

Project constraints in a manufacturing environment - beyond the Iron Triangle

Moloko Masopoga, A Wessels and JHC Pretorius,
Postgraduate School of Engineering Management, Faculty of Engineering and the Built
Environment, University of Johannesburg, South Africa
jhcpretorius@uj.ac.za; mochokwe@yahoo.com; awessels@gmail.com

Abstract

The objective of this research was to determine the project constraints that must be considered to ensure project success in a typical manufacturing environment like a pulp and paper plant. The research methodology used to answer the research questions was a mixed –method approach. The modes of data collection were literature study, case studies and a survey questionnaire. The data was analysed using between-methods triangulation. The research presented was limited to data obtained within the South African Pulp and Paper Industry. The research will give project managers, and anyone involved in execution of projects in a Pulp and Paper plant environment more insight and better understanding of which constraints to consider to ensure better project success rates. The research concluded that Triple constraints are not the only determinants of project success in the Pulp and Paper plant. Additional project constraints were identified were; Risk; Human resource management; Legal requirements; Technical performance

Keywords

Project management, Project constrains, Project success.

1. Introduction

Over the last few decades worldwide organisations have slowly but surely become more projects-centered. This has led to an expansion and redefinition of project management principles and tools (Andersen, 2010) (Taylor, 2013). The Iron triangle or, Triple constraints as it is commonly known, are a framework to evaluate the competing demands and manage trade-offs of a project. The triangle, indicates the balancing of the triple constraints of scope, time and cost. The general understanding is that project management is summarised in this triangle; the three elements must remain balanced for the project to be successful (Van Wyngaard, 2013). The triple constraints are defined by the Project Management Book of Knowledge (PMBOK) as a framework for evaluating competing demands and managing competing project requirements (PMI, 2004).

Manufacturing is mainly process based, thus project management will be effective as it is also process based (Bateman, 2012). A manufacturing environment can be described as a multi project environment. Multi project means that various projects of different sizes, importance, requirements and urgency are undertaken at the same time, utilizing the same pool of resources. Resources are the largest constraining factor in manufacturing plants (Gress, 1997).

The pulp and paper industry is a subsector in the Manufacturing industry. Projects in a manufacturing environment and typically in the pulp and paper industry are undertaken in order to optimize the process, improve efficiencies, upgrading of equipment, and improve quality of product and save costs. Project Management Institute (PMI) in the PMBOK Guide, Fourth Edition replaced the triple constraints by a larger list of project constraints that project managers should consider. The list of project constraints proposed by PMI is an extension of the triple constraints. Besides scope, time and costs, it includes resources, quality and risks (Nguyen, 2010). On a blog hosted by (Duggal, 2011) many of the respondents agreed that project managers must consider the environment in which projects are being undertaken and must broaden their perspective to include other constraints, besides the triple constraints, that may impact the project outcomes.

In this paper a brief literature review of the topic is given followed by the problem statement and research objectives. The results are then presented, discussed, then conclusions and recommendations are given.

2. Summary of Literature review

2.1 Project constraints

According to the dictionary a constraint is defined as “*something which controls what you do by keeping you within particular limits*” (Cambridge, 1996) It is a limiting condition on the project process that will have an impact on the outcomes of the project.

Assumptions and constraints form the foundation for project planning. An assumption is a calculated guess, a likely condition, circumstance or event, supposedly known and true in the absence of absolute certainty. A constraint is a limiting condition, circumstance or event, setting boundaries for the project process and expected results. Assumptions and constraints must be defined at the beginning of the project, tracked and monitored throughout the project. (Loyola University, 2017)

The Iron triangle, indicates the balancing of the triple constraints of scope, time and cost). The time, cost and scope are the three limitations that must be balanced, managed and monitored during the execution of a project to ensure project success. This is the traditional iron triangle that many regard as the project success criteria. If the project is not properly managed it can be finished late, over budget or not according to the client’s requirements. This would be regarded as a failed project. Constraints must be identified and defined at the beginning phase of a project. Constraints can evolve during the progression of a project therefore it is important that the constraints are assessed, controlled and reviewed throughout the project cycle Ways around the constraints can be identified that will allow for the project to progress despite a certain constraint (Van Wyngaard, 2011).

