greenhouse gas production and energy consumption (DCCEE 2010). However, fundamental methodologies for measuring GHGE produced *during* linear infrastructure construction have yet to be developed. This may be because much of the GHGE emissions research and data collection is focused on the output of vehicles travelling on *completed* roads and rails (Amekudzi, Khisty, and Khayesi 2009). While these data do provide some indication of GHG production in the transportation system, the absence of a framework for measuring emissions *during* road and rail construction means that a significant amount of negative environmental impact remains unreported (Coyle 2000). Therefore, methods to measure GHGE *during* infrastructure construction are urgently required (Chiou, Lan, and Chang 2010).

Currently, infrastructure design and operations are measured via calculation of a contractor's environmental performance score (EPS) which takes into account a limited number of factors: operational activities, site management, project management, environmental management technology, embedded energy and policy (Shen et al. 2005). However, this general index detracts from pollution control that is the outcome of construction. However, a macro-view of the construction process is too complex to easily isolate obtainable data for analysis using understandable metrics.

The usual method of focusing on a micro-process that is part of a complex system in order to gain some insights into the entire system is appropriate in this instance (Yannis, Kouikoglou, and Manousiouthakis 2010). A *micro-view* of road or rail construction is a practical way to focus on one well-defined construction process to mitigate the difficulties of identifying which categories to include in a sustainability index (Ding 2008).

3. INFRASTRUCTURE MICRO-PROCESS: MASS-HAUL

Earthworks is one *micro-process* of infrastructure construction, that is commonly known as mass-haul. Mass-haul is defined as the handling and movement of mass materials (soils, aggregates, rock) around the project. Although the environmental impact of the physical effort and movement of mass-haul operations is significant, very little research has produced findings of mass-haul emissions impacts (Askew et al. 2002). One exception is a study by Norgate and Haque (2010). Their study of the movement of a variety ores from the ground to the processing centre in Western Australia is concerned with embodied energy of the different processing stages. They found that mass-haul is the *biggest* polluter in the process chain from drilling to processing of both iron ore and bauxite. Although

limited in scope, these findings suggest the importance of a study into the mass-haul activities and GHGE.

However, construction industry mass-haul research appears to be confined to consideration of cost reduction through simulation. Sophisticated modelling considers a wide range of factors for purposes of estimating cost and time. A number of studies have devised cost optimising tools for the reduction of fuel or in the design of vehicles (Zang 2008, Hola and Schabowicz 2010). Dawood and Castro (2009) focus the simulation program RoadSim on mass-haul activities. They use a modular approach to outline a specific domain, based on 145 actual construction projects. The knowledge driven atomic models are aimed at productivity gain, thus identified parameters and units that could be useful in development of methodology and measures for GHGE tools.

4. MEASUREMENT ISSUES

The lag between available knowledge management technology and application is a universal starting point for much research. Automation of vehicles used in mass-haul has been researched using a variety of programs and systems. However, the problems associated with measurement and data remain a core problem (Navon and Shpatnitsky 2005).

It has been relatively easy to adopt data collection into electronic and digital systems for construction vehicles such as video, GPS, barcodes, frequency, and laser. For the most part, autonomous data collection focuses on controlling and reducing costs through more effective and efficient ways of monitoring actual work and materials use in relation to projected work and material requirements. Researchers who have solved the problem have paved the way for productivity improvements. However, the initial expectation that traditional manual data collection would be alleviated by automation, has been superseded the problem of how to manage and analysis the data that are generated.

The continuing development of automated construction has been in tandem the development of Business Process Modelling (BIM). The problem of isolating construction processes is particularly difficult for one-time construction projects. However, if Location-Based Management (LBM) methodologies (Kenley and Seppänen 2010), are used, location becomes the unit of analysis for real-time data generation. Navon and Shpatnitsky (2005) report a proto-type experiment using locations, vehicles and stop-start times and materials. They found that by comparing manually collected data and automated collection accuracy was significant. Their initial study provides support for the possibility of using LBM knowledge management systems to develop methodologies and measures for greenhouse gas emissions for mass-haul.

As noted above most environmental impact studies relate to transportation systems after they have been constructed. At the same time research using optimisation techniques applied to linear infrastructure construction is usually focused on cost reductions rather than accounting for greenhouse gas emissions. Therefore it is urgent to develop methodologies, measures and tools to monitor mass-haul GHGE during construction. ICT technologies and construction management programs such as DynaRoad appear to be able to meet this challenge.

DynaRoad is software designed for infrastructure project management, with a designated mass-haul module. This means the development of environmental measures and tools are able to move beyond simulation to work through these issues based on projects-in-progress. DynaRoad combines the unique features of location-based management that monitors and up-dates work/resources schedules integrating both internal and external changes (Kenley and Seppänen, 2010). Thus the scope of mass-haul activities based on micro-milestones can be utilised for optimising purposes from data generated *during* linear infrastructure construction.

5. PROCUREMENT ISSUES

E-government is the movement to use of information technology and knowledge management for government agencies and their providers. The development of these systems is predicated upon the need for government transparency of process and more effective means of communicating during complex construction projects (Kenley, London, and Watson 2000). The tension arises because open-

societies support competitive tendering at the same time comparing tenders requires standardised processes and procedures to ensure equitability.

The tendering processes for construction projects follow a generic pattern: procurement planning, solicitation, selection, project administration which involves both the client-side and the provider-side of this input-output process (Rankin, Chen and Christian 2005). Thus the design, development and implementation for electronic and digital tools to support procurement has dealt with, if not solved completely a commonly accepted set of issues (Vaidya, Sajeew, and Gao 2005). Table 1 indicates both the Canadian and Australian government issues that have been dealt with by 2010 as illustrated by the on-line construction procurement portals.

Table 1: Comparison of Canadian and Australian public procurement issues in 2005.

Supplier readiness-Australia	E-government in use-Canada
<ul style="list-style-type: none"> • Resources • Legal Framework • Capability • Interoperability • Open Standards • Security and Privacy • Authentication 	<ul style="list-style-type: none"> • Cost • Ownership/ responsibility • Capability • Integration • Standards • Security • Authentication

Developing evaluation criteria and weighting formula for comparing bids for costs resources can therefore be used as a benchmark for the development of measures and tools for assessing greenhouse gas production, specifically relating to the micro-processes mass-haul.

6. PROPOSED STUDY

Mass-haul of road and rail construction can represent up to 30% of the total project cost thus is an important component of procurement tenders. Much previous research has focused on increased productivity. At the same time concerns with sustainability means that reduction of cost probably means reduce of environmental impact. However, to-date procurement processes are unable to account for greenhouse gas production or reduction. It is pioneering in taking a holistic approach to reducing environmental impact by recognizing the dual roles of the client (procurement) and the provider (tendering and contracting) in resolving this complex problem.

The over arching aim of the project is to provide both the client-side and the provider-side of infrastructure construction with measures and methodologies based on mass-haul optimisation that can be applied to an integrated greenhouse gas emissions procurement protocol. In particular, the study aims to:

1. **Provider-side:** explore scheduling optimisation methodologies and develop methodologies to minimise mass-haul greenhouse gas emissions *during* linear infrastructure construction.
2. **Client-side:** develop procurement (tendering) processes to encourage adoption of optimisation and corresponding *bid comparison* methods for assessing greenhouse gas emissions optimisation.
3. **Integration:** provide proof-of-concept for optimisation techniques as the basis for measures and methodologies to reduce greenhouse gas emissions to drive sustainability practice change.

Both road and transport authorities (client-side) and contractors (provider-side) require sustainability assessment methodologies for calculating greenhouse gas emissions from infrastructure construction. Increasingly it is important to have methodologies to differentiate contractors during procurement (tendering). The significant innovation of this study acknowledges that both client-side and provider-side perspectives are necessary to inform the development of these types of measurements and methodologies. In addition, the project uses an inclusive systems-process approach that targets the *micro-level* as the logical place to connect the problem of reducing infrastructure construction greenhouse gas emissions with a generally applicable solution.

The purpose of the proposed research is two-fold. Firstly to provide procurement parties, both clients and providers, with the measures, methodologies and tools for greenhouse gas emissions created *during* infrastructure construction for the micro-process, mass-haul. Secondly, to expand

existing sustainability practices by providing proof of concept for optimisation of mass-haul operations *during* infrastructure construction as a step towards development of methods and measures for GHGE.

Proof of concept requires three phases. The first phase is to identify e-government procurement processes and knowledge management systems. The objective of this stage is to find the *commonality* of the individual state procurement tender process and to propose methods to qualify, calculate, and assess infrastructure construction tendering submissions for procurement bid comparisons. In addition definite state criteria for GHGE as it could be applied to tendering linear infrastructure construction projects will be explored.

Phase two is to focus on mass-haul optimisation. DynaRoad generated micro-process data will be analysed for methods of interfacing with environmental factors developed using construction macro-processes. Location-based micro-milestones will provide accurate parameters for both micro and macro mass-haul activities. On-site observation will compare theoretical haulage (following optimisation) with practical haulage (considering factors such as inclination, route variation, ground conditions, etc.). Both the location-based macro and micro segments of the mass-haul emissions problem will be explored for practical implementation of mass-haul optimisation. The modelling is expected to provide a more realistic view of and methods for measuring environment impacts.

Phase three is the linking of the procurement processes and knowledge management systems with the optimised models of mass-haul operations and methods for measuring environmental impact. A major portion of this phase will be the exploration of the necessary adaptation requirements for designing a comparative procurement process based on the associated GHGE tool.