2.2 Defining project success and project failure

There are obvious ways to recognise when the project fails, for instance when the project is abandoned and everyone working on the project is out of work. But there are also less obvious failures, i.e. when the: Project doesn’t meet specifications, project costs are much more than budgeted for, project exceeds the planned duration; and customer is discontented with the project outcomes. Failure to recognise, track, put control measures in place to manage the projects risks is one of the reasons why projects often fail (Mokoena, et al., 2012).

Another matter for deliberation is at what point is a project considered to be a success or a failure. One view is that the success or failure of a project be considered months or years after it is terminated. It may also happen that a project is managed successfully but fails to deliver on the required product and vice versa (Andersen, et al., 2006). In some instances, quality of work is added as a success component, that is, not only the deliverables themselves but how people went about producing them (Andersen, 2008).

(Chan, et al., 2002), describes diverse opinions of former researchers on project performance focusing on meeting objectives. A global approach was taken and considerations beyond the project were looked at. A comprehensive literature review taken over the last 15 years suggested that project success should be something much more significant than simply meeting cost, time and performance specifications. A review of the modern work of (Shenhar, et al., 1997), (Atkinson, 1999), and (Lim & Mohamed, 1999) concluded that the scale of project success measures goes beyond the project itself.

In summary, project success is decided based on the project success criteria. According to many scholars it is difficult and almost impossible to determine universal project success criteria. Each project is unique therefore it must have its own unique success criteria. There is a general consensus that the triple constraints alone cannot be used as success criteria. It can therefore also then be concluded that even the constraints of a project will be unique to the project and must be determined accordingly.

2.3 Projects in a manufacturing environment – South African Pulp and Paper industry

Manufacturing is an industry in which human activity and capital equipment are engaged in a production process to convert raw materials into products (Um Jwali Market, 2012). The business functions like human resources, marketing, engineering, production, material control and accounting are designed to support the manufacturing

processes. The maintenance function focuses on supporting the manufacturing processes by keeping the plant's equipment running and in good condition. Some of the maintenance activities like major machine repairs, equipment upgrades, modifications, process improvements etc. can interfere with operation on the plant and must thus be properly planned to be carried out during plant stoppages (Gress, 1997). These maintenance activities are normally undertaken as mini projects because they have a beginning and end, a budget, resource requirements and set objectives.

In a study conducted in 2010 in South Africa in the engineering, construction, petrochemicals, and mining sectors showed only (46%) of the projects were considered successful (Van Wyngaard, et al., 2012). The greatest restriction to success in a manufacturing environment is a group's lack of cross training, this then mean that resources cannot be shifted. Productivity can be increased if technical resources are well cross trained on different types of work and are adaptable enough (Shenhar & Fricke, 2000). A project in a manufacturing environment is constrained by the 4M's: money, manpower, machines and materials (Gress, 1997).

Pulp and Paper mills convert wood to final products that include different grades of paper and chemical cellulose. The mills are highly complex and have integrated process areas that include wood preparation, pulping, chemical recovery, bleaching, and papermaking. South Africa is ranked the 15th largest pulp producer and 24th paper producer in the world.

The scarcity of engineering and technical skills, demands for the industry to find ways to attract and retain talent to ensure the sustainability of long-term operations. In recent years there has been substantial increases in the costs of energy, transport, labour and licencing. This has significantly negatively impacted the industry from being able to remain competitively on the global stage (FP&M seta, 2014).

The Pulp and Paper industry is regulated amongst others by the Draft waste management bill, the National Environmental Management Act, of 1998 (107) and the National Water Act, of 1998 (36). Under the National Environmental Management Act, 107 of 1998, Pulp and Paper manufacturers that intend to establish or modify milling capacity are required to complete an environmental impact assessment report (EIS). This places a significant constraint to companies when carrying out expansion projects (FP&M seta, 2014).