The outcomes of the study will provide benefits all transport authorities and contractors through the identification of processes and the prototyping of tools to integrate greenhouse gas reduction resulting from optimising mass-haul operations during infrastructure construction. The expected outcome of the research is proof of concept leading to smart information use that will enable both road and transport authorities and contractors to embed sustainability objectives into their procurement practices for linear infrastructure construction.

ACKNOWLEDGEMENTS

The authors acknowledge the funding and support provided by the Australian Sustainable Built Environment National Research Centre (SBEnc) and its partners for this research. Core members include: Swinburne University of Technology, Queensland University of Technology, Curtin University, the Queensland Government, the Government of Western Australia, John Holland, Parsons Brinckerhoff Australia and the NSW Roads and Traffic Authority.

REFERENCES

- Amekudzi, A. A., Khisty, C. J. and Khayesi, M. (2009) "Using the sustainability footprint model to assess development impacts of transportation systems." *Transportation Research Part A*. 43. 339-348.
- Askew, W. H., Al-jibouri, S. H Mawdesley, M. J. and Patterson, D. E. (2002) "Planning linear construction projects: automated method for the generation of earthwork activities." *Automation in Construction*. 11. 643-653.
- Bon, R. and Hutchinson, K. (2000) "Sustainable construction; some economic challenges, *Building Research & Information*. 28. 310-314.
- Chiou, Y. C., Lan, L. W. and Chang, K. L. (2010) "Sustainable consumption, production and infrastructure construction for operating and planning intercity passenger transport systems." *Journal of Cleaner Production*. (in press).
- Coyle, M. (2000) "Reducing the environmental impact of road transport operations: a review of interventions that can be applied by fleet operators." Paper presented at the CANTIQUÉ Workshop, January, Rome.
- Dawood, N. and Castro, S. (2009) "Automating road construction planning with a specific-domain simulation system." *ITcon*. 14. 556-573.

- DCCEE Department of Climate Change and Energy Efficiency (2010) Australian National Greenhouse Accounts, Quarterly Update of Australia's National Greenhouse Gas Inventory, March Quarter 2010.
- Ding, G. (2008) "Sustainable construction-the role of environmental assessment tools." *Journal of Environmental Management*. 86. 451-464.
- DynaRoad.com < <http://www.dynaroad.fi>> accessed 1 May 2011.
- Huang, H. F. and Lo, S. L. (2011) "Review and classify the GHGs-related indicators." *Renewable and Sustainable Energy Reviews*. 15. 594-602.
- Hill, R. and Bowen, P. (1997) "Sustainable construction: principles and a framework for attainment." *Construction Management and Economics*. 15. 223-239.
- Hola, B. and Schabowicz, K. (2010) "Estimation of earthworks execution time-cost by means of artificial neural networks." *Automation in Construction*. 19. 570-579.
- Kenley, R., London, K. and Watson, J. (2000) "Strategic procurement in the construction industry: mechanisms for public sector clients to encourage improved performance in Australia." *Journal of Construction Procurement*. 6. 4-19.
- Kenley, R. and Seppänen, O. (2010) "Location-Based Management for Construction: Planning, Scheduling and Control", Spon Press, Abingdon.
- Navon, R. and Shpatnitsky, Y. (2005) "A model for automated monitoring of road construction." *Construction Management and Economics*. 23. 941-951.
- Norgate, T. E. and Haque, N. (2010) "Energy and greenhouse gas impacts and mineral processing operations." *Journal of Clean Production*, 18. 266-274.
- Rankin, J. H., Chen, Y. J. and Christian, A. J. (2006) "E-procurement in the Atlantic Canadian AEC industry." *ITcon*. 11. 75-87.
- Scacchi, W. and Mi, P. (1997) "Process life cycle engineering: a knowledge-based approach and environment." *Intelligent Systems in Accounting, Finance and Management*. 6. 83-107.
- Shen, L. Y., Lu, W.S., Yao, H. and Wu, D. H. (2005) "A computer-based scoring method for measuring the environmental performance of construction activities." *Automation in Construction*. 14. 297-309.
- Vaidya, K., Sajeev, A. S. M. and Goa, J. (2005) "E-procurement assimilation: an assessment of e-business capabilities and supplier readiness in the Australian public sector." *In proceedings of the 7th International Conference on Electronic Commerce*, 429-434.
- Yannis, P., Kouikoglou, V. S. and Manousiouthakis, V. (2010) "A review of sustainability assessment models as system of systems." *IEEE Systems Journal*. 4. 15-25.
- Zang, H. (2008) "Multi-objective simulation-optimization for earthmoving operations." *Automation in Construction*. 18. 79-86.