It is widely assumed that investment costs related to pollution reduction are high. Some of the environmental projects are yielding some return by increasing the overall efficiency of the mill and lowering the operational costs. Although it is theoretically possible to achieve 'zero pollution' it is economically necessary to set some sort of limit. The desire for a clean and healthy environment has to be traded off against other desires in society as well as the cost to the mills (Koren, 1975).

2.4 Beyond the triple constraints

The focus has always been on whether the project was done right. A project delivered on time, within cost and to some quality parameters requested, might not be used by the customers, not liked by the sponsors and might not seem to provide either improved effectiveness or efficiency for the organisation, is this successful project management? (Atkinson, 1999).

PMI recently in the PMBOK Guide, Fourth Edition substituted the triple constraints with a longer list of project constraints that project managers need to consider. This list is an extension of the triple constraints. Besides scope, time and costs, it includes risks, resources and quality. This list is not exhaustive, the project team and manager will have to evaluate and determine further which other factors are limiting to the project (Nguyen, 2010). Other criteria that can be used to determine project success is whether the objectives of the project have been achieved. Project objectives can vary from e.g. increasing turnover to higher productivity. With stricter environmental laws being enforced all over the world, doing a project within the environmental standards and laws has become a new constraint (Chokwe, 2012).

On a blog hosted by (Duggal, 2011) many of the respondents agreed that project managers must consider the environment in which projects are being undertaken and must broaden their perspective to include other constraints, besides the triple constraints, that may impact the project outcomes.

From this theory it can be established that the triple constraints are no longer sufficient to ensure project management success. It is also difficult to generate a generic list of project constraints that is applicable to all types of projects; hence this study focused on projects in a manufacturing environment

3. Problem statement and Research objectives

The manufacturing industry has the lowest project success rate at 44%. (Labuschagne, et al., 2013). Somehow some projects completed on time, within budget and to specification still find their way to the failure list. How is that so? One argument could be that project management continues to measure or judge project management using tried and failed criteria. Continuing to use those same criteria will simply repeat the failures of the past.

Projects are being judged on whether they have been done right. A project that is done right could meet the triple constraints criteria but might not be used by the customer, be disliked by the sponsors, or be ineffective or inefficient for the organisation (Atkinson, 1999).

The objective of this research is to determine the project constraints that must be considered to ensure project success in a typical manufacturing environment like a pulp and paper plant. The following research questions were asked:

- a) Are the Triple Constraints the only determinants of project success in a pulp and paper plant?
- b) Which other constraints, if any, contribute to project success/failure in a pulp and paper plant?

. A literature review was conducted and used in support of the rationale of the research. A survey and case studies were used as research tools. The three research methods were triangulated to answer the research questions. The research approach for this study was mixed-method of qualitative and quantitative methods. A literature study, a quantitative tool, was conducted and the following questions were deduced in respect to the research questions:

- Q1: Triple constraints are not the only constraints to project success in a pulp and paper plant.
- Q2: There are other constraints that must be considered that contribute to project success in a pulp and paper plant.

Secondary data from projects carried out at pulp and paper mills were used as explanatory case studies to gather qualitative data. Also, a questionnaire was used as a quantitative survey tool to gain insight from people with practical experience working on projects in the manufacturing sector. The computer or online questionnaire was chosen as a data collection tool because it can cover a large number of people, is not limited by geographical location and has increased speed of data collection. The disadvantages of this type of survey is that respondents can choose to ignore the surveys (Dudovskiy, 2011).

Most of the questions on the questionnaire were open-ended questions. This was to allow for a greater variety of responses. The shortcoming with open-ended questions is that the respondents might not interpret the same question the same way (Harrison, 2007). The questions were compiled from literature. The questions were formulated to be able to ascertain from the respondents' experiences and opinion what they think about project constraints and how they impacted their project outcomes.

The questionnaire was distributed through emails to a sample of 30 individuals involved in projects in the pulp and paper industry. An Online survey was also created using SurveyMonkey and distributed on social media platform LinkedIn on a project management group. The group have an average of 40 000 members. The reason this platform was chosen is that some professionals may hesitate to partake, a large pool of professionals had to be engaged. Sampling and non-sampling errors were expected. Sampling errors can be managed with sampling size but non-sampling errors cannot be eliminated. Non-sampling errors can be due to unclear definitions, reliability and validity of information, inability or unwillingness to answer, etc. (Greener, 2008). The data from the questionnaires was collected, captured, categorized and summarized in a tabular format. Key lessons from each case study were summarized.

The data analysis methodology that was chosen was "between methods" triangulation. Triangulation is the study of a phenomenon using a combination of methodologies. The advantage of using triangulation is that the data from the different methods is validated if the results are congruent. It allows for the study of the same phenomenon from different perspectives, which gives greater insight into the subject matter (Jick, 1979). The data from the literature

review, the questionnaire responses and the case study were analysed to identify cross patterns. This was done to determine if there was congruent data between the three sources. The congruent data from either two or all three data was extracted, and a list was compiled of the constraints as per triangulation methodology.

4. Results

A total of 12 completed questionnaires were received and were eligible for evaluation see Table 1.

Table 1. Summary of participants

Title	Years of experience working on projects	Number of responses
Project Engineer	14	4
Project Manager	22	1
Papermaking Technician	15	2
Production Superintendent	5	1
Process Engineer	5	1
Electrical Engineer	5	1
Mechanical Engineer	4	1
Technical Representative	6	1

The respondents have over 70 years cumulative work experience on projects combined and have worked on more than 180 projects all together.

In Question 4 the respondents were asked to give their own definition of what a project is. The respondents understanding of a project and triple constraints were consistent with the traditional definitions.

In Question 5.1 it was asked at what stage of the project had the project constraints been identified, on the projects that they had worked on. 60% of the time the project constraints were identified during the planning phase, 27% of the time during the Execution.

Question 5.2 asked the respondents to list the project constraints that had mostly impacted the outcomes of the projects they had worked on. The project constraints mentioned by the respondents that had mostly impacted project outcomes were summarised under these categories:

- Cost
- Time
- Scope
- Unreliable contractor performance,
- Conceptualisation and acceptance, Planning, Execution,
- People resourcing,
- Delivery of equipment and raw materials.
- Legal requirements

Question 6 asked which other constraints the respondents thought needed to be considered to ensure project success. The additional constraints besides the triple constraints that the respondents thought should be considered were:

- Customer influence,
- Delivery dates (equipment and spares),
- Pre-shut preparation,
- Communication, Blaming games,
- Unreliable unqualified service providers(contractors),
- Commissioning, Project monitoring,
- Resources, (for specialised tasks)
- Right project coordinator.

- Legal requirements (safety rules compliance)
- Labour unrest/strikes

Question 7 asked what the major causes of failure on some of the projects were that failed. The major causes of project failures were identified as:

- Poor planning,
- Failure to implement contingency plans,
- Contractors (late, unqualified),
- Poor pre-shut planning,
- Scope (creep, poorly defined),
- Poor communication,
- Lack of commitment from management and project team
- Bad decision making,
- Poor project management,
- Inadequate testing processes.
- Late delivery of components/equipment
- Poor workmanship, lack of specialised skills
- Wrong application
- Faulty equipment
- Legal requirements
- Costing not done properly

5. Case studies

Three case studies were done using secondary data from projects that were carried out at multinational pulp and paper plants based in South Africa.

5.1 Case study A

The scope of this project was to decommission, relocate and recommission equipment from paper mill AA to paper mill BB. The objective was to produce an additional 10 500 tons per annum. The installations were scheduled to be in operation by September 2011. The project budget was R17m.

The project schedule overran by 7 months and was over budget by R2m. The project failed to deliver on the expected 10 500 tons. This was due to the non-delivery of the sales plan.

5.2 Case study B

Table 2 : Mill emissions versus the legal limits.

Area	Dust (Dry)			TRS (as SO ₂)		
	Legal Limit (mg/Nm ³)	Mill Emissions Before (mg/Nm ³)	Mill Emissions After (mg/Nm ³)	Legal Limit (ppm)	Mill Emissions Before (ppm)	Mill Emissions After (ppm)
Scrubber #1	100	1800	27	50	90	39
Scrubber #2	100	1650	164	50	285	80

Company CC Board approved a Smelt Dissolving Tank Scrubber project in February 2007 at a cost of R23.5M. The purpose of the project was to reduce emissions of Dust and Total Reduced Sulphur (TRS) into the atmosphere from the Recovery Boilers (1 & 2) Smelt Dissolving Tanks. Existing control equipment had been installed during the

early 1980's. Revisions to Environmental Legislation over the years resulted in the Mill emissions being outside of the legal limit as seen in Table 2.

The project was completed 3 months late and over budget by R14 mil. The project was partially successful because it had met the required process deliverables (table2) in terms of compliance to the Environmental Requirements for Scrubber #1. Scrubber #2 was subsequently upgraded and now also complies.

5.3 Case study C

An analysis was done of projects completion audit reports from a multinational Company X in the pulp and paper industry. The data spanned from 1993 – 2013. The purpose of the reports was to determine the success rating of the projects, to comment on the reasons for the performance and to make recommendations for improvements in managing capital projects. 96 major capital expenditure projects that were carried out across the business. The projects were rated according to the following definitions:

Very successful – project objectives were met and or exceeded.

Moderately successful - Only external variables limited the attainment of the project objectives or partially met the project objectives but some categories of variables within the control of the project were not adequately met.

Unsuccessful - the project did not fully or partially meet the objectives and was a net cost to the company.

The rating results showed that 12% of projects were deemed as unsuccessful, 74% were moderately successful and 14% were deemed as successful.

The reasons given for the projects that were moderately successful and unsuccessful were:

- Plant restructuring
- Poor operational performance
- Market conditions
- Scope creep
- Schedule delays
- Cost overruns
- Insufficient skilled labour
- Poor vendor performance
- Insufficient pre-engineering

The reasons for failed projects included:

- Market conditions (Risk)
- Insufficient skilled labour (Human resource management)
- Poor vendor performance (Human resource management)

6. Discussion of results

From the respondents' definition of a project in the questionnaire it can be concluded that under normal circumstances any other possible constraint besides the triple constraints would not necessarily be identified at the onset of the project. Constraints must be identified and defined at the beginning phase of a project. Constraints can evolve during the progression of a project therefore it is important that the constraints are assessed, controlled and reviewed throughout the project cycle.

In Case Study A, the project failed due to market constraints and insufficient pre-engineering work being done.

A constraint is a limiting condition setting boundaries for the project process and expected results (Loyola University, 2017). In this case the market conditions set the limitation on the expected results. This had a great impact as the specific project justification was mainly on the projected sales volume. If the justification limits are not achieved or are below the set limits then that limit becomes the constraint (Siegelau, 2007). The insufficient pre-engineering in this study agrees with the poor pre-shut planning as identified in the survey.

In Case study B, although the project had been finished late and over budget, it was still deemed as successful. Compliance to the Environmental Requirements was a project constraint and the main deliverable. Koren stated that although it is theoretically possible to achieve 'zero pollution' it is economically necessary to set some sort of limit.

The desire for a clean and healthy environment has to be traded off against other desires in society as well as the cost to the mills (Koren, 1975). The respondents in the survey also cited that some project failures had been due to failure to meet the legal requirements. Legal requirements were also identified as an additional constraint.

In Case study C, the project failure rate was consistent with the statistics representing the manufacturing industry as stated by (Labuschagne, et al., 2013) that 20% of projects failed in this industry. Resources are the largest constraining factor in manufacturing plants (Gress, 1997). In this case the human resource of skilled labor was the main constraint that led to projects not being successful. The lack of skilled labor was also highlighted in a report by the Institute of Economic Research on Innovation (IERI), the report stated that over a third of the total, skilled trades' people and artisans account for the greatest proportion of vacancies in the Pulp and paper sector (Pogue, 2008).

7. Conclusion and Recommendations

The research questions were proven to be true. Q1: Triple constraints are not the only constraints to project success in a pulp and paper plant. Q2: There are other constraints that must be considered that contribute to project success in a pulp and paper plant. The additional constraints as triangulated from the literature review, case studies and survey are:

- Risk (including market condition assumptions)
- Human resource management (contractor management, scarce skills)
- Legal requirements
- Technical performance

These findings were found to be in line with the current theories and perspectives in terms of project constraints. The (PMI, 2017). (Duggal, 2010), (Gress, 1997) other sources are all in agreement that project constraints are unique to each project and that the triple constraints are an outdated parameter.

This study was based on a literature study, a limited number of secondary data as case studies and had a rather poor survey response rate. During the study it was evident that there is very limited information or literature on projects and project management in the Pulp and Paper Industry in general. There were little or no project management statistics obtainable. It is recommended that a study be done into the status of project management within the Pulp and Paper industry in South Africa to build up knowledge in this area. From this study it can be recommended that the additional constraints be taken into consideration as project success limiting criteria in order to improve the chances of project success.

References

- Andersen, E. S., Birchall, D., Jessen, S. A. & Money, H. A., 2006. Exploring Project Success. *Baltic Journal of Management*, 1(2), pp. 127-147.
- Andersen, E. S., 2008. *Rethinking Project Management: An Organisational Perspective*. England: Pearson Education Limited
- Andersen, E. S., 2010. Are we getting any better?: Comparing project management in the years 2000 and 2008. *Project Management Journal*, 41(4), pp. 4-16.
- Atkinson, 1999. R. *International Journal of Project Management*, 17(6), pp. 337-342.
- Cambridge, 1996. *Cambridge-International Dictionary of English*. United Kingdom: Press Syndicate of University of Cambridge.
- Chan, A. P. C., Scott, D. & Lam, E. W. M., 2002. Framework of success criteria for design-build projects. *Journal of Management in Engineering*, 18(3), pp. 120-128.
- Chokwe, M., 2012. *Beyond the Triple Constraints in Project Management*, University of Johannesburg: Engineering Management assignment.
- Company X Board, 1993-2013. Capex PCA reviews, South Africa: s.n.
- Dudovskiy, J., 2011. Research methodology.net. [Online] Available at: <https://research-methodology.net/research-methodology/research-approach/deductive-approach-2/> [Accessed 13 December 2017].
- Duggal, J. S., 2010. PMI Community Post. [Online] Available at: www.pmi.org/knowledge-centre [Accessed 17 August 2014].

- Greener, D. S., 2008. Business research methods. s.l.:Dr Sue Greenr & Ventus Publishing ApS.
- Gress, P. S., 1997. Project management in the manufacturing environment. Chicago Illinois, Project Management Institute.
- Harrison, C., 2007. Harvard University Program on Survey research. [Online] Available at: https://psr.iq.harvard.edu/files/psr/files/PSRQuestionnaireTipSheet_0.pdf [Accessed 12 December 2017].
- Jick, T. D., 1979. Mixing Qualitative and Quantitative Methods: Triangulation in action.. *Administrative Science Quarterly*, 24(4), pp. 602-611.
- Koren, C., 1975. Environmental constraints on the Pulp and Paper Industry. *Norsk Skogindustri*, Issue 12, pp. 329-333.
- Labuschagne, L. et al., 2013. Project Management Maturity versus Project Outcomes in Africa, South Africa: Project Management South Africa.
- Lim, C. S. & Mohamed, M. Z., 1999. Criteria of project success: an exploratory re-examination. *International Journal of Project Management*, 17(4), pp. 243-248.
- Loyola University, 2017. Project Management at Loyola. [Online] Available at: https://www.luc.edu/media/lucedu/pmo/pdfs/additionalreading/Assumptions_and_Constraints.pdf [Accessed 12 June 2017].
- Mokoena, T. S., Pretorius, J. H. C. & Van Wyngaard, C. J., 2012. *Triple Constraint Considerations in the Management of Construction Projects*, University of Johannesburg: Retrieved from <https://ujdigispace.uj.ac.za>.
- Nguyen, S., 2010. Are the Project Triple Constraints still relevant. [Online] Available at: <http://pmreviews.org/tag/triple-constraints>, [Accessed 10 October 2012].
- PMI, 2004. A Guide to Project Management Book of Knowledge. 3rd ed. Newtown Square: Project Management Institute.
- PMI, 2017. Project management institute. [Online] Available at: <https://www.pmi.org/learning/featured-topics/scope> [Accessed 13 November 2017].
- Pogue, T. E., 2008. A sectoral analysis of wood, paper and pulp industries in South Africa, Pretoria: Department of Labour South Africa.
- Shenhar, A. J., Levy, O. & Dvir, D., 1997. Mapping the dimensions of project success. *Project Management Journal*, 28(2), pp. 5-13.
- Shenhar, A. J. & Fricke, S. E., 2000. Managing multiple engineering projects in a manufacturing support environment. *IEEE*, 47(2), pp. 258 - 268.
- Siegelau, J., 2007. Six(yes six!) constraints : an enhanced model for project control. Atlanta, Project Management Institute.
- Taylor, J. J., 2013. Bright Hub Project Management. [Online] Available at: <http://www.brighthouse.com/monitoring-projects/11694-the-history-of-project-management-into-the-21st-century/>, [Accessed 8 January 2018].
- Um Jwali Market, 2012. *Research on the performance of the manufacturing sector*, South Africa: Seda.
- Van Wyngaard, C. J., Pretorius, J. H. & Pretorius, L., 2012. *Theory of the Triple Constraint - a Conceptual review*. Pretoria, IEEM.
- CJ Van Wyngaard, JHC Pretorius, L Pretorius, Dec 2013, Deliberating the Triple Constraint Trade-offs as Polarities to Manage – a Refreshed Perspective: 2013 (IEEM)

Biography / Biographies

Moloko Masopoga obtained her BEng Chemical Engineering (2009) at the University of Pretoria and a BTech in Pulp and Paper Technology (2010) at the Durban University of Technology and an MEng Engineering Management (2018) at the University of Johannesburg. She worked for over five years as a Process Engineer at Pulp and paper mills of SAPPI and Neopak. She also worked as a Systems Engineer for the power utility Eskom. She is currently a Senior Scientist at the SAPPI Technology Centre in the Fibre Processing department.

Arie Wessels obtained the following degrees: B.Sc. (Eng) (Elect), 1968, University of the Witwatersrand, M.Eng. (Eng Management), 1997 Cum Laude, Rand Afrikaans University, PhD (Eng Management), 2013, University of Pretoria. He worked at Telkom for 25 years and at Denel Aerospace Systems for 16 years. He is also part time lecturer and supervisor in Engineering Management at the University of Johannesburg.

Jan Harm C Pretorius obtained his BSc Hons (Electrotechnics) (1980), MEng (1982) and DIng (1997) degrees in Electrical and Electronic Engineering at the Rand Afrikaans University and an MSc (Pulse Power and Laser Physics) at the University of St Andrews in Scotland (1989), the latter cum laude. He worked at the South African Atomic

Energy Corporation (AEC) as a Senior Consulting Engineer for fifteen years. He also worked as the Technology Manager at the Satellite Applications Centre (SAC) of the Council for Scientific and Industrial Research (CSIR). He is currently a Professor and Head of School: Postgraduate School of Engineering Management in the Faculty of Engineering and the Built Environment. He has co-authored more than 200 research papers and supervised over 39 PhD and 220 Master's students in Electrical Engineering and Engineering Management. He is a registered professional engineer, professional Measurement and Verification (M&V) practitioner, senior member of the Institute of Electrical and Electronic Engineering (IEEE), fellow of the South African Institute of Electrical Engineers (SAIEE) and a fellow of the South African Academy of Engineering.